Correlative failure analysis of CNC equipment based on SNA

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ABSTRACT
In order to accurately describe and explore the relationship characteristics between the faults of the numerical control equipment and identify weak links in reliability, a new method for associated fault analysis of CNC equipment based on social network analysis (SNA) are proposed. First, an associated fault directed graph is established based on the statistical analysis on the associated faults of CNC equipment; then, a social network analysis method is introduced in consideration of the network attribute, the relationship between faults and the key subsystem affecting the reliability of CNC equipment are analyzed from three levels of association analysis, element analysis and matrix analysis, and then weak links in reliability of CNC equipment are identified; and finally, a series of fault records of a machining center production site are used as research objects for empirical research, thereby verifying the scientific validity of the method.

Abbreviations: CNC: Computer Numerical Control; FMECA: Failure Mode Effect and Criticality Analysis; SNA: Social Network Analysis; LAN: Local Area Network

1. Introduction
In recent years, with the widespread application of numerous new technologies and methods, many changes have occurred in the failure mode of Computer Numerical Control (CNC) equipment. At present, the typical faults mainly involve independent faults and related faults. The existing research on the related faults mainly focuses on the following three types: Common cause failure, Mutual interference failure and Multimode failure. The failure analysis of CNC equipment is conducted to explore its weak links, and the concrete measures in design, manufacturing, and maintenance can then be made to improve the reliability of CNC equipment (Dai & Jia, 2001). How to identify the weak links of CNC equipment by effective methods and improve its reliability is one of the key research issues of current theoretical circles. Specifically,
from the research point of view, most of these studies start from the product itself, and according to the failure statistical data in product operation. They pay less attention to the network attributes of the fault subsystem, which is the key to improve the reliability of CNC equipment.

From the point of view of research methods, the research encompasses several major topics, such as the failure mode effects and criticality analysis method (Mu et al., 2015), event tree (Wang & Fu, 2016), fault tree analysis (Y.M. Zhang et al., 2015), GO method (Chen et al., 2015). Although these methods take into account the influence of fault elements, they are not enough in studying whether the fault elements are in the core position. They cannot accurately describe and measure the relationship characteristics between the fault elements of CNC equipment, and embody the internal relations among the subsystems and components of CNC equipment. Moreover, although some failure modes may occur more frequently, they may not cause serious system failures. In this case, the system will even work normally. However, in some failure modes, such as the chip system failure mode, although the failure mode of the chip removal system seldom occurs, it will result in the failure of the entire machine to operate normally by transmission with the aid of the relationship between fault modes. Therefore, it weakens the accuracy of the traditional analytical method to some extent and cannot accurately identify the weaknesses.

Social network theory is a systematic research method. Thus, it provides a new perspective for the analysis of related failures. The fault subsystems are not isolated; however, they make up a highly complex relational subsystem network based on the association between the failure modes. To quantify the network, the social network analysis (SNA) method can be used to explore the relationship between related failures and determine the key subsystems. By analyzing the relationship between the actors (nodes), the SNA seeks to determine the characteristics of the relationship and then explore the influence of the relationship on the organization. This method has been widely applied in sociology, information science, and other fields. It is an analytical method for studying social structures and social relations (Wu et al., 2012; Xu et al., 2017). In recent years, SNA has been applied to the fields of economics, psychology, information science, and communication. However, thus far, it has not been applied to the fault correlation network of CNC equipment. Therefore, this study is the first to explore SNA in this field. According to the related fault records of a series of processing centers, the association relationship between the subsystems of each subsystem is expressed by the associated fault directed graph, the subsystems are considered as nodes of the network, and the interconnections between the subsystems are defined as the connections or edges of the network. The failure subsystem of the machining center is analyzed by SNA. This study starts from the angle of network relations neglected in the CNC equipment failure analysis and provides a new angle for the study of fault analysis. It opens the black box of the CNC equipment failure and directly depicts its internal mechanism with the help of social network analysis method.
2. Research methods

2.1. Directed graph

In this paper, a series of CNC equipment products – machining centers is regarded as the research object. 145 machining centers were selected as the samples of field test. After communication and coordination with the machine user operators, maintenance personnel, equipment management personnel, and after-sales service personnel of machine tool manufacturing enterprises, the reliability field test program was formulated. In this test, the period of time truncation is half a year. After the test, the fault data are classified and sorted according to the fault criterion and fault type, and then the related fault statistics table is obtained. Through the statistical analysis of the fault information of the acquired CNC equipment, the statistical table of the related fault analysis among the subsystems is obtained, the fault connection between the subsystems is determined, and the directed graph of the associated fault is then obtained (See Reference (Cai et al., 2008)). This study considers that the directed graph consists of a series of nodes $V = \{S_i\}, i = 1, 2, \ldots m$ and a series of edges $E = \{e_{ij}\}, i, j = 1, 2, \cdots n$, where $i$ represents the fault subsystem, $j$ denotes the fault subsystem, $m$ represents the object subsystem, and $n$ represents a subsystem associated with the object subsystem. Directed edge $e_{ij}$ from $i$ to $j$ denotes the causal relationship formed from the failure mode in fault subsystem i, which causes the occurrence of the failure mode of subsystem $j$. For example, if $i$ is the influence subsystem and $j$ is the affected subsystem, direction $e_{ij}$ should be drawn from $i$ to $j$. $e_{ij}$ indicates the total number of failures of subsystem $i$ that affects subsystem $j$. If no causal relationship of failure between the two subsystems is observed, then no directed edge exists, that is, the value of $e_{ij}$ is zero.

2.2. Social network analysis (SNA)

A social network is a collection that includes multiple nodes (social actors) and connections between the nodes (relationships between the actors) (Liu & Wang, 2016). Social network analysis mainly studies and analyzes the relationships in the network to obtain structural information of the network, and is a methodology of social network theory. It is the methodology of social network theory (Chatfield, Reddick, & Brajawidagda, 2015; Bourbousson et al., 2015; Jia et al., 2013; Ye et al., 2015; Zhong & Peng, 2015).

The method that can be used to analyze the network and the association between the participants thereof in the social network analysis method is a network centrality analysis method. Specifically, the centrality of each node is first calculated from a point degree centrality, a middle centrality and a close centrality, and then the network is analyzed on this basis. Therefore, in this study, network nodes are identified as fault subsystems of CNC equipment, and the network connections are identified as correlations between the fault subsystems. The associations between the fault subsystems (elements) are explored through the network centrality analysis method in the social network analysis method, and key elements of CNC equipment are identified accordingly.
2.2.1. **Degree centrality**

Degree centrality is a measure of the correlation capability between a node and other nodes in the network graph. It is the embodiment of a node’s direct influence on other nodes. If the network is an undirected network, then the node centrality of node $x$ is recorded as $C_D(x) = d(x)$, and $d(x)$ represents the number of nodes $x$ and other directly linked nodes. A higher value indicates more node that represents the central position in the network. The node has considerable power in the network. The present work aims at the directional network; thus, the centrality is divided into point in centrality and point out centrality. The former represents the link in value, which indicates the degree of correlation that a node receives from other nodes. It refers to the direct influence degree of other points on the point, that is, the in-degree of point $S_n$ corresponding to column $n$ in adjacency matrix. The point out centrality indicates the point out-degree value, that is, the influence degree of a node on other nodes, which is the total number of other points directly controlled by this point, that is, the point out-degree of point $S_m$ corresponding to $m$ row in the adjacency matrix. Among them, $n$ is the scale of the network, that is, the network has $n$ elements.

2.2.2. **Betweenness centrality**

Betweenness centrality is a measure of the degree to which a certain point in a network graph is in the middle of other points, that is, to what extent other nodes need this node to transmit when other nodes pass the fault. It reflects the role of a node as an intermediary that connects other nodes. It is also a reflection of the actual control influence of other nodes. The nodes with high centers can control several nodes simultaneously and play a key role in the network. Assume three points $X$, $Y$, and $Z$. Then, the ratio of the shortcut number (shortest path) of $X$ and $Z$ connected by point $Y$ to the total number of shortcuts between $X$ and $Z$ is called intermediary or betweenness centrality. For point $x$, its middle centrality can be expressed as follows:

$$C_B(x) = \sum_{i < k} g_{jk}(x) / g_{jk}$$

(1)

where $g_{jk}$ is the shortest path number between nodes $j$ and $k$ and is the shortest path number between each pair of nodes containing node $x$.

2.2.3. **Closeness centrality**

Closeness centrality reflects the degree of proximity between a node and other nodes and is a measure that cannot be influenced by other nodes. This index focuses on analyzing the independence or validity of a node for fault transmission. A point with high centrality has such a feature. The closer the point is to other points, the less it depends on other points. If the distance between a node and other points in the network is extremely short, then the point is the centroid of the all nodes and possesses a high degree of close centrality. Nodes with high centrality can transmit faults to several elements in short paths. In an undirected graph, for a node $x$, its close centrality is
\[ C_C(x) = \left( \sum_{i=1}^{n} d(x_i, x_j) \right)^{-1} \]  

where \( d(x_i, x_j) \) is the shortcut distance between nodes \( x_i \) and \( x_j \).

In a directed graph, the measurement of close centrality involves two indicators: inner close centrality and outer close centrality. The higher outer closeness centrality indicates that the node is less affected by other nodes, its own independence is stronger, and the impact on other nodes is more insusceptible to the control of other nodes. The higher inner closeness centrality of a node indicates that the node is more independent when affected by other nodes.

The measurement method of centrality should be selected according to the objectives of the study. Point centrality indicators can be selected when the focus is on the scope of transmission between failures; the center centrality index can be applied when focusing on the transmission control of failure nodes; and proximity index can be applied when the focus is on exploring the independence and effectiveness of fault propagation. Therefore, according to the different research targets, different indexes can be selected to evaluate the fault centrality. Then, the reliability improvement and fault prevention strategy can be selected according to the characteristics of each fault subsystem.

3. Fault association analysis of CNC equipment based on SNA

3.1. Factor analysis

Factor analysis determines the fault subsystem that affects the reliability of CNC equipment. The influence subsystem and the affected subsystem exist at the same time in the correlated fault transmission. The two kinds of subsystems are called the correlation subsystem. The fault correlation of subsystems can be obtained by fault causality analysis. In this paper, through the collection and analysis of a series of machining center failure data, the related fault statistics table can be obtained (Table 1). The fault correlation diagram of the subsystem is obtained by analyzing the fault causality of the machining center data from Table 1, as shown in Figure 1. The subsystem of failure is the element mentioned here. For example, electrical system \( S_2 \) is the influence subsystem and feed system \( S_2 \) is the affected subsystem, direction \( e_{2 \rightarrow 3} \) should be drawn from electrical system \( S_2 \) to feed system \( S_3 \), \( n_{e_{2 \rightarrow 3}} \) indicates the total number of failures of electrical system \( S_2 \) affects feed system \( S_3 \), \( n_{e_{2 \rightarrow 3}} = 2 \). There is no causal relationship of failure between the two subsystems like tool magazine \( S_1 \) and feed system \( S_3 \), then no directed edge exists, that is, \( n_{e_{1 \rightarrow 2}} = n_{e_{2 \rightarrow 1}} = 2 \).

3.2. Association analysis

Association analysis refers to the systematic analysis of the relationships among elements, that is, the analysis of the correlation between the associated fault subsystems. It aims to establish the network analysis matrix of the associated fault subsystem (also called adjacency matrix). As a data matrix that represents ‘actor – actor,’ the matrix reflects the relationship between elements and their interactions. The adjacency matrix is obtained through the directed graph of the aforementioned associated fault. The rows
Table 1. Relevant fault statistics table of the subsystems of the processing center.

| Order number | Initial fault system        | Successor fault system      | Cause of failure                                                                 |
|--------------|----------------------------|----------------------------|----------------------------------------------------------------------------------|
| 1            | Lubrication system         | Feed system                | Poor lubrication wears out the bearing                                           |
| 2            | Pneumatic system           | Tool magazine              | Insufficient pressure during machine tool change.                               |
| 3            | Lubrication system         | Feed system                | The screw is short of oil.                                                       |
| 4            | Cnc electrical system      | Tool magazine              | The program problem of CNC system.                                              |
| 5            | Electrical system          | Numerical control system   | Contactor damage.                                                                |
| 6            | Numerical control system   | Feed system                | The deviation of the stop position is extremely large.                           |
| 7            | Pneumatic system           | Principal axis             | Compressed air contains impurities, such as water, oil, and dust.                |
| 8            | Numerical control system   | Principal axis             | Problems exist in the setting of machine tool parameters.                        |
| 9            | Lubrication system         | Principal axis             | The seal contact is not tight, and leakage gap is observed.                      |
| 10           | Pneumatic system           | Tool magazine              | The pressure of the air pump is not normal.                                     |
| 11           | Electrical system          | Numerical control system   | The insulation superheat aging is finally knocked out and causes short circuit.  |
| 12           | Pneumatic system           | Principal axis             | The air pressure of the cutter cylinder (turbocharged cylinder) is insufficient. |
| 13           | Electrical system          | Cooling system             | Current overload.                                                               |
| 14           | Numerical control system   | Feed system                | Problems exist in setting the system parameters.                                |
| 15           | Numerical control system   | Feed system                | Memory deviation exists in the reference point position.                         |
| 16           | Electrical system          | Principal axis             | A problem with the wire is observed.                                             |
| 17           | Pneumatic system           | Principal axis             | The damage of the seal ring causes the air leakage of the main shaft cylinder.  |
| 18           | Cooling system             | Chip removal system        | The lack of cooling causes the motor temperature to be extremely high and be burned. |
| 19           | Pneumatic system           | Principal axis             | Gas valve failure causes gas leakage.                                            |
| 20           | Pneumatic system           | Tool magazine              | The cylinder is leaking.                                                         |
| 21           | Lubrication system         | Chip removal system        | The seal ring is damaged.                                                        |
| 22           | Electrical system          | Cooling system             | Relay burn out                                                                  |
| 23           | Electrical system          | Tool magazine              | Relay damage                                                                    |
| 24           | Lubrication system         | Principal axis             | Aging damage of seal ring                                                        |
| 25           | Lubrication system         | Chip removal system        | Lack of lubricating oil                                                          |
| 26           | Electrical system          | Tool magazine              | Damage of the electric cable of the motor                                        |
| 27           | Pneumatic system           | Principal axis             | Seal ring damage                                                                |
| 28           | Pneumatic system           | Principal axis             | Condensate and impurity in the cylinder                                           |
| 29           | Electrical system          | Tool magazine              | Wire problems                                                                   |
| 30           | Electrical system          | Feed system                | Related control circuit breakage                                                 |
| 31           | Electrical system          | Feed system                | Sensor damage                                                                   |
| 32           | Electrical system          | Tool magazine              | Poor contact of electric motor and cable                                         |
| 33           | Principal axis             | Feed system                | Spindle encoder damage                                                           |

and columns in the matrix represent each fault subsystem in turn. In this study, the number of failures of the object subsystem caused by the subsystem is the degree of influence on the object subsystem. When determining the influence value, the influence factors of row elements on column elements are filled in the corresponding column position of each row. That is, the influence values of the elements of line m on the elements of the column n must be written on the position line m and n column. Then, matrix A can be obtained.
An associated fault network graph with topological relations can be constructed using Ucinet software. As shown in Figure 2, the distribution of the network can be understood intuitively.

3.3. Matrix analysis

For the machining center-associated fault network, the fault elements that play a leading and dominant role in the network can be shown as a network centrality. Centrality is the concentrated expression of the power and centrality of the network participants. Therefore, the central analysis method is used to analyze the failure factors of machining centers. Ucinet SNA software is used to calculate the data in Table 1 and obtain the result, as shown in Table 2.
3.3.1. Centrality analysis of point degree

According to the adjacency matrix, the point in-degree and the point out-degree of the point centrality method can be used to study the centrality of the associated failure subsystems. It represents the connection strength and number of connections that have direct or adjacent connection with the subsystem.

The results reveal that the point out-degree of the pneumatic system is the greatest. The point out-degree reflects the core position of the pneumatic system in the entire system, followed by the electrical system (S2) and CNC system (S8); the sum of the point out-degrees of the three subsystems accounts for 75% of the total point out-degree. Thus, these fault subsystems have a relation with other fault subsystems, and directly affecting other fault subsystems is easy. They are at the source and upflow position of the failure transmission. The remaining fault subsystems have a smaller point out-degree, which

![Figure 2. Network diagram of the correlative failure.](image_url)

### Table 2. Centrality analysis.

|     | In-degree | Out-degree | Betweenness centrality | inner closeness centrality | outer closeness centrality |
|-----|-----------|------------|------------------------|----------------------------|----------------------------|
| S1  | 14        | 0          | 0                      | 16.667                     | 11.111                     |
| S2  | 0         | 12         | 0                      | 11.111                     | 32.000                     |
| S3  | 16        | 0          | 0                      | 24.242                     | 11.111                     |
| S4  | 2         | 4          | 1                      | 12.500                     | 12.500                     |
| S5  | 6         | 0          | 0                      | 16.327                     | 11.111                     |
| S6  | 0         | 19         | 0                      | 11.111                     | 16.327                     |
| S7  | 0         | 9          | 0                      | 11.111                     | 16.667                     |
| S8  | 2         | 11         | 0                      | 12.500                     | 16.667                     |
| S9  | 16        | 1          | 1                      | 20.000                     | 12.500                     |
| Mean value | 6.222     | 6.222      | 0.222                  | 15.063                     | 15.555                     |
| Standard deviation | 6.696     | 6.460      | 0.416                  | 4.382                      | 6.249                      |

**Figure 2.** Network diagram of the correlative failure.

**Table 2.** Centrality analysis.
implies that its influence capacity is limited. The point out-degree of tool magazine (S₁), feed system (S₃), cooling system (S₄), and chip rejection system (S₅) is 0, which indicates that these subsystems are only affected by other fault subsystems and do not affect other subsystems.

As far as point in-degree is concerned, the feed system (S₃), spindle (S₀), and tool magazine (S₁) are higher, and the sum of the point in-degree is 82.1% of the total amount of the entire point in-degree, which indicates that these subsystems are highly unstable and are easily affected by other subsystems. However, the residual subsystem’s point in-degree is relatively small and is not easily affected by other fault subsystems. The point in-degrees of the electrical system (S₂), pneumatic system (S₆), and lubrication system (S₇) are 0. Thus, these fault subsystem elements only affect other subsystems and are not affected by other subsystems.

The contrast analysis of point out-degree and point in-degree reveals that the point in-degrees of the pneumatic system (S₆), electrical system (S₂), and CNC system (S₈) are evidently lower than their point out-degrees. Hence, the degree of influence of these subsystems on other fault subsystems is greater than that of other fault subsystems on them. The point out-degrees of the feed system (S₃), spindle (S₀), and tool magazine (S₁) are clearly lower than their point in-degrees. Thus, these fault subsystems are more affected by other fault subsystems than they affect other fault subsystems.

3.3.2. Betweenness centrality analysis
According to the betweenness centrality values of each point in Table 2, the centrality degree of the spindle (S₀) and cooling system (S₄) is 1. This finding indicates that the two have greater control capability, whereas other factor nodes are easily connected through the node, that is, it is the fault transfer hub. The betweenness centrality of the other fault subsystems is all 0, and no intermediary control capability is observed. The standard deviation is 0.416; thus, the ratio of the standard deviation to the mean is 0.416/0.222 = 187%>100%. The element nodes with high intermediate betweenness degree in the network must be given considerable attention.

3.3.3. Closeness centrality analysis
Analyzing the key factors only by the degree centrality method is insufficient because this method may be the centrality of Local Area Network (LAN). The closeness centrality method, which can measure the distance between a node and other points, must be adopted to analyze the key elements. The closeness centrality index can reflect the capability of nodes to exert influence on other nodes through the network, especially the structure of the global network. It represents the sum of the shortcut distance between a node and all other points in the graph, and the formula is the reciprocal of the sum of the shortcut distance, that is, the point with higher closeness centrality has the ‘shortest path in the graph.’ In addition, the adjacency matrix is a directed graph; thus, the directivity of nodes should be considered. The dominant factor plays a leading role in the fault subsystem network system because the key elements are not affected by or are affected less by other elements. The present work uses node input degree and external proximity to reflect the key failure subsystem elements. Professor Freeman of the University of California–Irvine precisely adopted these two indicators to measure the core elements of the network system (Kasztler & Leitner, 2009). Therefore, based on SNA, the key subsystems have low node input degree and high external
centrality. As shown in Table 2, the electrical system (S2), lubrication system (S7), numerical control system (S6), and pneumatic system (S8) have a high external proximity degree; whereas the electrical system (S2), pneumatic system (S8), and lubrication system (S7) have a low node input degree in the analysis of degree centrality. Therefore, the electrical and pneumatic systems are the key failure subsystems in the associated fault network.

The three indicators used in this study measure the network centrality of a node in the network from different angles. If a certain element (node) has a high centrality index, then this element is relatively close to other elements in the network; if a certain element (node) has a high centrality value, then this element plays an important role in the middle control of the network; if a certain element (node) has a high closeness centrality, then this element is the core element of the entire network. Therefore, through the discovery and identification of the key elements with high point degree centrality value and high middle centrality value and high closeness centrality index, the weak link of the processing center can be determined, and different measures can be adopted to improve it.

### 3.3.4. Result and discussion

The results calculated by SNA method are compared with those calculated by FMECA, a traditional fault analysis method, as shown in Table 3.

As shown in Table 3, the key subsystems are pneumatic system, electrical system and numerical control system by using the point centrality analysis method of SNA method. The key subsystems are electrical system, lubrication system, numerical control system and pneumatic system by using closeness centrality analysis method of SNA method. These systems have strong independence and influence in the whole fault network. In the meantime, through the analysis of betweenness centrality, spindle system and cooling system have great control ability and belong to the fault transmission hub. On the whole, the two most critical subsystems are electrical system and pneumatic system by centrality analysis of point degree and closeness centrality analysis. At the same time, attention should be paid to the two fault transmission hubs of spindle and cooling system.

The traditional FMECA method is used to analyze the fault data in this study, and the key subsystems are tool library, feed system and spindle system. Compared with the results obtained by SNA, the results are quite different, mainly because this method does not consider the fault correlation and neglects the interaction between the faults. For example, the tool library and feed system are subsystems that are greatly affected by other subsystems, which will greatly reduce their hazards. Therefore, the results obtained are biased and the weak links of reliability cannot be accurately identified. However, SNA method takes into account the relationship between faults and can more objectively learn the relevant characteristics of faults and obtain more accurate weak links of reliability.

### 4. Conclusion

It takes a series of CNC equipment products-machining centers as an example in the paper. It uses the centrality analysis method in SNA method to accurately describe and explore the relationship between the fault characteristics of the machining centers, and identifies the reliability weak link based on the fault-related data collected. That is, the
| Method        | Key Subsystem Elements                                                                 | Subsystems at the End                                                                 | Remarks                                                                 |
|--------------|----------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| FMECA        | tool magazine, feed system, spindle system, electrical system                          | protective devices, workbenches, lubrication system                                    |                                                                        |
| SNA Point centrality analysis | pneumatic system, electrical system, numerical control system                       | feed system, spindle, tool magazine, other subsystems                                 | The most critical subsystems: electrical system, pneumatic system     |
| SNA Intermediate centrality analysis | spindle system, cooling system                                                        |                                                                                       |                                                                        |
| SNA Closeness centrality analysis | electrical system, lubrication system, numerical control system, pneumatic system   | tool magazine, feed system, chip removal system                                        |                                                                        |
key subsystems: electrical system and pneumatic system. Through theoretical analysis and empirical research, this paper draws the following three conclusions:

(1) It provides an important basis for this paper to use SNA method to study the relationship between elements and then identifies the key subsystems of the machining center that considering the machining center as a fault network for the study of fault network attributes.

(2) Correlative failure analysis of the CNC equipment based on SNA can be summarized in the following three steps: determining the fault subsystem affecting the reliability of CNC equipment through factor analysis; establishing the adjacency matrix of fault subsystem elements through correlation analysis between faults; finally, identifying the key fault subsystem through adjacency matrix analysis. In this paper, the fault analysis and key subsystem identification mode of CNC equipment based on SNA are explained with the help of fault-related data and data of a series of machining centers.

(3) In this paper, the fault subsystem elements of CNC equipment are defined as network nodes, and the relationship between the elements is defined as the network connection. SNA method is used to study the relationship between elements, which provides a strong basis for analyzing which are the key subsystem elements. Finally, the electrical system and pneumatic system are identified as the key subsystems of machining center failure through case study method.

In this paper, SNA method is used to explore the relationship between fault characteristics of CNC equipment and identify the weak links of reliability. The application scope of SNA method is expanded in theory, and new ideas are provided for the improvement of reliability of CNC equipment. In practical application, there are still many points worth exploring in the practical application of this quantitative research method. For example, the whole network of CNC equipment can be analyzed; the relevant fault elements can be monitored and quantified according to dynamic evolution management, and so on. In addition, if time variable is added to the study, it may be helpful to further reveal the formation and changes of key fault subsystems. The above issues need to be further explored and improved.

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