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Importance Analysis of System Related Fault Based on Improved Decision-Making Trial and Evaluation Laboratory

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Abstract: The existence of related faults between components brings great difficulties to the analysis of the importance of system components. How to quantify the influence of related faults and evaluate the importance of components is one of the hot issues in current research. In this paper, under the assumption that the fault propagation obeys the Markov process, the PageRank algorithm is integrated into the decision-making trial and evaluation laboratory (DEMATEL). On the basis, the calculation of influencing degree and influenced degree between components is studied to quantify the influence of related faults, and the problem of subjective evaluation of weight coefficient in traditional DEMATEL is solved. The rationality is verified through the method of combining the Interpretative Structural Modeling Method (ISM) and direct relation matrix. The importance of system related faults is identified accurately based on the calculation of center degree and cause degree, and the central-related faults of CNC machine tools are analyzed as an example to verify the effectiveness of the proposed method.

Keywords: Decision-Making trial and Evaluation Laboratory (DEMATEL), importance, Interpretative Structural Modeling Method (ISM), PageRank algorithm.

1. INTRODUCTION

Importance analysis is one of the key links in reliability analysis. It is mainly based on the contribution of each subsystem fault to the occurrence of system fault to evaluate the importance of the subsystem [1]. Birnbaum first puts forward the concept of "reliability importance" in 1969, that is, "some components may play the important role than others in systems whose functions or failures depend on the functions or failures of their components." Importance analysis is formally included in the research category of reliability analysis [2]. The definition of "importance degree" is used to determine the weakest part of system design improvement, fault diagnosis and maintenance, and the importance of fault tree establishment combined with fault mechanism is a further application of importance in reliability analysis, but most of the importance analysis based on fault tree analysis belongs to static analysis [3]. Fan Shaohua established the reliability function of each subsystem on the basis of fault independence, and then calculated the reliability function of each subsystem by partial derivation to obtain the dynamic model of reliability importance of each subsystem, but ignored the influence of fault correlation, so there is a deviation [4].

Fault correlation is a common feature of system fault, most of which do not exist independently. The correlation of system faults reflects the dependent relationship between system component faults and is an important part of system fault analysis. Therefore, ignoring its correlation will lead to the deviation of the analysis results and low application. For this reason, the DEMATEL (decision-making trial and evaluation laboratory) was introduced into the field of fault correlation analysis. With the help of graph theory knowledge and matrix tools, the fault correlation was fully considered, the direct and indirect influence relationship between related fault components was determined, and the correlation value was calculated, so as to clarify the specific fault transfer process between components and determine the main cause and degree of the fault transfer process [5]. In recent years, most of the research on DEMATEL is the fusion of it with other methods.

In this paper, we are focusing on the fusion of DEMATEL with other methods. Table 1. gives a picture of the comprehensive literature survey in this field. In Table 1., method of fusion considered by each paper, and the application area are summarized.

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Table 1. Literature survey on the fusion of DEMATEL with other methods.

Author (s) / Year	Integrated methods	Application
Chen, Jih-Kuang (2021)[6]	ISM	Determined the threshold by the maximum mean de-entropy method and an additional transitivity check procedure
Lopez, DS et al. (2021)[7]	Rough set theory	A systematic evaluation and analysis approach under ambiguity is proposed for evaluating, analyzing, and measuring aspects of internal healthcare performance
Li, JS, Xu, KL. (2021)[8]	CM	Established evaluation index model by identifying relevant hazards of converter steelmaking system
You, XL, Hou, FJ (2021)[9]	HFLTS	Proposed expert weights model based on the similarity and entropy of HFLTSs and introduced the consensus reaching process
Ortiz-Barrios, M et al. (2021)[10]	FAHP	Exploited the advantages of FAHP, DEMATEL methods for evaluating performances of GDs
Kou, G, et al. (2021)[11]	fuzzy TOPSIS	Evaluated Fintech-Based European Banking Services Investments by an Original Approach Considering Interval Type 2 Fuzzy DEMATEL and Fuzzy TOPSIS Models
Hasheminezhad, A, et al.(2021)[12]	COPRAS	Risk assessment of contributory factors in the collision was based on multi-criteria decision-making approaches such as fuzzy COPRAS and fuzzy DEMATEL
Raut, R, et al. (2021)[13]	ANP	Understand the barriers and subsequently and evaluating interrelationships and ranks of barriers in the successful adoption of BDA in a manufacturing organization context
Patel, T, et al. (2021)[14]	FCM	Help BIM user companies improve their BIM software selection framework and decision-making process during software purchases
El-Garaihy, WH (2021)[15]	DEA BSC	Determined the relationship between the four dimensions of the BSC by identifying supply chain metrics and applying the DEMATEL approach
Cui, HY, et al. (2021)[16]	QFD MOORA	Defined green supply chain criteria for each stage of QFD and build IVIF-DEMATEL and IVIF-MOORA hybrid models
Hosseini, A, et al. (2021)[17]	VIKOR	Based on Analytical network process of DEMATEL. Using a Hybrid Modified Fuzzy VIKOR Approach to assess and mitigate tourism risks to close the gap
Tsuei, HJ, et al. (2020)[18]	VIKOR	Built a decision model of search engine ranking for administrators to improve the performances of websites that satisfy users' needs
Li, TC, et al. (2020)[19]	GRNN	Based on the data of my country's marine engineering equipment industry, the grounded theory, and identifying the key influencing factors
Pourjavad, E, Shahin, A (2020)[20]	AHP TOPSIS	Developed by integrating fuzzy DEMATEL, fuzzy hierarchical analysis and by preference order techniques similar to the ideal solution TOPSIS method
Chen, TL, et al. (2020)[21]	VIKOR	Help decision makers choose the most appropriate design solution; designers can also improve the gap between product design and expectations
Rostamnezhad, M, et al. (2020)[22]	SD	Quantified the importance of the various influencing factors, Considered their complex interactions
Titiyal, R, et al. (2020)[23]	DANP	Investigated the relationship between performance levels and performance aspects and calculated their weights
Gul, S. (2020)[24]	Spherical fuzzy set	For considering the degree of hesitation of experts in assessing the potential impact between criteria
Shang, XQ, et al. (2020)[25]	Critical success factors	It is impractical to optimize all influential factors, a feasible way is to find out the critical success factors to improve
Cui, L, et al. (2019)[26]	Grey	Converted expert opinions into quantifiable data, took imprecise information into account to improve the validity of the results
Ma, F, et al. (2019)[27]	VIKOR	The model is applied to evaluate the service quality of bike sharing in Xi'an City
Liu, S, et al. (2019)[28]	FMEA	Enhanced the system's reliability and handled the correlation effects between failure modes and causes
Wang, SB, et al. (2019)[29]	AHP TOPSIS VIKOR	Weighted ranking of these criteria whereas alternatives

Abbreviations: ISM - Interpretive Structural Modeling; CM - Cloud Model; HFLTS - Hesitant Fuzzy Linguistic Term Set; FAHP - Fuzzy Analytic Hierarchy Process; TOPSIS - Technique for Order Preference by Similarity to an Ideal Solution; COPRAS - Complex Proportional Assessment; ANP - Analytic Network Process; FCM - Factor Comparison Method; DEA - Data Envelopment Analysis; BSC - Balanced Scorecard; QFD - Quality Function Deployment; IVIF - Interval-Valued Intuitionistic Fuzzy; MOORA - Multi-Objective Optimization by Ratio Analysis; VIKOR – Vlse Kriterijumska Optimizacija I Kompromisno Resenje; GRNN - General Regression Neural Network; SD - System Dynamic; FMEA - Failure Mode and Effects Analysis.

By analyzing the above research status, most of the studies are a fusion of DEMATEL and fuzzy methods, such as fuzzy ANP [23], FAHP [10], fuzzy TOPSIS [11], HELTS [9], Grey [26], etc. But DEMATEL still has two defects: on the one hand, the limitation of their own knowledge and experience or the excessive subjectivity for experts lead to decision-making errors, so that the direct influence matrix cannot reflect the real influence relationship. On the other hand, even though multiple fuzzy methods are used, subjective judgment mode is still used in the selection of key factors and the judgment of factor relationship, resulting in strong uncertainty. Objective quantitative analysis has not been realized.

From the literature, it is apparent that there is no paper proposing the fusion of DEMATEL and PageRank. Thus, the premise of considering the related fault and dynamic fault transmission among complex system components. In order to make up for the accuracy of expert subjective evaluation coefficient in traditional DEMATEL, this paper introduces the PageRank algorithm. PageRank itself originated from the traditional literature citation analysis. And it is the method of analysis and evaluation of related networking pages [30], [31]. Meanwhile, in the fault related system, the Markov process must be obeyed by applying the PageRank algorithm. Markov process is a stochastic process without forward looking and after delay. Ay took advantage of Markov processes carrying out the reliability analysis of system failure [32], Rajesh improved the future trends in the resilience of the town center based on the grey moving probability state Markov model [33], Patelli addressed the problem of community detection in networks by introducing a general definition of Markov stability [34], Huang introduces a new Markov chain model to forecast price trends [35]. Therefore, under the premise of obeying the Markov process, PageRank is applied, the transfer relation of the system fault in each subsystem is regarded as the interlink relation of the page in the Internet, and each subsystem is abstracted into the Internet page, and user browsing the page in the direction of the page link is regarded as the delivery of the failure between subsystems [36], so as to quantify the influence relationship between the correlation subsystems, realize the quantitative analysis of the influence degree, and improve rationality and accuracy of the influence relation analysis.

In view of the above background and research status, this paper proposes an improved DEMATEL that incorporates the PageRank algorithm under the assumption that the fault propagation obeys the Markov process. The calculation of influenced degree and influencing degree between components for system related faults is studied by using the PageRank algorithm to quantify the influence of faults between components, its rationality is verified through the method of combining the Interpretative Structural Modeling Method (ISM) and direct relation matrix, and the problem of subjective evaluation of the weight coefficient in the traditional DEMATEL is solved, and then the study accurately identifies the importance of system related fault based on center degree and cause degree, which are calculated, as a case analysis of related fault for the CNC machine center, to verify its effectiveness.

2. METHODS

A. DEMATEL

Decision-making trial and evaluation laboratory (DEMATEL) is a system analysis method that uses graph theory and matrix tools to analyze the logic between subsystems by constructing directed graphs between subsystems. Influencing degree, influenced degree, center degree and cause degree are calculated in combination with various related weight coefficients, the direct and indirect influence relationship between the fault system is determined, and the fault-related relationship between systems is analyzed. This is in order to make a quantitative analysis of the interdependence among the elements in the complex system, and then the key influencing factors are clarified.

The steps of decision-making trial and evaluation laboratory :

1. The relationship between various factors evaluated through relevant information extensively is collected, that is, the relationship between each failure mode is evaluated, and initial data matrix $\boldsymbol{M}$ is established.

$$\boldsymbol{M} = \begin{bmatrix} 0 & m_{12} & \cdots & m_{1n} \\ m_{21} & 0 & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ m_{n1} & m_{n2} & \cdots & 0 \end{bmatrix}. \tag{1}$$

2. According to formula (2) and formula (3), a standardized matrix $\boldsymbol{M}'$ of matrix $\boldsymbol{M}$ is established.

$$m_{ij}' = \frac{1}{S} m_{ij}. \tag{2}$$

$$S = \max_{i=1}^{n}\left\{\sum_{j=1}^{n} m_{ij}\right\}. \tag{3}$$

3. According to formula (4), the total relationship matrix $\boldsymbol{M}''$ is established.

$$\boldsymbol{M}'' = lim_{k\to\infty}(\boldsymbol{M}' + \boldsymbol{M}'^{2} + \cdots + \boldsymbol{M}'^{k}) = \boldsymbol{M}'(\boldsymbol{I} - \boldsymbol{M}')^{-1}. \tag{4}$$

Among them, $\boldsymbol{I}$ is the identity matrix. According to the calculation result, m'' can reflect the direct connection and indirect connection between the failure modes. $m'' > 0$ shows that the factor i has a direct or indirect influence on the factor j , and its influence degree is m''.

4. Influencing degree, influenced degree, center degree and cause degree of each factor are calculated. R represents the row sum of matrix $\boldsymbol{M}''$ and C represents the column sum of matrix $\boldsymbol{M}''$. Then influencing degree is R, influenced degree is C, and center degree is $R + C$, cause degree is $R - C$.

$$R_j = \sum_{j=1}^{n} m_{ij}, i = 1,2,\cdots,n. \tag{5}$$

$$C_j = \sum_{i=1}^{n} m_{ij}, j = 1,2,\cdots,n. \tag{6}$$

B. Improved DEMATEL

In improved decision-making laboratory method, the PageRank algorithm is the central link of the entire analysis method. The PageRank algorithm itself originated from the traditional literature citation analysis, which is the analysis and evaluation of related web pages, based on the complex correlation between the pages. Importance calculation, the importance index of each page is the PR value (PageRank value) of the page, and the ranking of the influence and relevance of the PR value on the web page is used to achieve effective information transmission for web users.

The PageRank algorithm is the central link of the entire analysis method [37]. It lies in the links between different web pages. The more data a single web page links to other web pages (the greater the degree of output), the greater its PR value. Otherwise the smaller it is. Assume that the PR value of each web page is evenly transmitted to the related system. Due to the interlinking relationship between web pages, the calculation process requires multiple iterations. After iteration, a stable convergence PR value is obtained, and the degree of influence and correlation. The order of degrees is as follows.

Fundamental formula：

$$PR(N) = \sum_{i=1}^{k} \frac{PR(t_i)}{C(t_i)}. \tag{7}$$

N is the requested web page, t is the node in the web page, $PR(t_i)$ is the PR value of the web page node, and $C(t_i)$ is the out-degree of the web page node.

Correction formula:

$$PR(N) = \frac{(1-d)}{n} + d \sum_{i=1}^{k} \frac{PR(t_i)}{C(t_i)}. \tag{8}$$

In the formula, d is the buffer factor to prevent the occurrence of level sinking and leakage, and $(1-d)/n$ is the initial value to prevent the occurrence of isolated nodes.

When the number of nodes is reasonable, the PR value of each node can be regarded as a component in the matrix, so that the matrix operation of PageRank can be implemented, and the ranking results of PR values can also be obtained. The matrix operation formula is as follows.

$$P^{x+1} = \frac{(1-d)}{n} \cdot E + d \cdot [C']^{T} \cdot P^{x}. \tag{9}$$

In the formula, P^{x+1} is the matrix of the PR values of each system obtained after the $x+1$ iterations, and E is the identity matrix, which is intended to transform the initial value into a matrix form, and $[C']^{T} \cdot P^{x}$ is equivalent to $\frac{\sum_{i=1}^{k} PR(t_i)}{C(t_i)}$.

Based on the premise that system fault propagation obeys the Markov process, the improved DEMATEL constructs the direct relation matrix according to the analysis of fault mechanism and converts it into the Markov probability transfer matrix. Based on the PageRank algorithm, the component's fault influence degree is evaluated, center degree and cause degree are calculated by the improved DEMATEL to evaluate the importance of system components.

The flow chart of improved DEMATEL analysis is shown in Fig.1.

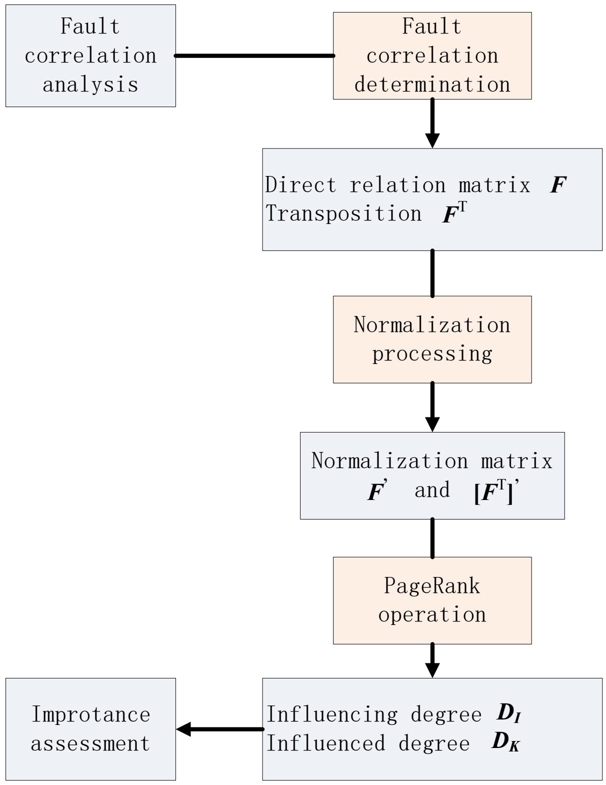

Fig.1. Improved DEMATEL analysis flow chart.

1. Fault correlation analysis

The mechanism of system fault is analyzed and the relationship between system components is analyzed.

2. Construction of direct relation matrix

A direct relation matrix $\boldsymbol{F}$ is constructed according to the fault correlation relationship between components, which f_{ij} indicates the number of times that the component i failure directly leads to the failure of the component j, when $i = j$, $f_{ij} = 0$. As shown in formula (10).

$$\boldsymbol{F} = [f_{ij}], f_{ij} = \begin{cases} n_{ij} \\ 0 \end{cases}. \tag{10}$$

In formula: f_{ij} indicates the number of times that a component i failure was caused by a component j failure.

For propagation mechanism, the failure influencing degree is opposite to failure influenced degree, so the direct relationship matrix $\boldsymbol{F}$ is transposed and $\boldsymbol{F}^{T}$ is obtained.

3. Matrix normalization

Normalizing the elements in the direct relation matrix, each element in the direct relation matrix $\boldsymbol{F}$ is divided by the sum of the elements of the row in which the element is located (except for all row elements are 0) to obtain a normalized matrix $\boldsymbol{F}$□. Similarly $[\boldsymbol{F}^{T}]$□ is obtained. Head and shoulders shots of authors appear at the end of our papers.

4. Operation of influenced degree and influencing degree

Traditional DEMATEL combines the weight coefficients between related components evaluated by experts to calculate the degree of influence and degree of influence. There is a lack of objective and scientific nature of quantitative analysis.

In this paper, PageRank's Matrix algorithm is introduced to replace nodes from web pages to system components, and links between web pages to fault propagation among system components, in order to calculate the page access value to quantify the influence degree and influence degree of system component-related faults.

Using the PageRank algorithm, the calculation of influencing degree failure and influenced degree failure are based on the following hypotheses.

Hypothesis 1: System failure propagation obeys the Markov process.

Hypothesis 2: The probability d that a system component failure is transmitted along the fault propagation model $(0 < d < 1)$.

Hypothesis 3: When the system does not propagate along the fault chain with probability $(1 - d)$, the next fault will occur in any one of the system components with equal probability.

Hypothesis 4: The influencing degree and the influenced degree of the system elements depend on the out-degree and in-degree of the factors.

The record is influenced degree by D_K, and its iterative formula is shown in formula (11):

$$\boldsymbol{D}_K^{(x+1)} = \frac{(1-d)}{n \cdot \boldsymbol{E} + d \cdot (\boldsymbol{F}')}^T \cdot \boldsymbol{D}_K^{(x)}. \tag{11}$$

Where d is the damping factor (the transfer probability), the value in this paper is the ratio between the number of related faults and the total number of faults, n is the number of system components, and $\boldsymbol{E}$ as the matrix $(n \times 1)$ with all elements is 1.

According to formula (11), the power method is used to solve the D_K value, as shown in formula (12).

$$D_K = \lim_{n\to\infty} \left[\frac{(1-d)}{n \cdot \boldsymbol{E} + d \cdot (\boldsymbol{F}')}^T \right] \boldsymbol{D}_K^{(1)}. \tag{12}$$

The direct relationship matrix $\boldsymbol{F}$ is transposed to obtain $\boldsymbol{F}^T$, and $\boldsymbol{F}$ is replaced by $\boldsymbol{F}^T$, and the influence degree of related faults can be obtained, and the influence degree of recording is D_I.

According to formula (11), the iterative formula of D_I is shown in formula (13).

$$\boldsymbol{D}_I^{(x+1)} = \frac{(1-d)}{n \cdot \boldsymbol{E} + d \cdot \left[[\boldsymbol{F}^T]' \right]^T} \boldsymbol{D}_I^{(x)}. \tag{13}$$

According to iterative formula (13), the power method is used to solve the D_I value, as shown in formula (14).

$$D_I = \lim_{n\to\infty} \left[\frac{(1-d)}{n \cdot \boldsymbol{E} + d \cdot \left[[\boldsymbol{F}^T]' \right]^T} \right] \boldsymbol{D}_I^{(1)}. \tag{14}$$

In theory and algorithm, Brin and Page ensured that the value of initial value $\boldsymbol{D}^{(1)}$ did not affect the convergence of node estimation value, and did not change the final ranking relation of important value [38], [39]. Therefore, the $\boldsymbol{D}_K^{(1)}$ value and $\boldsymbol{D}_I^{(1)}$ value in formula (12) and formula (14) are taken to facilitate the operation of $\boldsymbol{D}_K^{(1)} = [1,1,\cdots\cdots,1]$ value and $\boldsymbol{D}_I^{(1)} = [1,1,\cdots\cdots,1]$ value, respectively.

C. Verification of influenced degree and influencing degree

The ISM is used to verify the results of the improved DEMATEL, and the accuracy and effectiveness of the improved method are confirmed.

Step 1: The basic steps are as follows: establish an adjacency matrix $\boldsymbol{A}$ based on fault statistics. As shown in formula (15).

$$\boldsymbol{A} = [a_{ij}], a_{ij} = \begin{cases} 1, f_{ij} \geq 1; \\ 0, f_{ij} = 0; \end{cases} \tag{15}$$

In formula: a_{ij} indicates that component i failure is caused by component j failure.

Calculate the reachability matrix according to the operational rule of Boolean algebra.

Step 2: Components are divided into regions and levels to build a hierarchical structure model [40].

Step 3: Through the hierarchical structure model and direct relation matrix, the ranking of influenced degree and influencing degree for each component is obtained.

Step 4: Comparison and Verification.

The basic principle of ISM is to use various creative techniques to extract system components, it uses directed graphs, matrices and other tools to construct a multi-level hierarchical structure model.

In this way, the dependency between the elements and the internal structure of the system are visually displayed, and the relationship is organized and hierarchical.

The basic steps are as follows:

1. A directed graph of failure relationships is constructed.
2. An adjacency matrix $\boldsymbol{Y}$ based on the directed graph is established.

$$\mathbf{Y} = [y_{ij}], y_{ij} = \begin{cases} 1, n_{ij} \geq 1; \\ 0, n_{ij} = 0; \end{cases} \tag{16}$$

y_{ij} indicates that subsystem i causes subsystem j to malfunction.

3. According to the Boolean algebra algorithm, the reachability matrix $\boldsymbol{T}$ of the adjacency matrix is calculated.
4. Area Decomposition and Rank Division.

The fault subsystem is divided into regions and levels from the analysis and statistics of reachable set, antecedent set, starting set and ending set.

Reachable set $R(S_i) = \{S_i | S_i \in S, a_{ij} = 1, j = 1,2,\cdots,n\}$

Antecedent set $A(S_i) = \{S_j | S_j \in S, a_{ji} = 1, j = 1,2,\cdots,n\}$

Common set $C(S_i) = R(S_i) \cap A(S_i)$

Starting set $B(S_i) = \{S_i | S_i \in S, C(S_i) = A(S_i), i = 1,2,\cdots,n\}$

Ending set $E(S_i) = \{S_i | S_i \in S, C(S_i) = R(S_i), i = 1,2,\cdots,n\}$

Area decomposition obtains the starting set from the analysis of the reachable set, the antecedent set, and the common set, and it performs the reachable set intersection test on the starting set. When the intersection set is not an empty set, all subsystems are a region, and vice versa. Area decomposition is required.

Rank division is to obtain the ending set by analyzing the reachable set, the antecedent set, and the common set. From the surface set to the deep set, it is screened and eliminated layer by layer. The hierarchical division from shallow fault factors to deep fault factors is realized.

5. Build a hierarchical structure model.

The icon model is established by using graph theory knowledge from the collection obtained after domain decomposition and hierarchical division.

D. Importance assessment

The center degree and cause degree of the system are obtained from the influence degree D_I and the influence degree D_K, as shown in Table 2. The center degree and the cause degree carry on the importance assessment and sorting.

Table 2. Calculation and Meaning for center degree and cause degree.

Influence factor	Calculation formula	Meanings
Center degree	$D_I + D_K$	The position of this factor in the whole system and the extent to which it plays a role.
Cause degree	$D_I - D_K$	If the cause degree is greater than 0, it is called the cause factor, which means that this factor has a great influence on other factors; if the cause degree is less than 0, it is called the result factor, which indicates that the factor is easily affected by other factors; if the cause degree is equal to 0, the factor has no influence on other factors and is not affected by others.

It can be seen from the significance of center degree and cause degree that the greater the center degree ($D_I + D_K$), the greater the importance of the system elements, and the system elements are classified according to positive or negative of the cause degree ($D_I - D_K$). The two are interrelated and complementary to each other. Therefore, through the combination analysis of center degree and cause degree, the importance value w_i of system related fault components is obtained, as shown in formula (17). Then the importance of related fault components is sorted.

$$w_i = \frac{\sqrt{(D_I+D_K)^2+(D_I-D_K)^2}}{\sum_{i=1}^{m}\sqrt{(D_I+D_K)^2+(D_I-D_K)^2}}. \tag{17}$$

Because of the distinction between positive value and negative value of cause degree, the important parts of system related fault can be distinguished and refined, and the classification criteria of importance evaluation are as follows:

The center degree of the component is larger, and the cause degree value is positive and the value is large, indicating that the component is highly important in the system and easily propagates the fault to other components, which is a key component of the system and is of high importance;

The center degree of the component is larger, and the cause value is negative and the absolute value is large, indicating that the component is highly important in the system and is susceptible to the failure of other components, which is a weak link of the system and is of high importance.

3. APPLICATION EXAMPLE

In this paper, based on a reliability test, a certain type of the CNC machine center is used to obtain 29 related faults as an example for research. The components of production center are divided as shown in Table 3.

Table 3. Production center component division.

Components	Code	Components	Code
Spindle system	S	Pneumatic system	G
Tool library system	M	Lubrication system	L
Feed system	J	Cooling system	W
CNC control system	NC	Chip removal system	K
Hydraulic system	D	Workbench	T
Electrical System	V	Server system	Q

Through the fault mechanism analysis of the fault information associated with the CNC machine center, the data analysis table of the associated faults of each system component is obtained, as shown in Table 4.

Table 4. Production center relation failure analysis.

Fault cause component	Fault result component	Number of associated faults
Spindle system	Tool library system	5
Pneumatic system	Tool library system	4
Lubrication system	Tool library system	1
Hydraulic system	Tool library system	1
Electrical System	Feed system	2
Chip removal system	Feed system	1
Spindle system	Feed system	2
CNC control system	Feed system	1
Cooling system	Feed system	1
Lubrication system	Feed system	4
Pneumatic system	Spindle system	1
Lubrication system	Spindle system	1
Hydraulic system	Spindle system	1
CNC control system	Spindle system	1
Electrical System	Spindle system	1
Electrical System	Cooling system	1
Electrical System	CNC control system	1

A. Application of improved DEMATEL

The frequency of faults in Table 4. data can directly reflect the degree of fault correlation, so a direct relation matrix is established in this paper according to the number of related faults between components.

$$\boldsymbol{F}=\begin{array}{c}\\ S\\ M\\ J\\ NC\\ D\\ V\\ G\\ L\\ W\\ K\\ T\\ Q\end{array}\begin{array}{c} \begin{array}{cccccccccccc} S & M & J & NC & D & V & G & L & W & K & T & Q\end{array}\\ \begin{bmatrix} 0 & 5 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 1 & 0 & 2 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0\\ 1 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 1 & 1 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}\end{array}$$

Matrix $\boldsymbol{F}$ transpose to matrix $\boldsymbol{F}^T$.

$$\boldsymbol{F}^{\mathrm{T}}=\begin{array}{c}\\ S\\ M\\ J\\ NC\\ D\\ V\\ G\\ L\\ W\\ K\\ T\\ Q\end{array}\begin{array}{c} \begin{array}{cccccccccccc} S & M & J & NC & D & V & G & L & W & K & T & Q\end{array}\\ \begin{bmatrix} 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0\\ 5 & 0 & 0 & 0 & 1 & 0 & 4 & 1 & 0 & 0 & 0 & 0\\ 2 & 0 & 0 & 1 & 0 & 2 & 0 & 4 & 1 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}\end{array}$$

The damping factor $d=0.3$ is calculated according to the proportion of the number of related faults in the machine center to the total number of faults.

According to the calculation formula of influencing degree and influenced degree (11), (12), (13), (14), the influencing degree D_I and influenced degree D_K of each system component are obtained by using the MATLAB software. Taking D_K as an example, the algorithm flow is shown in Fig.2.

The influenced degree D_K and influencing degree D_I, details are shown in Table 5.

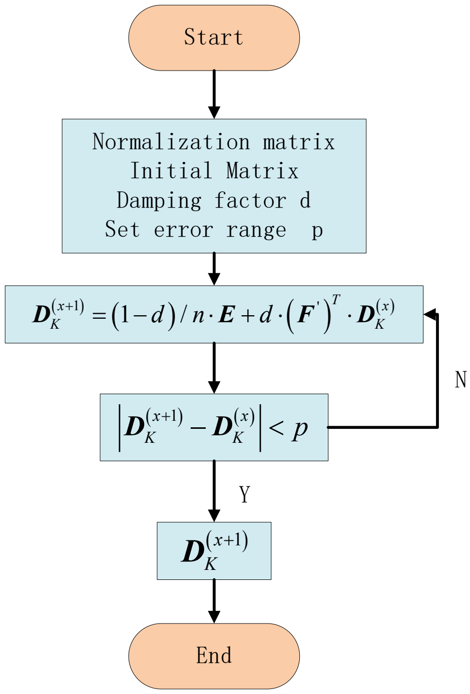

Fig.2. Algorithm flow chart.

Table 5. Ranking of influencing degree, influenced degree, center degree, and cause degree.

Ranking	D_I	Ranking	D_K
V	0.103	J	0.130
L	0.071	M	0.103
S	0.070	S	0.086
D	0.069	NC	0.062
G	0.064	W	0.062
NC	0.064	D	0.058
W	0.060	V	0.058
K	0.060	G	0.058
M	0.058	L	0.058
J	0.058	K	0.058
T	0.058	T	0.058
Q	0.058	Q	0.058

B. Result verification

We use the traditional DEMATEL to analyze the correlation of examples and compare the analysis results of the above-mentioned improved DEMATEL with the results of the traditional DEMATEL, as shown in the Table 6.

By comparison, it can be seen that influencing degree of V (Electrical System) and D (Hydraulic system) calculated by the improved decision-making trial and evaluation laboratory increased, that of influencing degree of S (Spindle system), G (Pneumatic system), NC (CNC control system) decreased, and that of other subsystems remained unchanged. By comparing the ranking of influenced degree, it can be seen that the ranking of J (Feed system) increased, the ranking of M (Tool library system) decreased, other subsystems remained unchanged.

Table 6. Comparison of influencing degree and influenced degree.

Influencing degree		Influenced degree	
D_I	R	D_K	C
V	S	J	M
L	L	M	J
S	V	S	S
D	G	NC	NC
G	NC	W	W
NC	D	D	D
W	W	V	V
K	K	G	G
M	M	L	L
J	J	K	K
T	T	T	T
Q	Q	Q	Q

In this paper, the ISM is used to verify the results of influencing degree and influenced degree for improved DEMATEL.

According to failure data of the CNC machine center, when component $i$causes component j to fail, matrix element y_{ij} is recorded as 1, and when there is no influence relationship between component $i$and component j, matrix element y_{ij} is recorded as 0, thereby establishing the adjacency matrix $\boldsymbol{Y}$ of system components.

According to the Boolean calculation algorithm, the reachability matrix $\boldsymbol{T}$ is calculated by MATLAB.

$$\boldsymbol{T} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

We constructed a hierarchical structure model for domain decomposition and hierarchical division of system components., as shown in Fig.3.

Combined with the direct relation matrix, the ranking of influencing degree and influenced degree can be obtained, as shown in the Table 7.

According to the actual working conditions of the CNC machine center and the above comparison results, the expert subjective score of the weight coefficient in the traditional DEMATEL may have some limitations and errors, while the improved DEMATEL fully considers the dynamic transmission of the related faults among the machining center subsystems according to the specific data, which makes calculation results more reasonable and effective. What is more, the important components of the CNC machine center can be determined more accurately, which has a higher application value for the reliability improvement of the CNC machine center.

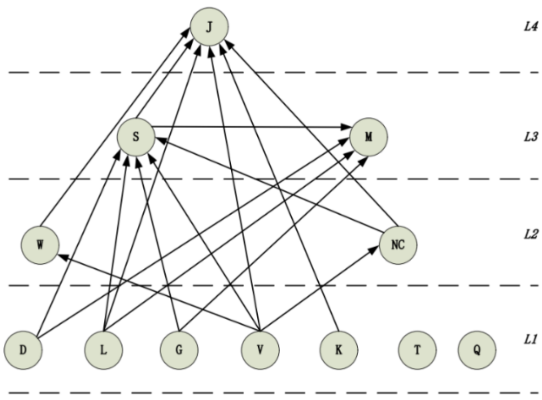

Fig.3. Production center hierarchical structure model.

Table 7. Ranking of influencing degree, influenced degree.

Influencing degree	Influenced degree
V	J
L	M
S	S
D	NC
G	W
NC	D
W	V
K	G
M	L
J	K
T	T
Q	Q

C. Importance assessment.

Based on the influenced degree D_K and influencing degree D_I, center degree and cause degree of the CNC machine center component are calculated. Details are shown in Table 8.

According to the importance formula (17), we sorted the importance of the related faults of the machining center, as shown in Table 9.

The importance assessment chart is shown in Fig.4.

The results show that the feed system (J) is the most important, followed by the electrical system (V) and the tool library system (M). For the machining center, these three aspects should focus on reliability improvement design, and monitoring the fault propagation process and related faults in real time.

At the same time, it can be seen from Table 4. that the electrical system (V) has the largest factor, which is much larger than other subsystems, and this system is the main fault cause element; the tool library system (M) and the feed system (J) have the smallest factor, which is far smaller than other subsystems, and is the main fault result element. Therefore, taking the three components of the machining center system with the largest related fault importance as examples, through the analysis of the classification criteria of importance evaluation, we can see that the key components are the electrical system (V), the weak link is the feed system (J) and the tool library system (M), these three are important components of system related faults, and the importance is higher.

Table 8. Ranking of center degree and cause degree.

Ranking	$D_I + D_K$	Ranking	$D_I - D_K$
J	0.1880	V	0.045
V	0.1612	L	0.012
M	0.1608	D	0.011
S	0.1558	G	0.006
L	0.1288	NC	0.002
D	0.1272	K	0.001
NC	0.1259	T	0
G	0.1224	Q	0
W	0.1217	W	-0.002
K	0.1182	S	-0.012
T	0.1166	M	-0.044
Q	0.1166	J	-0.071

Table 9. Ranking of significant degree.

Components Code	w_i	Components Code	w_i
J	0.1203	NC	0.0754
V	0.1002	G	0.0733
M	0.0998	W	0.0729
S	0.0936	K	0.0708
L	0.0774	T	0.0698
D	0.0766	Q	0.0698

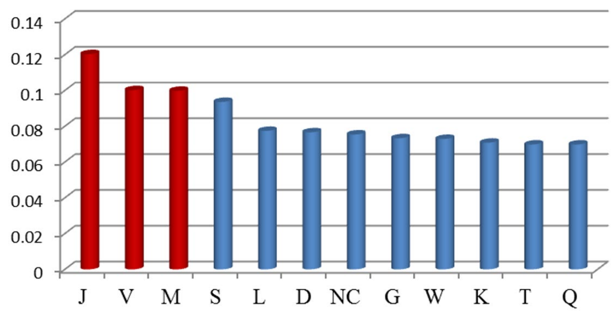

Fig.4. Significance assessment graph.

In this paper, taking the related faults of the CNC machine center as an example, the problem of subjective evaluation of the weight coefficient in the traditional DEMATEL is solved by using the PageRank algorithm in the improved DEMATEL to analyze the importance of the fault related systems, and the quantitative ranking of the importance of the relevant fault components of the system is realized, which makes the analysis results more accurate, the application value is higher, and the direction of improving the reliability of the system is clarified. The proposed method has a higher application value to improve the reliability of the CNC machine center.

4. CONCLUSIONS

In view of the existence of related faults and dynamic fault transmission among complex system components, the PageRank algorithm is used to quantify the influence relationship among related elements in fault related systems, and the quantitative analysis of the influence among components in complex systems is realized, so as to improve the rationality and accuracy of the influence relationship analysis.

Under the assumption that the fault propagation obeys the Markov process, the improved DEMATEL fused with the PageRank algorithm is proposed to calculate the correlation value of system related faults between components, which solves the problem of subjective evaluation of weight coefficients in the traditional DEMATEL. At the same time, the analysis results of the improved DEMATEL are verified through the method of ISM, which proves that the analysis results are accurate and have high application value, and then the importance of the system related fault is accurately identified.

Based on the relevant fault data of the CNC machine center, improved DEMATEL is used to perform the importance analysis, and the importance ranking is obtained for feed systems, electrical systems, and tool library system, etc., and the quantitative ranking of the importance of system-related faults is achieved. It makes the analysis results more accurate, increases application value, clearly points out the improvement direction of system reliability, and provides a reliable basis for comprehensive system importance analysis.

In the fault related systems, importance analysis can clarify the important components and weak links of the system, the overall reliability of the system is improved. The application of system-related fault importance analysis based on DEMATEL-PageRank for system related fault solves the problem of traditional subjective evaluation by experts, the quantitative analysis of influence relationship between system elements is carried out, and then the importance of system elements is accurately identified, the importance ranking of system elements is completed. The method provides a new idea for the importance analysis of fault related system, prerequisite basis for the improvement of system reliability is provided, pre-preparation for the subsequent fault-related system reliability test is offered, theoretical basis for system reliability research is supplied, and the high theoretical value is obtained.

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