Research Article

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A human error risk priority number calculation methodology using fuzzy and TOPSIS grey

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Abstract: In the implementation of management error proofing, enterprises need to carry out risk evaluation and ranking of management activities error, to determine error proofing improvement order. We note that management function failure is different from industrial failure, and the management activity error as its cause is also different from operational or device error, so the method generally used in industry is not suitable for the risk assessment of management activity error. To address this issue, this study integrates the FMEA (failure modes and effect analysis) with the ISO9001 standardized management system framework describing multilevel and multi-attribute management activities, and the human errors that may lead to functional failure of quality management activities are identified at each level and each category. The three factors (severity (S), occurrence (O), and detection (D)) of errors in each management activity are evaluated and integrated into the risk priority number for each quality management activity error. The two major defects of the traditional FMEA in the practical application process are as follows: (1) the evaluation of error attributes of various management activities is basically qualitative language description, which cannot be quantified; (2) the other one disadvantage is that it ignores the fact that three factors have the different weights in the system rather than equality, and not considering the relative importance of between them. In this article, the fuzzy set theory and the grey relational decision theory are, respectively, applied to improve the two defects and to improve the accuracy of the decision. Finally, a numerical example of a coal mine is given to verify the effectiveness of the proposed method. This study provides a basis for managers and practitioners to quantitatively evaluate and prevent errors in management activities.

Keywords: human error, FMEA, ISO9001, fuzzy set theory, TOPSIS grey

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1 Introduction

Error proofing has long been used in industries as a feedforward method to prevent product/service defects in design and manufacturing processes. Studies show that 90% of industrial accidents are caused by people's unsafe behaviors, and ultimately, 10% of the unsafe state of objects is also caused by people's mistakes [1,2]. Obviously, human error has always existed, but error-proofing in management activities has been seriously neglected. In recent years, frequent quality and safety accidents have been criticized by social media. The root cause is still a management problem. Management error proofing is a new idea to improve the robustness of the system, which can help enterprises prevent the failure of management functions, reduce the potential risks in the process, and make the sustainable development of enterprises.

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Human error in management refers to unintentional errors in management activities that deviate from standards, plans, objectives, values (strategies, procedures, work instructions, and contracts), and other requirements. Management is a human activity, management activities are invisible, and cannot leave the manager an independent existence. So, management errors are basically human errors. Due to the influence of enterprise culture deviation, process complexity, personality, psychological state, health state, and other factors, management errors are inevitable and difficult to control, and hence, the application of traditional industrial quality control methods in the field of management is limited to a certain extent.

In the stage of management error identification and risk assessment, this article tries to apply FMEA (failure modes and effect analysis) to the field of management. FMEA is a very powerful and effective analytical tool that is widely used in automotive, aerospace, machinery and electronics, and other fields. FMEA has been widely adopted by reliability practitioners and has become standard practice in Japanese, American, and European manufacturing companies [3,4].

This article will integrate the FMEA and ISO9001 quality management standard framework, which is the analysis of the management process failure mechanism. ISO 9001 is so far the world's most mature quality management framework, with strong logic, and guidance, and is considered to be the international certification review body that only designated quality management standards. According to the management framework, managers can decompose management activities layer by layer. The system ensures the comprehensiveness of the evaluation and also reflects the hierarchy and the structure of the causal chain of risk factor transmission. That is, the potential management function failure risk caused by each management activity error under each level and each process can be considered.

FMEA is made by addressing problems in order from the biggest risk priority number (RPN) to the smallest ones. However, traditional FMEA analysis has two shortcomings: (1) Due to the limitations of experts' knowledge and experience, management failure modes are usually described in subjective or qualitative language, making it difficult to make an accurate judgment on the three factors. (2) This method ignores that three factors (S, O, and D) may have different weights in the system, so the relative importance of the three factors is not taken into account. For example, the multiplication of different S, O, and D sometimes yields the same RPN. In other cases, the multiplication may lead to ranking reversals, such as higher RPN for less severe failure modes than for more severe failure modes. This makes it a big problem to judge the risk sequence of various quality management errors by RPN value only in practical application. Therefore, FMEA is best combined with other methods in risk diagnosis assessment.

To overcome and improve the limitations of the FMEA method in practical application, scholars have done a lot of research from various angles [5–8]. This article will combine fuzzy set and grey decision theory to improve it, to promote enterprise quality management FMEA analysis to obtain better application and development. First, based on the knowledge and experience of experts and managers, the fuzzy evaluation language term set of quality management errors and the corresponding triangular fuzzy number are established by applying the fuzzy set theory. Then, according to the fuzzy evaluation language terminology set established before and the corresponding triangular fuzzy number, the FMEA team makes a quantitative evaluation on the severity S, occurrence O, and detection D of all kinds of quality management errors. Finally, combined with the relevant method of grey decision theory, the grey correlation degree of all kinds of quality management errors is calculated and sorted to determine their risk order. In this way, the proposed method can effectively deal with all kinds of fuzzy and uncertain information, severity S, occurrence O, and detection D among the relative importance of the three variables have also been considered comprehensively, effectively overcome the limitations of the FMEA method in the practical application process.

2 Construction of human error identification analysis framework

Human management error identification cannot be derived from experimental data, and the traditional approach is based on expert experience or case analysis. Here, a new system analysis framework is considered to be generated to be applied in the field of management. Through rigorous research, existing theories and methods are integrated to facilitate the application, standardization, and promotion of enterprises.

The ISO9001 quality management system is a universal standard applicable to all kinds of organizations in all kinds of industries and sizes. It covers enterprise management activities from large to small, from macro to micro, from surface to point, and from abstract to concrete, which can ensure the integrity of management error-proofing system structure to the greatest extent. The identification of management errors should be discussed at different levels. Heterogeneous enterprises should combine their own basic situation, industry characteristics, etc., by managers and department experts to form an evaluation group, according to the high- to low-quality management activities of the relative levels of decomposition. This study will be based on the ISO9001 standard framework, the management activities according to the strategic layer, managerial layer, and operational layer. Because the language of the management failure mode is relatively vague, this article provides an idea; that is, according to the standard requirements of the ISO9001 quality management system, the management activity error represented by the lower level index in the index system is used to describe the failure mechanism and the reason of its upper-level index is due to the potential functional failure mode.

In the case study of this article, the evaluation team is composed of coal mine safety management experts. They will complete the analysis for three-level management activities based on the FMEA analysis framework table. Taking a managerial layer indicator as an example, the management function requirement is the attribute requirement of the managerial activity indicator, the function failure of managerial activity is the potential failure mode, and the error of operational activity is the potential failure reason of managerial activity. At the same time, it does not exclude the use of historical data, brainstorming, employee complaint collection, customer complaint information, and other means to identify the potential failure modes at all levels as well as the human management errors as the causes as detailed as possible. After identifying the error, its risk priority RPN value is calculated to obtain the error-proofing order.

3 Quantitative analysis of severity, occurrence, and detection on fuzzy set theory

The traditional FMEA method has been criticized to have many deficiencies and significant efforts have been made to overcome the shortcomings of the RPN. Applying fuzzy set theory to FMEA can effectively overcome the shortcomings of the traditional index of FMEA, and greatly improve its credibility and accuracy [9–11].

3.1 Establishment of fuzzy assessment language terms set of evaluation index

The FMEA method has a good solution for complex problems with multiple levels of multiple attributes, and severity (S), occurrence (O), and detection (D) are the main index variables in the FMEA analysis of enterprise quality management errors, which are uniformly defined and summarized in the article. There are five types of language evaluation terms of S, O, and D: extreme (E), high (H), medium (M), low (L), and rare (R). Based on each evaluation term, the meaning of each index is varied.

3.2 Identification of triangle fuzzy value for the fuzzy language evaluation term

Combining the fuzzy theory, the article makes a quantitative description by the use of five qualitative languages of E, H, M, L, and R. By and large, the triangle fuzzy number A is expressed as (a_l, a_m, a_u), and its feature functions (membership function) can be expressed in equation (1), where $a_u \geq a_m \geq a_l < 0$, a_l and a_u represent the lower and upper limits of A, respectively, and a_m is the mid-value for the subjection degree of A of 1.

$$\mu_A(\chi) = \begin{cases} (\chi - a_l)/(a_m - a_l), \ \chi \in [a_l, a_m], \\ (a_u - \chi)/(a_u - a_m), \ \chi \in [a_m, a_u], \\ 0, \chi \in (-\infty, a_l] \cup [a_u, +\infty). \end{cases} \tag{1}$$

Algorithms for triangular fuzzy numbers are as follows: set $A = (a_l, a_m, a_u)$; $B = (b_l, b_m, b_u)$, then

$$A + B = (a_l + b_l, a_m + b_m, a_u + b_u). \tag{2}$$

$$A \times B = (a_l b_l, a_m b_m, a_u b_u). \tag{3}$$

$$\omega A = (\omega a_l, \omega a_m, \omega a_u), \quad \omega \geq 0. \tag{4}$$

$$1/A = (1/a_l, 1/a_m, 1/a_u). \tag{5}$$

The triangular fuzzy number for a group of linguistic evaluation term set can be determined by the Delphi method and based on the knowledge and experience of FMEA experts [12]. Suppose there are n members, the authority or ability of the ith member is ω_i, his or her evaluation on a factor (S, O, and D) of quality management errors is χ_i, the relevant triangle fuzzy number is (a_{li}, a_{mi}, a_{ui}), to establish the opinions set of FMEA members and combine the membership function of the triangular fuzzy number and its algorithm, as shown in equations (1)–(5), from which the triangular fuzzy number related to the language evaluation term of the index variable can be obtained, as shown in equation (6).

$$a_l = \sum_{i=1}^{n} \omega_i a_{li}, \ a_m = \sum_{i=1}^{n} \omega_i a_{mi}, \ a_u = \sum_{i=1}^{n} \omega_i a_{ui}, \ \sum_{i=1}^{n} \omega_i = 1, \ \omega_i \in [0, 1]. \tag{6}$$

3.3 Defuzzification of triangular fuzzy numbers

The defuzzification process is required for the related triangular fuzzy numbers to evaluate the results of S, O, and D for various quality management errors after being determined to obtain the clear number of the relevant index evaluation [10].

a) Expected value of triangular fuzzy number A

$$E(A) = [(1 - \lambda)a_l + a_m + \lambda a_u]/2, \tag{7}$$

where $0 \leq \lambda \leq 1$, and the risk preference of experts determines the value of λ. In the case of risk aversion, $\lambda > 0.5$. In the case of risk neutral, $\lambda = 0.5$, and in the case of risk lover, $\lambda < 0.5$. Many experts adopt the principle of mediocrity to evaluate, and generally let $\lambda = 0.5$.

b) Using fuzzy probability for handling the triangular fuzzy numbers

In the case of triangular fuzzy numbers $A = (a_l, a_m, a_u)$, considering a_m as the median, the possibility of the result a_m is N times that of the result a_l, based on the deviation extent of a_m and a_l. In the same way, the possibility of the result a_m is M times that of the result a_u, which is determined in light of the deviation extent of a_m and a_u, and so, the fuzzy probabilities of a_l, a_m, and a_u are $\frac{1}{2(1+N)}$, $\frac{N+2NM+M}{2(1+N)(1+M)}$, and $\frac{1}{2(1+M)}$, respectively. The defuzzification formula of the triangular fuzzy number is equation (8), where the clear number of evaluation index of each error can be obtained [13].

$$A(\chi) = \frac{1}{2(1 + N)} \cdot \alpha_l + \frac{N + 2NM + M}{2(1 + N)(1 + M)} \cdot \alpha_m + \frac{1}{2(1 + M)} \cdot \alpha_u. \tag{8}$$

4 Application of grey relational decision theory in RPN evaluation

The grey relational decision theory has the advantages of simple, practical, and strong operability, and can effectively solve the problems of multi-index analysis and evaluation, multi-attribute decision-making, and so on. After the FMEA team evaluates the S, O, and D of all human management errors, the corresponding clear number can be obtained, and then, the theoretical method of grey correlation decision can be applied to determine the effect evaluation vector corresponding to the ideal scheme. The grey correlation degree between each scheme and the ideal scheme is calculated. Through the gray correlation degree, gray correlation relative closeness to determine the risk sequence of all kinds of human management errors, so as to overcome the limitations of only RPN value to judge the risk sequence of all kinds of quality management errors in the practical application, has a methodological significance for the management of FMEA analysis [7–9].

4.1 Establishment of evaluation matrix

In the case of m quality management errors, n evaluation index, and evaluation value for each index of x_{ij} $(1 \le i \le m, 1 \le j \le n)$, the evaluation matrix $X = (x_{ij})_{m\times n}$ can be established. In the FMEA analysis, suppose m quality management errors are denoted as $(x_1, x_2,..., x_\mathrm{m})$. X_i is the quality management error of ith, with the three evaluation indexes: severity, occurrence, and detection, of which the evaluation value can be expressed by (x_{i1}, x_{i2}, x_{i3}). Evaluation matrix $X = (x_{ij})_{m\times 3}$ can be established according to the aforementioned method to show FMEA expert group evaluation values of S, O, and D of various quality management errors [14].

$$X = (x_{ij})_{m\times n} = (x_{ij})_{m\times 3} = \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ x_m \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ & \cdots & \\ x_{m1} & x_{m2} & x_{m3} \end{bmatrix}. \tag{9}$$

4.2 Determination of positive and negative ideal solutions

Since the ideal solution is established for the evaluation matrix, the ideal solution of the enterprise quality management FMEA analysis shall be based on the worst value and optimal value of the S, O, and D of quality management errors [15,16]. The enterprise quality management errors with the highest risk will be determined in this article via the quality management FMEA analysis, and hence, the worst value of indexes is identified as the positive-ideal solution $X_0{}^+$, and the optimal value (ideal value) of indexes is the negative-ideal solution X_0^-. For the comprehensive evaluation of the risk ranking of quality management errors, their relevance to the positive and negative matrices shall be considered.

Positive-ideal solution:

$$X_0^+ = (x_0^+)_{m\times n} = \begin{bmatrix} E & E & E \\ \vdots & \vdots & \vdots \\ E & E & E \end{bmatrix} = \begin{bmatrix} 10 & 10 & 10 \\ \vdots & \vdots & \vdots \\ 10 & 10 & 10 \end{bmatrix}. \tag{10}$$

Negative-ideal solution:

$$X_0^- = (x_0^-)_{m\times n} = \begin{bmatrix} R & R & R \\ \vdots & \vdots & \vdots \\ R & R & R \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \vdots & \vdots & \vdots \\ 0 & 0 & 0 \end{bmatrix}. \tag{11}$$

4.3 Establishment of grey relational coefficient matrix

Grey relational coefficients between the index evaluation value of various quality management errors and the positive and negative ideal solutions will be calculated [17]. The formula for the grey relational coefficient of the ith quality management error and positive-ideal solution on the jth index is shown in equation (12):

$$r_{ij}^{+} = \frac{\min_i \min_j |x_0^{+} - x_{ij}| + \zeta \max_i \max_j |x_0^{+} - x_{ij}|}{|x_0^{+} - x_{ij}| + \zeta \max_i \max_j |x_0^{+} - x_{ij}|}, \tag{12}$$

where ζ is discrimination coefficient, $\zeta \in (0,1)$, and the general value is 0.5.

So, the grey relational coefficient matrix of various quality management errors and positive-ideal solution is R^{+}:

$$R^{+} = \begin{bmatrix} r_{11}^{+} & r_{12}^{+} & r_{13}^{+} \\ r_{21}^{+} & r_{22}^{+} & r_{23}^{+} \\ \vdots & \vdots & \vdots \\ r_{m1}^{+} & r_{m2}^{+} & r_{m3}^{+} \end{bmatrix}. \tag{13}$$

Similarly, the formula for the grey relational coefficient of the ith quality management error and negative-ideal solution on the jth index is shown in equation (14):

$$r_{ij}^{-} = \frac{\min_i \min_j |x_0^{-} - x_{ij}| + \zeta \max_i \max_j |x_0^{-} - x_{ij}|}{|x_0^{-} - x_{ij}| + \zeta \max_i \max_j |x_0^{-} - x_{ij}|}, \tag{14}$$

where ζ is ditto, and the grey relational coefficient matrix of various quality management errors and the negative-ideal solution is R^{-}:

$$R^{-} = \begin{bmatrix} r_{11}^{-} & r_{12}^{-} & r_{13}^{-} \\ r_{21}^{-} & r_{22}^{-} & r_{23}^{-} \\ \vdots & \vdots & \vdots \\ r_{m1}^{-} & r_{m2}^{-} & r_{m3}^{-} \end{bmatrix}. \tag{15}$$

4.4 Calculation of grey relational degree of various quality management errors

The risk ranking of various quality management errors shall be determined with consideration of the relative importance of the S, O, and D, and assume that the weight between S, O, and D is λ_j. Then, the grey relational degree of the ith quality management error and the positive-ideal solution is expressed in equation (16):

$$R_i^{+} = \sum_{j=1}^{3} \lambda_j \cdot r_{ij}^{+}, \left(i = 1, 2, \ldots, m; j = 1, 2, 3; \lambda_j \in (0, 1); \sum_{j=1}^{3} \lambda_j = 1 \right). \tag{16}$$

Similarly, the grey relational degree of ith management error and the negative-ideal solution is shown in equation (17):

$$R_i^{-} = \sum_{j=1}^{3} \lambda_j \cdot r_{ij}^{-}, \left(i = 1, 2, \ldots, m; j = 1, 2, 3; \lambda_j \in (0, 1); \sum_{j=1}^{3} \lambda_j = 1 \right). \tag{17}$$

4.5 Calculation of the grey relational relative closeness of various management activities

Calculate the relative closeness C_i of distance that an alternative is close to the ideal solution, which is defined in equation (18):

$$C_i = \frac{R_i^+}{R_i^- + R_i^+}, \quad i = 1, 2, \ldots, m. \tag{18}$$

4.6 Conclusion

Finally, the order of improvement is determined by the RPN values.

R_i^+, R_i^-, and C_i of various quality management errors will be observed and compared. Obviously, the greater grey relational relative closeness C_i of an error indicates that the quality management error is closer to the positive-ideal solution, and the risk is higher. The greater grey relational degree R_i^+ shows that it is closer to the positive-ideal solution with higher risk [18]. The grey relational degree R_i^- is larger and indicates that it approximates the negative-ideal solution with a lower risk ranking.

After comprehensive comparison and analysis, improvement approaches shall be studied and developed for the enterprise quality management errors with higher risk levels and ranking to correct and improve various functional failures and reduce the values of C_i and R_i^+.

5 Case study of a coal mine

Take a coal mine as an example. A group of experts from relevant departments of the enterprise (proficient in strategy, transportation and marketing, human resources, finance, electromechanical, production, and safety) is convened to decompose the quality management activities of the coal mine according to the ISO9001 framework and fill in the FMEA analysis framework form [19]. Error identification and analysis first shall comply with the basic principle of FMEA table design, which mainly includes management functional requirement, potential functional failure mode, consequences of potential failure and impact, factor and mechanism of potential failure, RPN, and the improvement measures [20].

First, according to the semantic structure of the basic requirements of ISO9001 standardization standard, according to the three relative levels from high to low (strategic layer, managerial layer, and operational layer), the quality management activities are decomposed and expanded step by step. The subproject management activities of the five categories are grouped into strategic activities, then the requirements of the next level are the managerial activities, and the specific activities of the basic requirements under the terms are the operational activities. When the failure mode of management functions is traced back, it is generally that one error is caused by multiple errors. For ease of presentation, after the management activities are decomposed into three levels, the inconsistency between the lower-level management activities and the requirements of the clause is used to describe the reason why its upper-level management activities do not conform to the clauses. That is, the failure of the upper-level management function is caused by the inconsistency of the requirements caused by the errors of the lower-level management activities [21,22].

They will complete the analysis for three-level management activities based on the FMEA analysis framework table. Taking a managerial layer indicator as an example, the management function requirement is the attribute requirement of a managerial activity indicator, the function failure of managerial activity is the potential failure mode, and the error of operational activity is the potential failure reason of managerial activity.

According to the aforementioned term set of fuzzy evaluation language: extreme (E), high (H), medium (M), low (L), and rare (R), the group of experts evaluate the S (severity), O (occurrence), and D (detection) of various quality management errors to obtain the comprehensive evaluation, and results are filled in the framework table. The selected example is presented in Table 1 [23].

To simplify the calculation, the fuzzy numbers of S, O, and D are deblurred according to equation (8). In equation (8), referring to the empirical coefficients proposed by the previous scholars and related literature for the method of three-value estimation, it is concluded that the occurrence of a_m is double that of a_l and a_u. So, the fuzzy probabilities of a_l, a_m, and a_u, respectively, are $\frac{1}{6}$, $\frac{4}{6}$, and $\frac{1}{6}$, followed by $A(\chi) = \frac{1}{6}a_l + \frac{4}{6}a_m + \frac{1}{6}a_u$.

The clear numbers corresponding to the fuzzy evaluation terms are as follows: extreme (E) is 9.783, high (H) is 8.000, medium (M) is 5.583, low (L) is 3.317, and rare (R) is 1.300.

The following evaluation matrix is established according to the evaluation of the failure modes of various quality management functions and human errors from the group of experts as well as the clear numbers corresponding to fuzzy evaluation terms.

$$X = (x_{ij})_{23\times 3} = \begin{vmatrix} H & L & H \\ H & L & L \\ R & R & R \\ M & M & M \\ M & M & H \\ M & L & M \\ M & L & M \\ M & H & M \\ M & M & R \\ M & L & L \\ M & M & L \\ M & E & L \\ H & L & M \\ H & L & L \\ H & M & H \\ H & R & R \\ H & L & L \\ H & E & M \\ L & L & L \\ L & M & L \\ L & H & M \end{vmatrix} = \begin{vmatrix} 8.000 & 3.317 & 8.000 \\ 8.000 & 3.317 & 3.317 \\ 5.583 & 1.300 & 1.300 \\ 5.583 & 5.583 & 5.583 \\ 5.583 & 5.583 & 8.000 \\ 5.583 & 3.317 & 5.583 \\ 5.583 & 3.317 & 5.583 \\ 5.583 & 8.000 & 5.583 \\ 5.583 & 5.583 & 1.300 \\ 5.583 & 3.317 & 3.317 \\ 5.583 & 5.583 & 3.317 \\ 5.583 & 9.783 & 3.317 \\ 8.000 & 3.317 & 5.583 \\ 8.000 & 3.317 & 3.317 \\ 8.000 & 5.583 & 8.000 \\ 8.000 & 1.300 & 1.300 \\ 8.000 & 3.317 & 3.317 \\ 8.000 & 9.783 & 5.583 \\ 3.317 & 3.317 & 3.317 \\ 3.317 & 5.583 & 3.317 \\ 3.317 & 8.000 & 5.583 \end{vmatrix}.$$

The positive and negative ideal solutions are determined. It is also determined that the worst value of each index is the positive-ideal solution $X_0{}^{+}$, while the optimal value (ideal value) is the negative-ideal solution X_0^{-}.

Positive-ideal solution and negative-ideal solution:

$$X_0^{+} = (x_0^{+})_{23\times 3} = \begin{bmatrix} E & E & E \\ \vdots & \vdots & \vdots \\ E & E & E \end{bmatrix} = \begin{bmatrix} 10 & 10 & 10 \\ \vdots & \vdots & \vdots \\ 10 & 10 & 10 \end{bmatrix},$$

$$X_0^{-} = (x_0^{-})_{23\times 3} = \begin{bmatrix} R & R & R \\ \vdots & \vdots & \vdots \\ R & R & R \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \vdots & \vdots & \vdots \\ 0 & 0 & 0 \end{bmatrix}.$$

According to equation (12) and (14), the grey relational coefficient between the index evaluation value of each type of quality management error and the positive and negative-ideal solution is calculated. If $\zeta = 0.5$, the following grey relational coefficient matrix can be established:

Table 1: Selected example of quality management FMEA framework

Requirements for management functions	Potential failure modes	Potential failure consequences	S	Quality management human errors	O	D
Establishment of quality management system	Ineffectiveness and unsuitability of quality management system	Affect the enterprise's the effective development of various quality management activities and the realization of quality objectives	H	1-1 Deviation from the general requirements for establishing the quality management system	L	H
				1-2 Deviation from requirements of documents and no systematic documents for control of files and quality records, such as quality manuals, coal mine safety regulation, control procedures of functions, and so on	L	L
Management responsibility	Unclear management responsibility	Not conducive to the establishment and operation of the quality management system and continuous improvement of its effectiveness	M	2-1 Lack of management commitment without effective communication of quality objectives	R	R
				2-2 No customer focus	M	M
				2-3 No effective communication of quality policy	M	H
				2-4 No effective plans of management responsibilities	L	M
				2-5 Unclear responsibilities of the centralized department, the coordination department and the department for strategic management, and specific implementation engaged in the quality management work	L	M
				2-6 The unreasonable management review and the improper plans for special management review, missing information in reports of input, output and management review, and no reports of corrective action implementation	H	M
……	……	……	……	……	……	……

$$R^{+} = \begin{vmatrix} 0.719 & 0.414 & 0.719 \\ 0.719 & 0.414 & 0.414 \\ 0.521 & 0.350 & 0.350 \\ 0.521 & 0.521 & 0.521 \\ 0.521 & 0.521 & 0.719 \\ 0.521 & 0.414 & 0.521 \\ 0.521 & 0.414 & 0.521 \\ 0.521 & 0.719 & 0.521 \\ 0.521 & 0.521 & 0.350 \\ 0.521 & 0.414 & 0.414 \\ 0.521 & 0.521 & 0.414 \\ 0.521 & 1.000 & 0.414 \\ 0.719 & 0.414 & 0.521 \\ 0.719 & 0.414 & 0.414 \\ 0.719 & 0.521 & 0.719 \\ 0.719 & 0.350 & 0.350 \\ 0.719 & 0.414 & 0.414 \\ 0.719 & 1.000 & 0.521 \\ 0.414 & 0.414 & 0.414 \\ 0.414 & 0.521 & 0.414 \\ 0.414 & 0.719 & 0.521 \\ 0.414 & 0.719 & 0.719 \\ 0.414 & 0.521 & 0.521 \end{vmatrix} \quad R^{-} = \begin{vmatrix} 0.480 & 0.754 & 0.480 \\ 0.480 & 0.754 & 0.754 \\ 0.591 & 1.000 & 1.000 \\ 0.591 & 0.591 & 0.591 \\ 0.591 & 0.591 & 0.480 \\ 0.591 & 0.754 & 0.591 \\ 0.591 & 0.754 & 0.591 \\ 0.591 & 0.480 & 0.591 \\ 0.591 & 0.591 & 1.000 \\ 0.591 & 0.422 & 0.754 \\ 0.591 & 0.754 & 0.754 \\ 0.480 & 0.754 & 0.754 \\ 0.480 & 0.591 & 0.591 \\ 0.480 & 1.000 & 0.754 \\ 0.480 & 0.754 & 0.480 \\ 0.480 & 0.422 & 1.000 \\ 0.480 & 0.754 & 0.754 \\ 0.754 & 0.422 & 0.591 \\ 0.754 & 0.754 & 0.754 \\ 0.754 & 0.591 & 0.754 \\ 0.754 & 0.480 & 0.591 \\ 0.754 & 0.480 & 0.480 \\ 0.754 & 0.591 & 0.591 \end{vmatrix}.$$

On the basis of their experience and knowledge as well as the actual quality management of the enterprise, the group of experts determines the weights of S (severity) of quality management functions' failure modes, and the O (occurrence) and D (detection) of quality management errors as $\lambda_1 = 0.4$, $\lambda_2 = 0.35$, and $\lambda_3 = 0.25$, respectively. Then, the correlation coefficients R_i^{+} and R_i^{-} between various quality management errors and positive and negative bases and the RPN are obtained. At the same time, according to equation (18), C_i, the relative closeness coefficient of grey relation and RPN of various quality management human errors, can be calculated (Table 2).

The severity (S), occurrence (O), and detection (D) of the identified errors in the error risk assessment shall be evaluated and integrated into the RPN of errors in each quality management activity. By comprehensively comparing the various quality management human errors RPN confirmed by R_i^{+}, R_i^{-}, and C_i, the human errors ranking in RPN is studied. Ranking the RPN means that the greater grey relational relative closeness of an error indicates that the quality management error is closer to the positive-ideal solution and the risk is higher. According to the RPN value, the sequence of error-proofing improvement is determined. As a result, effective measures of error proofing and improvement can be formulated.

The results show that the top five errors in RPN as follows:

I. 4-6 No ledger of monitoring and measuring devices, inconformity with national standards and no effective monitoring and measurements for the entire processes, key processes, special processes, and working environments of mechanical manufacturing.

II. 4-3 Deviation of input and output of the design and development and no efficient control or records of review, verification, confirmation, and alteration of plans.

III. 3-4 The failed control program of equipment and work environment, noncompliant supply and maintenance of equipment, and failure in the environmental inspection.

IV. 2-6 The unreasonable management review and the improper plans for special management review, missing information in reports of input, output and management review, and no reports of corrective action implementation.

V. 1-1 Deviation from the general requirements for establishing the quality management system of the enterprise.

These are high-risk human errors, which should be first considered for error proofing.

Table 2: Risk order of various quality management human errors

Functional failure modes	Error items	R_i^+ and risk priority number		R_i^- and risk priority number		C_i and risk priority number	
Ineffectiveness and unsuitability of quality management system	1-1	0.61225	4	0.57590	6	0.51530	**5**
	1-2	0.53600	10	0.64440	12	0.45408	**11**
Unclear management responsibility	2-1	0.41840	22	0.83640	23	0.33344	**23**
	2-2	0.52100	13	0.59100	8	0.46853	**10**
	2-3	0.57050	7	0.56325	4	0.50320	**6**
	2-4	0.48355	16	0.64805	15	0.42732	**15**
	2-5	0.48355	16	0.64805	15	0.42732	**15**
	2-6	0.59030	6	0.55215	3	0.51670	**4**
Ineffective management of resources	3-1	0.47825	18	0.69325	19	0.40824	**18**
	3-2	0.45680	20	0.68880	18	0.39874	**19**
	3-3	0.49425	15	0.63175	11	0.43894	**14**
	3-4	0.66190	2	0.57260	5	0.53617	**3**
Products failing to be produced or meet the given requirements	4-1	0.56275	8	0.60365	9	0.48247	**8**
	4-2	0.53600	10	0.64440	12	0.45408	**11**
	4-3	0.64970	3	0.51885	2	0.55599	**2**
	4-4	0.49760	14	0.79200	21	0.38586	**21**
	4-5	0.53600	10	0.64440	12	0.45408	**11**
	4-6	0.76785	1	0.48745	1	0.61169	**1**
Deviation in measurement, analysis, and improvement	5-1	0.41400	23	0.75400	21	0.35445	**22**
	5-2	0.45145	21	0.69695	20	0.39311	**20**
	5-3	0.54750	9	0.61735	10	0.47002	**9**
	5-4	0.59700	5	0.58960	7	0.50312	**7**
	5-5	0.47820	19	0.65620	17	0.42154	**17**

Through the case study, we found that the error caused by the management function failure probability is different from the industrial operation. It presents a clear representation of the experimental data and the involved person's activities because it is not an intuitive survey and statistics, and because of the different industries and the characteristics of the enterprise, it is more difficult to quantify and unification, so it can only be combined with their own characteristics. Four to five experts are invited from key activities to conduct a comprehensive evaluation.

This method can be widely applied to other engineering fields. The reason is that the management activities of each industry run through the whole process. The need for management risk control and improvement of the management level is universal to any industry. This article helps mainly to prevent potential management errors, rather than post-accident analysis. So it only provides a kind of daily operation management ideas and tools based on management architecture, and each enterprise should combine its own characteristics and management procedures to use.

6 Summary

The deep cause of enterprise quality accidents is that the management activities at all levels and processes deviate from the target, resulting in functional failure. While quality management activities have abnormal deviations, the traceability mechanism is caused by the injection of human errors. The propagation and spread of human errors in the system will continue to cause the failure of management functions at all levels. Problems and omissions in each process will not only diverge horizontally but also evolve step by step, even cross-coupling, and follow the evolution path of "error → failure → risk," and finally lead to systemic accidents and incalculable generalized loss. In this article, through the risk assessment and risk ranking of human errors related to quality management activities under different management levels, preparation for the next stage of coal mine quality management error prevention is made, aiming to achieve feedforward control of coal mine risks at all levels.

In the first stage of error prevention, based on the ISO9001 quality management standard framework, the enterprise quality management error identification and analysis framework is constructed. FMEA is used to analyze the quality management errors that lead to the failure of management functions. In view of the defects of FMEA in the practical application process, the fuzzy set theory and the grey relational decision theory are, respectively, applied to improve these two defects. Finally, taking a coal mine as an example, the improved RPN calculation methodology based on the fuzzy sets and grey theory is used to evaluate the human errors of the enterprise in the course of quality management, with determining the RPN of various quality management errors.

I. Application of fuzzy theory can effectively overcome the shortcomings and deficiencies that the input language and information during the analysis are subjective, qualitative, and fuzzy. Fuzzy language evaluation will be conducted on the severity (S) of quality management function failure, and the occurrence (O) and detection (D) of quality management error via the triangular fuzzy number method to determine the triangular fuzzy number and conduct defuzzification, from which the evaluation value of severity (S) of quality management function failures, and quality management error occurrence (O) and detection (D) can be obtained to greatly improve the reliability and accuracy.

II. FMEA team adopts the aforementioned defuzzification method to obtain the relevant clear number after evaluation of the severity (S), occurrence (O), and detection (D) of enterprise quality management human errors, and then use the TOPSIS grey theory to determine the risk priority of quality management errors via the grey relational degree and grey relational relative closeness coefficient, and to overcome the limitation that the risk priority of quality management error is judged only by RPN value and the relative importance of three factors is not considered in the practical application. It has methodological significance for the FMEA analysis of enterprise quality management.

The risk assessment methodology of enterprise quality management error based on fuzzy set and TOPSIS grey adapts all kinds of business activities, but it should be noted that different structures will lead to different error-proofing measures. In the future, the methods to reduce the RPN value still need to be further studied and summarized. Reducing the severity and the frequency of each failure mode made them easy to be detected and controlled.

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