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Assessment of operation safety risk for South-to-North Water Diversion Project: a fuzzy VIKOR-FMEA approach

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ABSTRACT

The South-to-North Water Diversion Project (SNWDP) is a cross-basin large-scale water infrastructure, whose operational management faces many complex risks. This study constructs an operational safety risk analysis model based on fuzzy VIKOR-FMEA. First, the expert team used linguistic variables to evaluate the severity of each failure mode (*S*), frequency of occurrence (*O*), and difficulty of detection (*D*) in the failure mode and effects analysis (FMEA). Then, the fuzzy analytic hierarchy process (AHP) and the maximal deviation approach were integrated to carry out risk factor weights. The risk factor weight analysis matrix integrates the subjective and objective weights to obtain the comprehensive weights of the risk factors. Secondly, VIKOR is introduced to improve the traditional FMEA model and is used to calculate the risk priority number. The case study shows that untimely flood protection, irregular maintenance, and untimely emergency response are in the top order. Finally, it is compared with the traditional FMEA method, which verifies the feasibility and effectiveness of the proposed method, and provides a reference algorithm for risk analysis of operation management for the water diversion project.

Key words: failure mode and effects analysis (FMEA), maximal deviation approach, risk ranking, South-to-North Water Diversion Project, VIKOR

HIGHLIGHTS

- FMEA is employed to assess the operational risks of the South-to-North Water Diversion Project.
- The triangular fuzzy number is used to evaluate the severity (*S*), frequency of occurrence (*O*), and difficulty of detection (*D*) of each failure mode.
- VIKOR is introduced to improve the traditional FMEA model.
- Untimely flood control and irregular maintenance are the greatest risks.

INTRODUCTION

Since the official operation of the South-to-North Water Diversion Project (SNWDP) in December 2014, the allocation of water resources along the route has been further optimized and has provided uninterrupted and safe water supply for about 1,700 days, playing a significant role in ensuring water security, restoring water ecology, and improving the water environment. The project has improved the water supply pattern in the receiving area and has become one of the main water sources for the receiving area (Zhang 2012). The operation and management of the SNWDP faces complex risk factors, and any risk in any part of the whole system will affect the safe operation of the whole system, resulting in huge economic losses and adverse social impacts. The study of the operation and management risks of the SNWDP can be used as a reference for the actual operation and management of the project to reduce the risks that may exist in the operation and management of the project, and is also of great importance for the scheduling and operation of the South–North Water Diversion Project and the innovation of the operation and management system (Liu & Geng 2010).

The SNWDP is leading in the international arena and is a major infrastructure indispensable to national economic development, and is a demonstration of universal significance for water infrastructure. Its operation management has received great attention from many scholars in China. Rong *et al.* (2012) compared it with the operation and management of traditional water conservancy projects, from theoretical and practical perspectives, to explore the operation and management of the South-to-North Water Diversion East Route Project, and provided useful research and thinking for the benefit of the project design. Jin *et al.* (2015) analyzed the situation and the main difficulties faced by the operation and management of the South-to-North Water Diversion Storage Reservoir, and the benefit of the first phase of the Middle Route Project and the optimal dispatch of water resources in the receiving area. Shi (2017) put forward optimization suggestions from the perspectives of emergency rescue, routine inspection, maintenance and pipe care, as well as annual age repair and overhaul of the SNWDP in terms of speeding up project inspection, improving pipe care efficiency, and reducing pipe care costs. A small number of scholars have conducted studies on the risk factors during the operation period of the SNWDP. Geng *et al.* (2012) identified the risks to the water transfer system from the external load, internal structure and operation and management, and used hierarchical-fuzzy analysis to calculate the risk level of each water transfer channel through cluster analysis. Hu *et al.* (2013) introduced intuitive fuzzy set theory and used the TOPSIS method to identify the operation risk of the South-to-North Water Transfer Main Canal in Chaohe River. Nie *et al.* (2019) fully considered the vagueness and randomness of the risk factors, used the gray correlation degree and Delphi method to build a risk evaluation index system based on the cloud model for project operation safety, and took the South-to-North Water Diversion Middle Route Project as an example for analysis, which played a reference role for the actual project operation safety risk management work. Most of the current studies on SNWDP operation management are limited to the management model itself, and less consideration is given to the risk factors of project operation. Moreover, many studies adopt methods that only consider objective risk factors, lacking consideration of both subjective and objective factors. Therefore, this study applies a combined subjective and objective approach to assess the important potential risk factors.

Traditional risk assessment methods only consider the probability and severity of the risk, but Failure Mode and Effects Analysis (FMEA) methods take into account the ease with which the risk can be detected, increasing the reliability of the assessment results. FMEA has been widely used in various fields such as engineering management to identify potential failure modes and causes so that failures can be predicted before they occur and prevented from occurring at the source. Traditionally, FMEA risk assessment is achieved by calculating the Risk Priority Number (RPN) for each failure mode, i.e., multiplying the severity (S), occurrence (O) and difficulty of detection (D) of the risk factors to obtain a final risk value, and the higher the failure mode score, the greater the risk. However, the vagueness of risk evaluation information, the determination of expert weights and risk factor weights, and risk prioritization issues are still flawed in practical applications. Therefore, in order to overcome the shortcomings of traditional FMEA methods and improve the validity of FMEA risk assessment results, the researchers have made some improvements. Song *et al.* (2013) used triangular fuzzy numbers to characterize the FMEA expert's assessment information in the risk assessment process of failure modes. An *et al.* (2016) used fuzzy rough numbers in the form of intervals to process the expert's assessment information in the FMEA process of the ambiguity. Emovon *et al.* (2015) proposed an integrated assignment method to determine risk factor weights based on a combination of variance and entropy weighting methods. FMEA can also be considered essentially as a multi-attribute group decision problem, so TODIM (Tomada de decisão interativa multicritério) (Li & Cao 2019), TOPSIS (Technique for Order Preference by Similarity to Solution) (Song *et al.* 2013), VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje) (Liu *et al.* 2015), AHP (Analytic Hierarchy Process) (Ilangkumaran *et al.* 2014) and multi-attribute decision methods such as DEMATEL (Decision-Making and Trial Evaluation Laboratory) (Chang 2009) have been widely used in FMEA studies to improve their deficiencies. This study proposes a failure mode evaluation method based on the VIKOR model, which can not only effectively overcome the problem that the TOPSIS model cannot reflect the inadequate proximity of each scenario to the positive and negative ideal points, but can also fully consider the maximization of group benefits and minimization of individual regrets, and fully reflect the subjective preferences of decision makers.

Traditional risk assessment methods cannot meet the operational needs of large-scale water infrastructure. The operational failure modes of SNWDP have not been fully considered in previous research. In order to overcome shortcomings in the traditional risk assessment and traditional FMEA method, this study proposes an improved FMEA risk assessment method based on VIKOR and combined weights in an uncertain environment. Firstly, the fuzzy AHP is used to construct the importance comparison matrix of risk factors, and the subjective weights of risk factors are obtained by optimizing the solution with the goal of minimum consistency. Secondly, the triangular fuzzy number is used to evaluate the risk factors of each failure mode, and the objective weight calculation based on the maximum deviation method is obtained, and the combined weights of risk factors are obtained by integrating the objective and subjective weights. The VIKOR method is introduced to evaluate the risk factors of traditional FMEA. The improved model is used for risk ranking. The feasibility and validity of the proposed method is verified by taking the analysis of the operation and management failure mode of the Huixian section of the SNWDP as an example. Finally, the evaluation results are analyzed and discussed using sensitivity analysis.

OPERATIONAL MANAGEMENT RISK FAILURE MODE

In this study, nine potential failure modes in operation and management were selected based on literature review and expert opinion: Irregular Operation and Scheduling (FM1), Inadequate Engineering Inspection (FM2), Irregular Maintenance (FM3), Power Supply System Failure (FM4), Untimely Flood Control (FM5), Inadequate Safety Protection (FM6), Emergence of Biological Hazards (FM7), Problems with Water Quality and Safety (FM8) and Untimely Emergency Response (FM9), as shown in Table 1.

METHODS

This study proposes a fuzzy VIKOR-based FMEA to assess the operational risk. In the traditional FMEA calculation, if $\text{FM} = (\text{FM1}, \text{FM2}, \cdots, \text{FM}m)$ is the failure mode to be evaluated in m and $\text{FM}i(1 \leq i \leq m)$ is the failure mode in i, the experts score the actual performance under occurrence (O), severity (S), and difficulty of detection (D), and the risk priority is calculated by Equation (1):

$$RPN = O \times S \times D \tag{1}$$

The resulting RPNs are ranked from smallest to largest, from which the calculation of the final risk priority number can be obtained.

This study is based on an improved FMEA approach to assessing the safety risks of the operation and management of the SNWDP. Assuming that the FMEA expert team consists of s experts $DM_k(k = 1, 2, \cdots, s)$, different weights are assigned to the scores of the s experts according to their knowledge structure and domain experience. The expert team uses linguistic variables to evaluate the actual performance of m potential failure modes $\text{FM}i(i = 1, 2, \cdots m)$ under n risk factors $RF_j(j = 1, 2, \cdots, n)$ as well as the relative importance between risk factors, and converts the evaluation results into corresponding triangular fuzzy numbers, and the fuzzy AHP and maximum deviation methods are used to obtain the combined weights. Then the failure modes are ranked according to VIKOR, and the ranking results are evaluated and analyzed. The research framework of this paper is shown in Figure 1.

Risk expression based on triangular fuzzy numbers

Definition 1: Let U be a theoretical domain, called a mapping:

$$\begin{aligned} &\mu_{\underset{\sim}{A}}: U \rightarrow [0, 1], \\ &x| \rightarrow \mu_{\underset{\sim}{A}}(x) \in [0, 1] \end{aligned} \tag{2}$$

Determine a fuzzy subset $\underset{\sim}{A}$ on U. Mapping $\mu_{\underset{\sim}{A}}$ is called the affiliation function of $\underset{\sim}{A}$ and $\mu_{\underset{\sim}{A}}(x)$ is called the degree of x's affiliation to $\underset{\sim}{A}$. The larger $\mu_{\underset{\sim}{A}}(x)$ is, the greater the degree of x is in affiliation to $\underset{\sim}{A}$.

Fuzzy logic uses different types of fuzzy affiliation functions, such as triangular fuzzy numbers and trapezoidal fuzzy numbers. The triangular fuzzy numbers are of high practical value due to their simplicity of computation and ease of processing and have good representation and information processing functions in fuzzy environments. Therefore, this study chooses triangular fuzzy numbers to express the language evaluation of experts.

Definition 2: A trigonometric fuzzy number can be expressed as: $M = (l, m, u)$, whose subordinate function $\mu_M(x)$ is as in Equation (3):

$$\mu_M(x) = \begin{cases} 0 & x < l \\ \dfrac{x-l}{m-l} & l \leq x \leq m \\ \dfrac{u-l}{u-m} & m \leq x \leq u \\ 0 & x > u \end{cases} \tag{3}$$

Table 1 | Failure modes and description

Serial number	Failure mode	Main causes of failure	Effects of the failure	Documentary sources
FM1	Irregular Operation and Scheduling	Failure to follow dispatch protocols (or plans) for reasonable dispatch operations and inadequate dispatch mechanisms	All levels of management staff cannot be connected in real time, and an alarm cannot be transmitted in a timely manner	Geng *et al.* (2010) Nie *et al.* (2019)
FM2	Inadequate Engineering Inspection	Failure to comply with the standard or required inspection visits	The presence of serious defects in the works that endanger safety, the presence of certain factors in the environment that endanger the safety of the works	Sun (2018)
FM3	Irregular Maintenance	Failure to maintain works areas or facilities to standard or in a timely manner	Failure of an engineering site or failure of a facility	Zhu & Wang (2018) Geng *et al.* (2012)
FM4	Power Supply System Failure	Inappropriate personnel handling, failure to deal with malfunctions on time, failure to perform troubleshooting measures in a timely manner as required	Inability to supply electricity properly, resulting in significant economic losses	Chen *et al.* (2019) Nie *et al.* (2019)
FM5	Untimely Flood Control	Flood control measures are not taken on time or are poorly implemented	Causing damage to works or likely to affect water supply	Zhu & Wang (2018) Han *et al.* (2018)
FM6	Inadequate Safety Protection	Failure to regularly inspect, replace protective equipment (including firefighting supplies), inadequate protective equipment	Casualties, major property damage, impact on the safety of works	Zhu & Wang (2018) Jiang *et al.* (2010)
FM7	The Emergence of Biological Hazards	Termites and other organisms found in the embankment	Threaten the safety of the levee, which can lead to dam failure	Geng *et al.* (2010) Geng *et al.* (2012)
FM8	Problems with Water Quality and Safety	Leakage of hazardous objects, contaminants into dry canals, algal blooms	Interruption of water supply at the diversion gate, (severely) affecting normal water delivery	Xiao *et al.* (2010) Wang *et al.* (2009)
FM9	Untimely Emergency Response	Failure to address emergencies as they arise	Interruption of water supply, major economic losses, casualties	Wang & Huai (2019) Xiao *et al.* (2010)

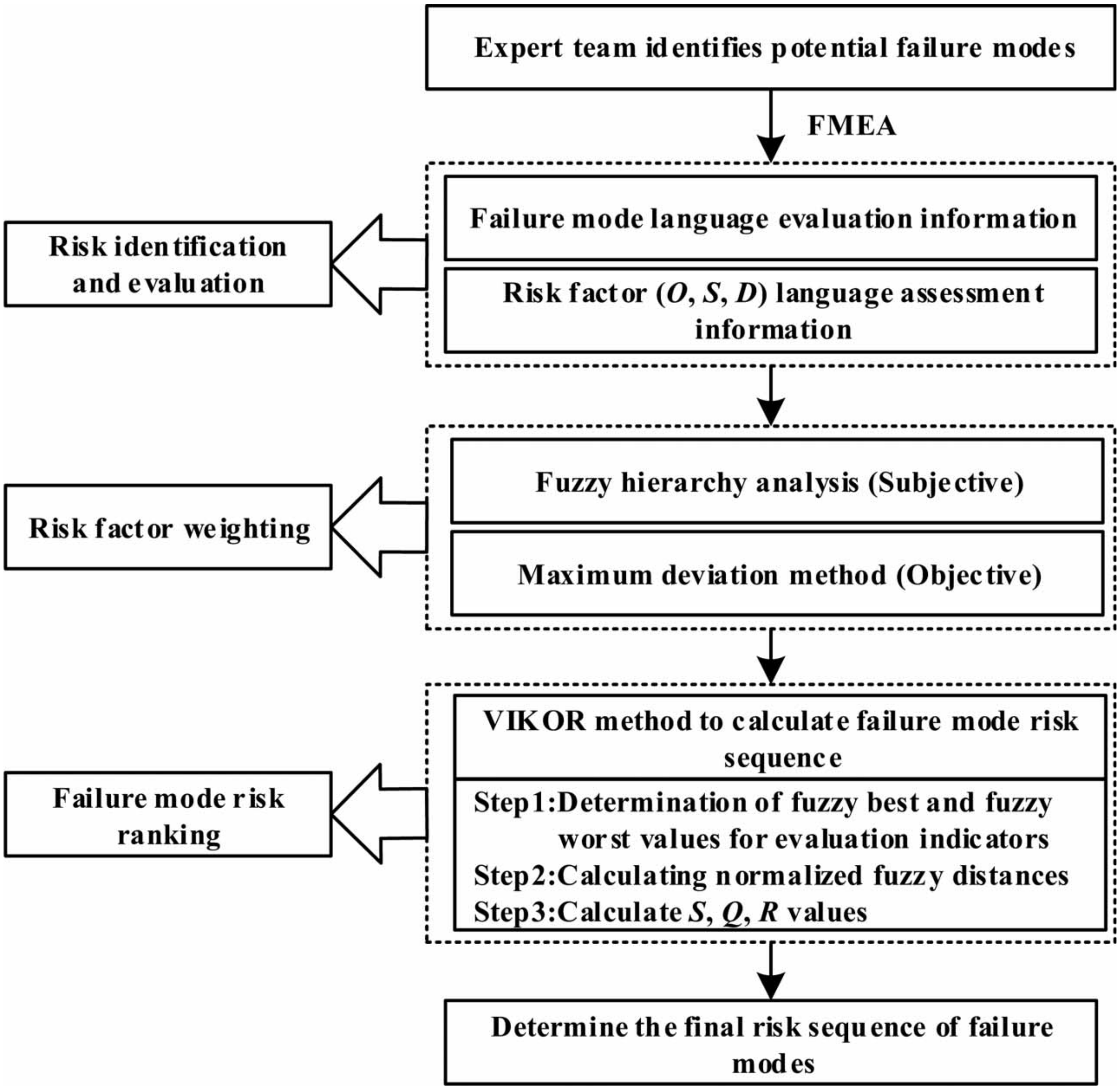

Figure 1 | Research framework of FMEA model.

where l and u represent the upper and lower bounds of this triangular fuzzy number, and m is the modal value of the fuzzy number M.

Definition 3: Let $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ be two triangular fuzzy numbers, given any real numbers λ, $\lambda > 0$, $\lambda \in R$. The algebraic operation of triangular fuzzy numbers can be expressed as follows:

$$M_1 \oplus M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (4)$$

$$M_1 \otimes M_2 = (l_1 \cdot l_2, m_1 \cdot m_2, u_1 \cdot u_2) \quad (5)$$

$$\lambda M_1 = (\lambda l_1, \lambda m_1, \lambda u_1) \quad (6)$$

$$(M_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \quad (7)$$

Definition 4: The distance between any two triangular fuzzy numbers $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ can be expressed as:

$$d(M_1, M_2) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]} \quad (8)$$

Determining risk factor weights based on fuzzy AHP and maximum deviation methods

Traditional FMEA methods consider the occurrence (O), severity (S) and difficulty of detection (D) of risk occurrence as equally important, and do not consider the risk factor weighting information, since it is difficult to determine the risk factor weights directly. There are many calculation methods to determine the FMEA risk factor weights, mainly including the objective assignment method, subjective assignment method, and integrated assignment method. Among them, the integrated assignment method can take both subjective and objective factors into account, which overcomes the limitation of calculating weights from unilateral methods and is widely used. In this study, by combining the fuzzy AHP and maximum deviation method, the integrated assignment method overcomes the shortcomings of traditional FMEA that does not take into account the risk factor weights by considering both subjective and objective factors.

Subjective weighting based on fuzzy AHP

Fuzzy hierarchy analysis is a method that combines fuzzy numbers and the Analytic Hierarchy Process (AHP) and is widely used in subjective evaluation to reflect the fuzzy thinking of people. Triangular fuzzy numbers are one of the most common forms of fuzzy numbers. Chang (1996) proposed the most widely used method of fuzzy hierarchy analysis, which converts experts' verbal judgments into triangular fuzzy numbers, constructs a judgment matrix for processing, and obtains subjective weights of risk factors.

The conversion relationship between the fuzzy triangle and the linguistic terms that team members can use to evaluate the subjective weight vector of risk factors is shown in Table 2.

Let $X = \{x_1, x_i, \cdots x_n\}$ be a set of objects and $G = \{g_1, g_i, \cdots g_n\}$ be a set of targets. For each object x_i, perform a degree analysis for each target g_i. You can obtain m range analysis values for each object with the following notation:

$$M_{gi}^{i}, M_{gi}^{j}, \cdots, M_{gi}^{m}, i = 1, 2, \cdots n$$

where $M_{gi}^{j}(j = 1, 2, \cdots, m)$ is a triangular fuzzy number and then the steps to obtain the subjective weights of the three risk factors S, O and D are as follows:

Table 2 | Language variables for risk factor weighting

Linguistic terms	Triangular fuzzy numbers
Absolutely strong (AS)	(2,5/2,3)
Very strong (VS)	(3/2,2,5/2)
Fairly strong (FS)	(1,3/2,2)
Slightly strong (SS)	(1,1, 3/2)
Equal (EI)	(1,1,1)
Slightly weak (SW)	(2/3,1,1)
Fairly weak (FW)	(1/2,2/3,1)
Very weak (VW)	(2/5,1/2,2/3)
Absolutely weak (AW)	(1/3,2/5,1/2)

Step 1: Calculate the value of the degree of fuzzy integration concerning the ith target according to Equation (9):

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{m} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \tag{9}$$

where $\sum_{j=1}^{m} M_{gi}^{j}$ can be calculated by fuzzy addition of m range analysis values of a particular matrix:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{10}$$

The reciprocal of $\sum_{j=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}$ is calculated as in Equation (11):

$$\left[\sum_{i=1}^{m} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} u_j}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} m_j}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} l_j} \right) \tag{11}$$

Step 2: The degree of likelihood between the two fuzzy integrated intervals of A and B is defined by Equation (12):

$$V(S_2 \geq S_1) = \sup_{y \geq x} [\min (\mu s_2(y), \mu s_1(x))] \tag{12}$$

The above formula can also be described as:

$$\begin{aligned} V(S_2 \geq S_1) &= hgt(S_1 \cap S_2) = \mu s_1(d) \\ &= \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ (l_1 - u_2)/((m_2 - u_2) - (m_1 - l_1)) & \text{else} \end{cases} \end{aligned} \tag{13}$$

In Equation (13), the point D located between μs_1 and μs_2 is at the coordinates of the highest point of the intersecting part, as shown in Figure 2. In order to compare the sizes of $S_1$and S_2, the sizes of $V(S_1 > S_2)$and $V(S_2 > S_1)$ are required.

Step 3: The degree of likelihood that the number of convex ambiguities is greater than k convex ambiguities $S_i(i = 1, \cdots, k)$ can be calculated from Equation (14) as follows:

$$\begin{aligned} V(S \geq S_1, S_2, \cdots, S_k) &= V[(S \geq S_1) \text{ and } (S \geq S_2) \cdots (S \geq S_k)] \\ &= \min V(S \geq S_i), \quad i = 1, 2, \cdots, k \end{aligned} \tag{14}$$

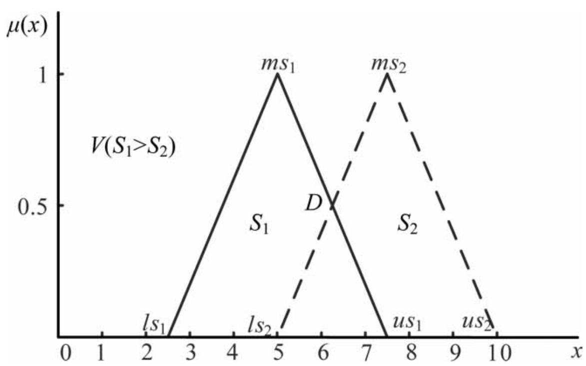

Figure 2 | Intersection of S_1 and S_2.

Step 4: Subjective weights for risk factors can be calculated from Equation (15):

$$w_j^{s*} = (d'(A_1), d'(A_2), \cdots, d'(A_k),)^T \tag{15}$$

Assumptions:

$$d'(A_i) = \min V(S_i \geq S_j), i = 1, 2, \cdots, kj = 1, 2, \cdots k, k \neq j \tag{16}$$

where A_i denotes the number of elements.

After normalization, the normalized subjective weight vector for each risk factor is expressed as Equation (17), where w_j^s is the non-fuzzy number:

$$w_j^s = (d(A_1), d(A_2), \cdots, d(A_k),)^T \tag{17}$$

Objective weights based on maximum deviation method

In order to determine the objective weights of risk factors S, O and D, a model for calculating risk factor weights based on the maximum deviation method is developed in a fuzzy environment. According to the idea of the maximum deviation method, if the degree of difference in the assessed values of all the scenarios under an attribute is not significant, i.e., the attribute does not play a significant role in the overall decision process, the attribute should be assigned a smaller weight value; conversely, if the degree of difference is significant, the attribute should be assigned a larger weight value.

Safety Failure Mode is set as $A_i(i = 1, 2, \cdots, m)$, the evaluation index of failure mode as $C_j(j = 1, 2, \cdots, n)$, and the expert for $E_k(k = 1, 2, \cdots, s)$. The evaluation group composed of experts makes the semantic evaluation of the evaluation index of each failure mode, and quantifies the evaluation result by using a triangular fuzzy number, as shown in Table 3; $\tilde{p}_{ij}^k = (p_{ijl}^k, p_{ijh}^k, p_{iju}^k)$ represents the evaluation value of expert E_k on the evaluation indicator C_j in failure mode A_i. The arithmetic means algorithm is used to find the group decision value $\tilde{p}_{ij}^k$ for the evaluation value $\tilde{p}_{ij} = (p_{ijl}, p_{ijh}, p_{iju})$ given by different experts, and $\tilde{p}_{ij}$ constitutes the fuzzy evaluation matrix $\tilde{R} = [\tilde{p}_{ij}]^{m\times n}$.

Step 1: De-blurring of the assessment value $\tilde{p}_{ij}$:

$$\tilde{p}_{ij} = \frac{1}{s}(\tilde{p}_{ij}^1 \oplus \tilde{p}_{ij}^2 \oplus \cdots \oplus \tilde{p}_{ij}^s) \tag{18}$$

In Equation (18), in order to determine the weight of decision indicators by the maximum deviation method, the evaluation value $\tilde{p}_{ij}$ in the fuzzy evaluation matrix should be de-fuzzified first. In this paper, the fuzzy evaluation number de-fuzzification rule is used to de-fuzzify $\tilde{p}_{ij}$, $L = \min(p_{ijl})$, $U = \max(p_{iju})$, $\Delta = U - L$. The exact evaluation value p_{ij} after de-fuzzifying each

Table 3 | Semantic evaluation form for failure modes

Language variables	Triangular fuzzy number
Very low (VL)	(0,0,0.1)
Low (L)	(0,0.1,0.3)
Moderately low (ML)	(0.1,0.3,0.5)
Moderate (M)	(0.3,0.5,0.7)
Moderately high (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1)
Very high (VH)	(0.9,1,1)

evaluation value $\underset{ij}{\tilde{p}}$ in the fuzzy evaluation matrix is as follows:

$$p_{ij} = L + \Delta \times \frac{(p_{ijh} - L)(\Delta + p_{iju} - p_{ijh})^2(U - p_{ijl}) + (p_{iju} - L)^2(\Delta + p_{ijh} - p_{ijl})^2}{(\Delta + p_{ijh} - p_{ijl})(\Delta + p_{iju} - p_{ijh})^2(U - p_{ijl}) + (p_{iju} - L)(\Delta + p_{ijh} - p_{ijl})^2(\Delta + p_{iju} - p_{ijh})} \quad (19)$$

Step 2: Normalization of the matrix. The evaluation matrix r_{ij} is composed of $R = [p_{ij}]^{m\times n}$. For the evaluation index C_j, the highest value of m failure modes is $p_j^{\max}$ and the lowest value is $p_j^{\min}$. The matrix is normalized to obtain a standardized matrix. The matrix R is normalized to obtain the standardized matrix $NR = [np_{ij}]m \times n$.

$$np_{ij} = (p_ij - p_j^{\min})/(p_j^{\max} - p_j^{\min}) \quad (20)$$

Step 3: Develop a model for calculating the evaluation indicator C_j importance IR_j based on the maximum deviation method.

$$\max D(IR) = \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{m} |np_{ij} - np_{kj}| \times IR_j;$$
$$\sum_{j=1}^{n}(IR_j)^2 = 1, IR_j > 0 \; 1 \le j \le n \quad (21)$$

The model is solved as follows:

$$IR_j = \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}|np_{ij} - np_{kj}|}{\sqrt{\sum_{j=1}^{n}\left(\sum_{i=1}^{m}\sum_{k=1}^{m}|np_{ij} - np_{kj}|\right)^2}} \quad (22)$$

Step 4: Based on the above solution, the objective weight w_j^{o} for the evaluation indicator C_j is obtained as follows:

$$w_j^{\mathrm{o}} = IR_j / \sum_{j=1}^{n} IR_j \quad (23)$$

Determine the combined weights

In this study, the comprehensive weighting method is proposed, which introduces a risk factor weight adjustment factor φ (usually $\varphi = 0.5$) as the relative importance of the subjective and objective weights. The comprehensive weight is as follows:

$$w^{\mathrm{c}} = \varphi w_j^{\mathrm{c}} + (1 - \varphi) w_j^{\mathrm{o}}, \quad 0 \le \varphi \le 1 \quad (24)$$

Fuzzy VIKOR-based FMEA approach for risk ranking

The VIKOR method is proposed by Opricovic's formula-criteria optimization of complex systems (Opricovic 1998), which identifies compromise solutions to problems with conflicting criteria and helps experts to make final decisions. In this section, an improved fuzzy method is proposed for dealing with uncertain data and solving fuzzy multi-criteria problems with conflicting criteria. The proposed fuzzy VIKOR method provides a more rational way to calculate the distance between the state of the failure mode and the ideal failure point.

Suppose a failure mode risk ranking problem has k experts $DM_k(k = 1, 2, \cdots, K)$, m failure modes $A_i = (i = 1, 2, \cdots, m)$ and n criteria $C_j = (j = 1, 2, \cdots, n)$, and is evaluated against the n criteria; and order $\tilde{x}_{ij}^k = (x_{ij1}^k, x_{ij2}^k, x_{ij3}^k)$ to be the jth fuzzy rating of the ith failure mode provided by the k experts, and $\lambda_k(k = 1, 2, \cdots, K)$ to be the relative importance weight of the k experts, both of them are satisfying $\sum_1^K \lambda_k = 1$ and $\lambda_k > 0(k = 1, 2, \cdots, K)$. The improved VIKOR method is as follows:

Step 1: Aggregate the opinions of experts to obtain a pooled fuzzy evaluation of the failure modes and construct a fuzzy decision matrix. The pooled fuzzy evaluation ($\widetilde{x}_{ij}$) of each failure mode relative to each criterion can be calculated as:

$$\widetilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}) \tag{25}$$

where $x_{ij2} = \sum_{k=1}^{K} \lambda_k x_{ij1}^k$, $x_{ij2} = \sum_{k=1}^{K} \lambda_k x_{ij2}^k$, $x_{ij3} = \sum_{k=1}^{K} \lambda_k x_{ij3}^k$

A failure mode risk ranking problem can be succinctly expressed in matrix format as follows:

$$\widetilde{D} = \begin{bmatrix} \widetilde{x}_{11} & \widetilde{x}_{12} & \cdots & \widetilde{x}_{1n} \\ \widetilde{x}_{21} & \widetilde{x}_{22} & \cdots & \widetilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \widetilde{x}_{m1} & \widetilde{x}_{m2} & \cdots & \widetilde{x}_{mn} \end{bmatrix}$$

where $\widetilde{x}_{ij}$ is the score of failure mode A_i relative to criterion C_j, $\widetilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3})$, $i = 1, 2, \cdots m$, $j = 1, 2, \cdots n$.

Step 2: Determine the fuzzy best $\widetilde{f}_j^*$ and $\widetilde{f}_j^-$ fuzzy worst values for all evaluation indicators:

$$\widetilde{f}_j^* = \left\{ \begin{array}{ll} \max_i \widetilde{x}_{ij}, & \text{for benefit criteria} \\ \min_i \widetilde{x}_{ij}, & \text{for cost criteria} \end{array} \right\} i = 1, 2, \cdots, m, \tag{26}$$

$$\widetilde{f}_j^- = \left\{ \begin{array}{ll} \min_i \widetilde{x}_{ij}, & \text{for benefit criteria} \\ \max_i \widetilde{x}_{ij}, & \text{for cost criteria} \end{array} \right\} i = 1, 2, \cdots, m \tag{27}$$

It is worth emphasizing that all the methods used in the literature to determine non-fuzzy values also apply to ranking fuzzy numbers. For simplicity, this study recommends using the gravity method to rank the fuzzy composite scores and to determine the fuzzy best and fuzzy worst scores.

Step 3: Calculate the normalized fuzzy distances $d_{ij}(i = 1, 2, \cdots, m$ and $j = 1, 2, \cdots, n)$:

$$d_{ij} = \frac{d(\widetilde{f}_j^*, \widetilde{x}_{ij})}{d(\widetilde{f}_j^*, \widetilde{f}_j^-)} \tag{28}$$

Step 4: Calculate the maximum group utility S_i and the minimum individual regret R_i by Equations (29–30), $i = 1, 2, \cdots, m$:

$$S_i = \varphi \sum_{j=1}^{n} w_j^s d_{ij} + (1-\varphi) \sum_{j=1}^{n} w_j^o d_{ij} = \sum_{j=1}^{n} [\varphi w_j^s + (1-\varphi) w_j^o] d_{ij} = \sum_{j=1}^{\text{n}} w_j^c d_{ij} \tag{29}$$

$$R_i = \max_j [\varphi w_j^s d_{ij} + (1-\varphi) w_j^o d_{ij}] = \max_j (w_j^c d_{ij}) \tag{30}$$

where $\varphi w_j^s + (1-\varphi) w_j^o$ is the combined weight of the evaluation criteria, and $\varphi \in [0, 1]$ represents the relative importance of the subjective and objective weights; $\varphi > 0.5$ denotes decision-making based on maximizing group utility, $\varphi < 0.5$ denotes decision-making based on minimizing individual regret mechanisms, and $\varphi = 0.5$ denotes decision-making based on negotiated consensus mechanisms. In this study, both weights are considered equally important and $\varphi = 0.5$.

Step 5: Calculate Q_i according to Equation (31):

$$Q_i = v \frac{S_i - S^*}{S^- - S^*} + (1-v) \frac{R_i - R^*}{R^- - R^*} \tag{31}$$

where $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i R_i$, v is introduced as the weight of the maximum group utility strategy, while $1 - v$ is the weight of individual regret. In this study, the value of v is set to 0.5.

Step 6: Rank the failure modes in descending order of S, R, and Q values, with lower values indicating less risk.

Step 7: Determine the compromise failure mode risk ranking. That is, failure mode ($A^{(1)}$), which measures this risk ordering as Q (maximum) is best if the following two conditions are met:

① $Q_{A^{(1)}} - Q_{A^{(2)}} \geq 1/(n-1)$, where n is the total number of failure modes.
② Failure mode risk ranking $A^{(1)}$ based on S_i and R_i ranking is also the optimal risk ranking, then $A^{(1)}$ is judged to be the stable maximum risk ranking.

If the above conditions are not met simultaneously, then the two compromise risk rankings are obtained, with the following two situations:

(1) If condition ① is satisfied but condition ② is not satisfied, there are two compromise risk rankings: $A^{(1)}$, $A^{(2)}$.
(2) If condition ① is not satisfied but condition ② is satisfied, there are M compromise risk rankings: $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$, where M is the maximized M value determined from $Q(A^{(1)}) - Q(A^{(M)}) < 1/(m-1)$.

CASE ANALYSIS

Case description

This study selects the Huixian section of the Middle Route of the South-to-North Water Diversion Project as an example for operation risk evaluation. The Huixian section is located within Huixian City, Henan Province. The total length of the channel section is 48.951 km, including 43.631 km of open channel, 5.320 km of hydraulic structures. The total waterway is mainly an open canal, and 26 rivers are crossed by the vertical intersection of the canal line. The designed flow of the channel is 260 m^3/s, and the increased flow is 310 m^3/s.

Step 1: Evaluate the Occurrence (O), Severity (S), and Difficulty detection (D) using the linguistic variables. There are four experts in the FMEA evaluation team, namely a scientific expert, engineering design expert, engineering operation manager, and engineering site inspector. They are prioritized according to their knowledge structure and domain experience, with weights of 0.25, 0.30, 0.28, and 0.17. The four experts evaluated the actual situation of nine potential failure modes under the three risk factors of Occurrence (O), Severity (S), and Difficulty detection (D) using the linguistic variables in Table 2, and the results of the evaluation are shown in Table 4. The experts' semantic evaluation information is transformed into the corresponding triangular fuzzy number, and the comprehensive fuzzy level of the failure mode is calculated to determine the fuzzy decision matrix, which constitutes the triangular fuzzy evaluation matrix of the failure mode, as shown in Table 5.

Step 2: The integrated assignment method solves for the combined weights. The FMEA team members used linguistic variables to assess the relative importance of the risk factors. The results of the four experts' evaluations using a two-comparison approach are shown in Table 6. For example, when comparing the severity and frequency of occurrence of risk factors, the

Table 4 | Evaluation information of expert language variables

	Severity (S)				Occurrence (O)				Difficulty detection (D)			
Failure modes	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4
FM1	MH	H	MH	MH	M	M	ML	M	M	ML	M	M
FM2	M	MH	MH	H	ML	M	ML	M	MH	ML	MH	M
FM3	M	MH	MH	MH	M	MH	M	M	M	ML	M	MH
FM4	M	MH	MH	MH	L	ML	L	L	ML	L	L	L
FM5	H	VH	VH	VH	M	M	MH	M	ML	L	ML	ML
FM6	M	MH	M	MH	ML	M	M	M	ML	M	MH	M
FM7	MH	MH	M	MH	L	L	VL	L	MH	M	MH	MH
FM8	MH	H	H	H	L	L	VL	L	MH	M	MH	M
FM9	H	VH	VH	VH	VL	L	VL	VL	L	ML	L	L

Table 5 | Aggregated fuzzy ratings of failure modes

Risk factor	Severity (*S*)	Occurrence (*O*)	Difficulty detection (*D*)
FM1	(0.54,0.74,0.92)	(0.27,0.47,0.67)	(0.26,0.46,0.66)
FM2	(0.47,0.67,0.845)	(0.19,0.39,0.59)	(0.37,0.57,0.77)
FM3	(0.42,0.62,0.82)	(0.34,0.54,0.74)	(0.31,0.51,0.71)
FM4	(0.42,0.62,0.82)	(0.02,0.14,0.34)	(0.04,0.18,0.38)
FM5	(0.82,0.96,1)	(0.33,0.53,0.73)	(0.08,0.26,0.46)
FM6	(0.39,0.59,0.79)	(0.22,0.42,0.62)	(0.25,0.45,0.65)
FM7	(0.47,0.67,0.87)	(0,0.085,0.27)	(0.46,0.66,0.86)
FM8	(0.62,0.82,0.96)	(0,0.085,0.27)	(0.41,0.61,0.81)
FM9	(0.82,0.96,1)	(0,0.02,0.14)	(0.02,0.14,0.34)

Table 6 | Scoring of subjective weights of risk factors

Risk factor	Severity (*S*)	Occurrence (*O*)	Difficulty detection (*D*)
Severity (*S*)	E,E,E,E	FS,SS,SS,FS	FS,SS,FS,FS
Occurrence (*O*)	–	E,E,E,E	SS,E,SS,S
Difficulty detection (*D*)	–	–	E,E,E,E

four experts' responses were fairly strong (FS), slightly strong (SS), slightly strong (SS), and fairly strong (FS), respectively. Team members can convert the linguistic variables into triangular fuzzy numbers using the method in Table 1, as shown in Table 7; a weighted average is performed to obtain subjective weights for the risk factors, as shown in Table 8.

Equations (8)–(10) are used to calculate the degree of fuzzy integration for each risk factor:

$$S_1 = (3.00, 3.38, 4.38) \otimes \left(\frac{1}{10.75}, \frac{1}{9.13}, \frac{1}{7.96}\right) = (0.28, 0.37, 0.55)$$

$$S_2 = (2.62, 2.92, 3.38) \otimes \left(\frac{1}{10.75}, \frac{1}{9.13}, \frac{1}{7.96}\right) = (0.24, 0.32, 0.42)$$

$$S_3 = (2.33, 2.83, 3.00) \otimes \left(\frac{1}{10.75}, \frac{1}{9.13}, \frac{1}{7.96}\right) = (0.22, 0.31, 0.38)$$

Table 7 | Fuzzy pairwise comparison matrix of subjective weights of risk factors

Risk factor	Severity (*S*)	Occurrence (*O*)	Difficulty detection (*D*)
Severity (*S*)	(1,1,1)	(1,3/2,2) (1,1,3/2) (1,1,3/2) (1,3/2,2)	(1,3/2,2) (1,1,3/2) (1,3/2,2) (1,3/2,2)
Occurrence (*O*)	(1/2,2/3,1) (2/3,1,1) (2/3,1,1) (1/2,2/3,1)	(1,1,1)	(1,1,3/2) (1,1,1) (1,1,3/2) (1,1,3/2)
Difficulty detection (*D*)	(1/2,2/3,1) (2/3,1,1) (1/2,2/3,1) (1/2,2/3,1)	(2/3,1,1) (1,1,1) (2/3,1,1) (2/3,1,1)	(1,1,1)

Table 8 | Weighted average of subjective weight matrix for risk factors

Risk factor	Severity (*S*)	Occurrence (*O*)	Difficulty detection (*D*)
Severity (*S*)	(1,1,1)	(1,1.13,1.63)	(1,1.25,1.75)
Occurrence (*O*)	(0.63,0.92,1)	(1,1,1)	(1,1,1.38)
Difficulty detection (*D*)	(0.58,0.83,1)	(0.75,1,1)	(1,1,1)

Subjective weight vector based on Equations (11–16): $w^s = (0.4671, 0.2899, 0.2430)$.

According to Equation (3), the fuzzy evaluation values in Table 1 are de-fuzzyified, and then the maximum deviation method is used, that is, according to Equations (18–23). The objective weight $w^o = (0.3159, 0.3534, 0.3306)$ for each evaluation indicator is calculated; and $\varphi_1 = \varphi_2 = 0.5$, that is, assuming that the objective and subjective weights are equally important, the combined weight of the risk factors is determined to be $w^c = (0.3915, 0.3217, 0.2868)$.

Step 3: VIKOR-based FMEA. Occurrence, Severity, and Difficulty detection are all cost-based risk factors, and fuzzy best $\tilde{f}_j^*$ and fuzzy worst $\tilde{f}_j^-$ are obtained from Equations (26–27).

$$\tilde{f}_S^* = (0.394, 0.594, 0.794), \quad \tilde{f}_S^- = (0.85, 0.975, 1)$$

$$\tilde{f}_O^* = (0, 0.03, 0.16), \quad \tilde{f}_O^- = (0.36, 0.56, 0.76)$$

$$\tilde{f}_D^* = (0.025, 0.15, 0.35), \quad \tilde{f}_D^- = (0.44, 0.64, 0.84)$$

For each of the failure modes identified in the FMEA, the normalized fuzzy distance can be calculated using Equation (27), as shown in Table 9. Then, the *S*, *R* and *Q* values are calculated for all the fault modes, as shown in Table 10.

Step 4: Risk priorities of the failure modes. Based on the decreasing order of *S*, *R*, and *Q*, the risk priorities of the failure modes are derived as shown in Table 11.

Table 9 | Normalized fuzzy distance for failure modes

Risk factor	Severity (*S*)	Occurrence (*O*)	Difficulty detection (*D*)
FM1	0.431	0.777	0.573
FM2	0.233	0.682	0.799
FM3	0.154	1.000	0.646
FM4	0.154	0.274	0.000
FM5	1.000	0.992	0.167
FM6	0.000	0.788	0.714
FM7	0.138	0.107	1.000
FM8	0.644	0.107	0.927
FM9	1.000	0.000	0.019

Table 10 | *S*, *Q*, *R* values of failure modes

Failure modes	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9
S	0.583	0.540	0.567	0.148	0.759	0.458	0.375	0.552	0.397
R	0.250	0.229	0.322	0.088	0.392	0.254	0.287	0.266	0.392
Q	0.623	0.553	0.728	0.000	1.000	0.527	0.513	0.624	0.704

Table 11 | Failure modes in descending order of *S*, *R* and *Q*

Failure modes	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9
S	2	5	3	9	1	6	8	4	7
R	7	8	3	9	1	6	4	5	2
Q	5	6	2	9	1	7	8	4	3

From Table 11, in descending order of Q, FM5 > FM3 > FM9 > FM8 > FM1 > FM2 > FM6> FM7 > FM4. In addition, $Q_{A^{(1)}} - Q_{A^{(2)}} = 0.513 - 0 > 1/(9-1)$, so condition 1 is satisfied. In the descending order of S and R, FM5 is in the first place, so condition 2 is satisfied. That is, it is the optimal risk ranking scheme according to the descending order of Q values.

In summary, the combined risk ranking for the nine failure modes is: FM5 > FM3 > FM9> FM8 > FM1 > FM2 > FM6 > FM7 > FM4. Among all the failure modes, the highest risk is caused by untimely flood control.

In the operation safety risks of SNWDP, rainfall concentrated in July and August each year, is very likely to cause flooding. In actual operation and management, new flood control work mechanisms are still in the run-in period, coupled with the existence of project flood control pressure, and task complexity. So flood control is of great significance to protect the smooth operation of the SNWDP. The second place in the risk ranking is the maintenance of non-standard maintenance. In the operation of the SNWDP, this risk will be affected by many factors. In order to promote the improvement of the overall quality of the project, it is necessary to focus on maintenance, project structure, and mechanical and electrical equipment on-time maintenance.

Sensitivity analysis

A sensitivity analysis is performed on the risk assessment results of the FMEA method proposed in this study, where φ takes 0, 0.5, and 1 as the raw weights obtained by the objective, combined, and subjective assignment methods, respectively. From Figure 3, it can be found that as the value of φ increases progressively from 0 to 1, the failure mode order of FM4, FM5, and FM6 does not change. The changes in the weights of the risk factors greatly impact the final risk ranking of the failure modes. When $\varphi = 0$, the integrated weight $w^c = (0.3159, 0.3534, 0.3306)$, when the risk factor Occurrence (O) and Difficulty Detection (D) weight are higher, the Severity (S) weight is lower, the risk ranking of FM9 is eighth, the risk is lower. When $\varphi = 1$, the integrated weight $w^s = (0.4671, 0.2899, 0.2430)$, the risk factor Occurrence (O) and Difficulty Detection (D) weight are lower and the Severity (S) weight is higher. FM9 ranking rises sharply to second place. If it is not handled in time, extremely serious consequences would be caused. The risk ranking of FM1, FM2, and FM7 remains stable after a small decrease, because the severity of irregular operation and scheduling, inadequate engineering inspection, and biohazard are lower than other failure modes. Therefore, it is particularly important to select an appropriate method to determine the weight of risk factors. The comprehensive assignment method proposed in this study can fully consider the role of expert opinion and evaluation information itself. It makes the risk ranking of failure modes more realistic. In addition, the comprehensive weighting approach is used in this study, and φ can be determined by the decision-maker regarding the actual situation. When the

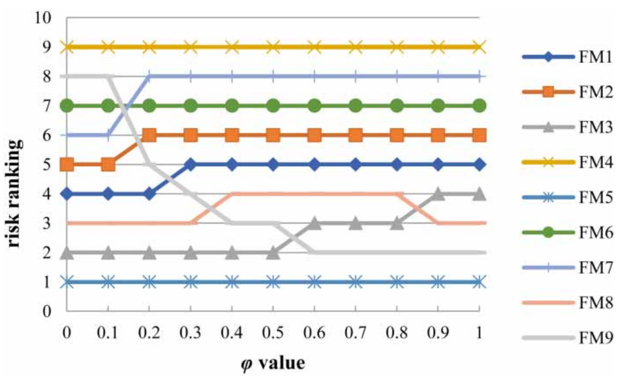

Figure 3 | Sensitivity analysis results.

FMEA expert team is less certain or it is difficult to evaluate the weighting information for the risk factors, $\varphi < 0.5$ should be assumed. When the expert team is more certain about the weighting information for the risk factors, $\varphi > 0.5$ should be assumed.

DISCUSSION

This study constructed nine typical failure modes: Irregular Operation and Scheduling (FM1), Inadequate Engineering Inspection (FM2), Irregular Maintenance (FM3), Power Supply System Failure (FM4), Untimely Flood Control (FM5), Inadequate Safety Protection (FM6), Emergence of Biological Hazards (FM7), Problems with Water Quality and Safety (FM8) and Untimely Emergency Response (FM9). All of those failure modes are common in the water division project (Nie *et al.* 2019). This output makes a good foundation for theoretical and practical research on cross-basin large-scale water division infrastructure.

This study proposed an improved FMEA risk assessment method based on VIKOR and combined weights in a fuzzy environment. This assessment model is a theoretical framework for the operational risk management of large-scale infrastructure. In order to further illustrate the validity of the constructed model, the risk ranking results of the failure model in this study are compared with the calculation results of RPN in traditional FMEA, as well as comparing the weighting calculation method using only fuzzy AHP and the weighting calculation method using only the maximum deviation method. Based on the calculation results in Table 12, the superiority of the FMEA method proposed in this paper relative to other methods can be seen, and the comparison results can be summarized as follows:

(1) When only the subjective or objective weights of the risk factors are considered, the failure modes can also be ranked, but the ranking results may be biased or even misleading. When φ takes 0, 0.5, and 1, respectively, six of the nine failure modes (66.7%) show different degrees of variation in the risk ranking, indicating that the differences in risk ranking can vary greatly under the constraints of different risk factor weights.

(2) Compared with the traditional RPN method, the risk ranking of the proposed risk assessment model is inconsistent except for FM4 and FM5. FM4 and FM5 represent the power supply system failure and flood control delay respectively, which correspond to the minimum risk value and maximum risk value, and in the traditional FMEA model, the results calculated by $RPN = S \times O \times D$ tend to vary widely, and there are higher requirements for the accuracy of expert scoring.

(3) The traditional FMEA method uses real numbers for calculation, and there is the same risk value ranking situation. For example, FM1 and FM6 correspond to irregular operation and scheduling and incomplete safety protection respectively, and the expert scores are inconsistent in Severity (S), Occurrence (O) and Difficulty Detection (D), but the calculated RPN value appears with the same value, so the risk ranking is the same. It is difficult to determine the risk order of the two failure modes, because of the information loss.

Table 12 | Comparison of failure mode rankings

	$\varphi = 0$		$\varphi = 0.5$		$\varphi = 1$		Traditional FMEA method				
Failure modes	***Q***	**Ranking**	***Q***	**Ranking**	***Q***	**Ranking**	***S***	***O***	***D***	**RPN**	**Ranking**
FM1	0.741	4	0.591	5	0.471	5	6	5	4	120	3
FM2	0.702	5	0.519	6	0.378	6	7	4	6	168	2
FM3	0.908	2	0.680	3	0.489	4	5	5	3	75	7
FM4	0.000	9	0.000	9	0.000	9	6	3	3	54	9
FM5	0.995	1	1.000	1	1.000	1	9	8	4	288	1
FM6	0.675	7	0.488	7	0.331	7	5	4	6	120	3
FM7	0.687	6	0.473	8	0.302	8	7	3	5	90	6
FM8	0.758	3	0.603	4	0.600	3	6	3	5	105	5
FM9	0.580	8	0.715	2	0.769	2	9	2	4	72	8

In this study, the comprehensive weighting method is used to consider the weight of risk factors in both subjective and objective aspects, which makes the risk analysis results more consistent with the actual situation (Song *et al.* 2013). The fuzzy VIKOR method is used to evaluate the failure mode, which improves the robustness of the existing FMEA results (Emovon *et al.* 2015). From the above analysis, it can be concluded that the proposed method is better than the traditional FMEA method.

CONCLUSION

The geographical span of the SNWDP is large, the operational reliability requirements are high, the management is difficult, and the operational management safety risk has a significant impact on the operational reliability of the project. This study proposes a risk assessment model for the operational management safety of the SNWDP based on the integrated empowerment method and fuzzy VIKOR-FMEA.

The main contributions of this paper are:

(1) The established risk assessment framework for project operation and management is an effective method for identifying project risks and is capable of identifying key risk factors in the operation of water division projects.
(2) The extended fuzzy VIKOR-FMEA risk assessment method proposed in this study makes up for the shortcomings of traditional risk assessment methods such as single perspective and easy loss of important information in the process of information fusion, and provides a theoretical algorithm for operation and management risk analysis of similar engineering projects.

The research results have a certain reference effect on actual engineering operation safety risk management. Only by identifying the important risk factors in the project operation process in advance can we take correct operation and management measures to better ensure the safe and stable operation of the project.

At present, there is no comprehensive and reasonable diagnostic method for the key risk sources faced in the operation of water transfer projects, therefore, the way of thinking about the identification of risk factors in the operation of water transfer projects in this paper is not comprehensive enough, and a detailed theoretical framework for conducting scientific identification and assessment of important risk factors in the operation management of water transfer projects is expected to be constructed in the future.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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