Risk Assessment for Geological Exploration Projects Based on the Fuzzy-DEMATEL Method

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***Abstract*—This paper briefly introduces the analytic hierarchy process (AHP) method and uses the fuzzy decision-making and trial evaluation laboratory (DEMATEL) method to adjust the index weight in it. The geological exploration project of Qingdao undersea tunnel project in Shandong Province was selected as the subject of case study. Firstly, the fuzzy-DEMATEL method was used to analyze the degree of influence between different risk factors in the project and the types of risk factors. Then, the AHP method divided the risk factors and calculated their weight. Finally, the influence parameters calculated by the fuzzy-DEMATEL method was employed to adjust the weight of the indicators in the AHP method. The fuzzy-DEMATEL analysis obtained the driving, conclusion, and transitional risk factors. It was found from the analytic results of the AHP method that the construction supervision unit's qualification risk, management mechanism, and awareness risk had the greatest impact on the risk of the project, and the overall risk level of the project was 2.1 points.**

Keywords—Geological exploration project; analytic hierarchy process; DEMATEL; fuzzy theory; risk assessment

I. INTRODUCTION

With the extensive development of geological exploration projects around the world, its risk management has become the key to ensure the smooth progress and successful implementation of projects [1]. Geological exploration projects are faced with a variety of risk factors due to their technical complexity, long cycle, large investment, and changing environment [2]. Geological exploration projects have a wide range of risk sources, including but not limited to technical risk, market risk, environmental risk, management risk, financial risk, etc. Therefore, in the risk management assessment of geological exploration projects, it is necessary to first identify the source of risk and then set corresponding indicators for investigation and analysis [3]. In order to solve the complexity and uncertainty problems in the risk assessment of geological exploration projects, this paper introduced the fuzzy decision-making and trial evaluation laboratory (DEMATEL) method [4]. The DEMATEL method is a structural modeling method used to visualize the structure of complex causal relationships and can calculate the influence degree of each element in the system on other elements. The fuzzy DEMATEL method introduces the fuzzy mathematics theory and is used to deal with the problems of complex systems with fuzziness and uncertainty [5]. The advantage of the fuzzy DEMATEL method in the risk assessment of geological exploration projects lies in that this method can reveal the mutual influence and causal relationship among various risk factors, which is helpful to identify the key risk factors and potential risk chains. Secondly, by calculating indicators such as the influence degree, influenced degree, centrality, and cause degree of each risk factor, the fuzzy DEMATEL method can provide a quantitative basis for risk assessment, enabling decision-makers to understand the distribution and severity of risks more intuitively [6]. Finally, based on the assessment results, it can also provide targeted risk management suggestions for the project team and help formulate effective risk response strategies. Liu et al. [7] proposed a risk assessment method that combined fuzzy weighted average and fuzzy decision-making trial with evaluation laboratory to sort the failure risks in system failure mode and effects analysis. Mentes et al. [8] proposed an integrated approach to identify and evaluate the driving factors, including the geographical location at the time of the accident and the failure mode leading to the death on the cargo ship. Sangaiah et al. [9] used a hybrid fuzzy multi-criteria decision-making method to effectively identify and rank significant software project risks. The evaluation results showed that compared with the existing software project risk evaluation methods, the fuzzy comprehensive evaluation method was effective and accurate. The above-mentioned related studies have all conducted relevant analyses on how to evaluate risks. Some adopted the method of fuzzy weights to evaluate risks, while others focused on the identification of related factors affecting risks. This paper used the analytic hierarchy process (AHP) to assess the risks of geological exploration projects and utilizes the Fuzzy DEMATEL method to adjust the hierarchical weights in the AHP method, thereby improving the accuracy of risk assessment. This paper briefly introduces the AHP method and uses the fuzzy DEMATEL method to adjust the indicator weights in the AHP method. A case study was performed on the geological exploration project of an undersea tunnel project in Qingdao, Shandong Province. The structure of this article is: abstract - introduction - introduction of AHP and fuzzy DEMATEL method - case analysis - discussion - conclusion.

II. AHP METHOD AND FUZZY-DEMATEL METHOD

With the rapid development of economy, in order to adapt to the rapid growth of population, a variety of basic livelihood projects continue to be established. The specifications of these livelihood projects are large or small, but they require a certain area of land, so before the implementation of livelihood projects, it is necessary to carry out geological exploration of the construction area, in order to improve safety [10]. The main purpose of geological exploration projects is to understand the geological conditions of the construction area. The geological conditions are unknown during the implementation of geological exploration projects [11], which means that there are risks in projects. In addition, geological exploration projects will be affected by various risk factors such as market, management mode, and finance during operation. Therefore, geological exploration projects also need to carry out risk management assessment, so as to reduce the risks of projects.

The AHP method is one of the many methods that can analyze the risk of geological exploration projects. As a multi-criteria decision-making technology [12], the AHP method can divide the problem into small problems at multiple levels and then carry out qualitative and quantitative analyses on the small problems. The steps of the AHP method are as follows. (1) The risk sources of geological exploration projects are divided into different hierarchies, and the risk indicators of each hierarchy are obtained. ② Starting from the lowest risk indicator, the pairwise judgment matrix is constructed for the different indicators of each hierarchy. ③ The indicator weight is calculated according to the pairwise judgment matrix [13], and the consistency check is used to adjust the weight. After the weight of the risk indicators is obtained, the score of each risk indicator can be collected by questionnaire, and the risk level is calculated based on it.

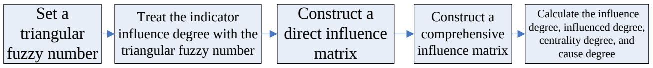

Fig. 1. The flow of the fuzzy-DEMATEL method.

When the AHP method is used, the key is to build a suitable pairwise judgment matrix to calculate the weight of indicators. In this process, the AHP method usually regards each indicator as an independent indicator, but in actual geological exploration projects, there are more or less mutual influences among risk indicators, which will affect the result of risk assessment [14]. Therefore, DEMATEL is adopted in this paper to revise the weights of the AHP method. The function of DEMATEL is to evaluate the influence degree of one indicator on other indicators and then to correct the weights in the AHP method. However, DEMATEL also needs to build an indicator influence matrix when calculating the influence degree of indicators, and the element values in the matrix are also obtained by manual evaluation. Therefore, a triangular fuzzy number [15] is introduced to process the element values in the matrix, thereby minimizing the subjective influence. The steps are shown in Fig. 1.

1) A triangular fuzzy number is set [16], and the expression of triangular fuzzy number A is: $A=(l,m,r)$, where l is the minimum value, m is the most likely value, and r is the maximum value. This paper adopts the form of manual scoring to evaluate the influence degree of a risk indicator on other indicators and sets an A for each influence degree level. The greater the influence degree, the closer A is to 1; otherwise, the closer A is to 0. For example, the A of the evaluation level of "no influence" is set as $(0,0.1,0.3)$.

2) The evaluation level of the influence degree of the indicator given by the manual score is converted into a triangular fuzzy number according to the setting.

3) Direct influence matrix B is constructed, and the matrix is expressed as:

$$B=\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1j} \\ b_{21} & b_{22} & \cdots & b_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ b_{i1} & b_{i2} & \cdots & b_{ij} \end{bmatrix}, \tag{1}$$

where b_{ij} represents the value of the influence of risk indicator i on risk indicator j after fuzzy processing. Its calculation formula is:

$$\begin{cases} b_{ij}=\dfrac{\sum_{k=1}^{k} b_{ij}^{k}}{k} \\ b_{ij}^{k}=\min l_{ij}^{k}+x_{ij}^{k}\Delta_{\min}^{\max} \\ \Delta_{\min}^{\max}=\max r_{ij}^{k}-\min l_{ij}^{k} \\ x_{ij}^{k}=\dfrac{x_{lsij}^{k}(1-x_{lsij}^{k})+x_{rsij}^{k}x_{rsij}^{k}}{1-x_{lsij}^{k}+x_{rsij}^{k}} \\ x_{lsij}^{k}=\dfrac{x_{mij}^{k}}{1+x_{mij}^{k}-x_{lij}^{k}} \\ x_{rsij}^{k}=\dfrac{x_{rij}^{k}}{1+x_{rij}^{k}-x_{mij}^{k}} \end{cases}, \tag{2}$$

where x_{lij}^{k}, x_{mij}^{k}, and x_{rij}^{k} are triangular fuzzy numbers of the influence degree between risk indicators i and j given by rater k after standardization, x_{lsij}^{k} and x_{rsij}^{k} are the left and right standard values of the triangular fuzzy number of the influence between indicators i and j given by rater k, x_{ij}^{k} is the total standard value of the triangular fuzzy number of the influence between indicators i and j given by rater k [17], $\Delta_{\min}^{\max}$ is the difference between the largest maximum value and the smallest minimum value among the triangular fuzzy numbers given by all raters, and b_{ij}^{k} is the clear value between indicators i and j given by rater k [18].

4) The formula of the comprehensive influence matrix is:

$$\begin{cases} C=\dfrac{B}{\max_{1\le i\le n}\sum_{j=1}^{n} b_{ij}} \\ D=C\cdot(E-C)^{-1} \end{cases}, \tag{3}$$

where C is the direct influence matrix after normalization, D is the comprehensive influence matrix, and E is the identity matrix [19].

5) The comprehensive influence parameter of the risk indicators is calculated according to D:

$$\begin{cases} d_i = \sum_{j=1}^{n} d_{ij} \\ e_i = \sum_{j=1}^{n} d_{ji} \\ f_i = d_i + e_i \\ g_i = d_i - e_i \end{cases}, \tag{4}$$

where d_i is the influence degree of risk indicator i, e_i is the influenced degree, f_i is the degree of centrality, and g_i is the degree of cause [20].

After obtaining the comprehensive influence parameter of risk indicators through the above steps, the degree of centrality can be used to adjust the weight of indicators calculated in the AHP method. The adjustment formula is:

$$W_i = \frac{\omega_i f_i}{\sum_{i=1}^{n} \omega_i f_i}, \tag{5}$$

where ω_i is the weight of risk indicator i in the AHP method and W_i is the weight of risk indicator adjusted by the fuzzy-DEMATEL method.

III. CASE ANALYSIS

A. Case Overview

This paper took the geological exploration project of an undersea tunnel project in Qingdao, Shandong province as a case analysis. The project is located at Jiaozhou Bay in Qingdao. The main purpose of the undersea tunnel project is to directly connect the economic zones on both sides of Jiaozhou Bay, so as to improve the efficiency of freight and passenger transport and further promote economic development.

In the geological exploration project, the method of drilling was used to survey the seabed geology of Jiaozhou Bay, and a total of 16 drilling points were set up. The ship-borne drilling platform was used at the drilling point. In the process of drilling, the ship-borne drilling platform was fixed to the drilling point by using multiple ship anchors. Then, the drilling casing was driven vertically into the sea bed by traction until the casing reached the stable layer.

B. Methods for Risk Analysis of the Geological Exploration Project

Firstly, 20 experts from the related field were invited to identify and summarize the risk sources of the geological exploration project. The risk hierarchical structure of the geological exploration project was constructed, as shown in Fig. 2.

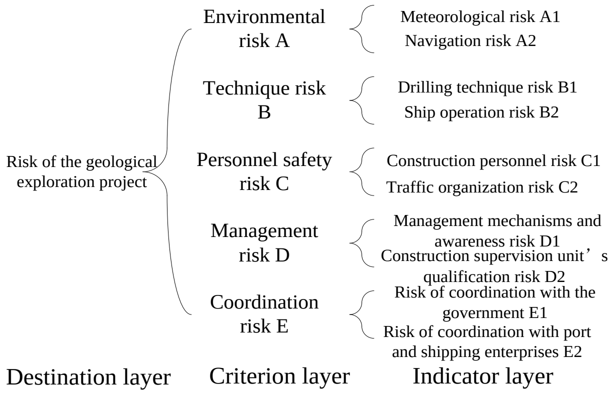

Fig. 2. Hierarchical structure.

After that, 20 experts were distributed the criterion-level rating table and the indicator level rating table. They marked the importance degree of the risk factors in the criterion level and the indicator level through the rating tables. Taking the criterion level score table as an example, as shown in Table I, the five risk factors in the criterion level were compared pairwise, and "1, 2, 3... 8, 9" was used to evaluate the relative importance between two factors. "1" indicates that the two factors are equally important; the larger the value, the more important the former factor is than the latter factor. When the former and latter factors are exchanged during comparison, the reciprocal of the value is used. The same is true for the indicator level score table, but the difference is that the risk indicators of the indicator level for pairwise comparison needs to belong to the same criterion level indicator. According to the rating tables, the judgment matrix of the criterion layer and indicator layer was constructed successively, and the weight of risk factors of the criterion layer and indicator layer was calculated based on it. At the same time, consistency check was used to determine whether the weight is reasonable. If not, the score in the judgment matrix was re-adjusted, and the weight was calculated until passing the consistency check.

TABLE I. INDICATOR OF IMPORTANCE RATING TABLE

Risk factor	Factor A	Factor B	Factor C	Factor D	Factor E
Factor A	1				
Factor B		1			
Factor C			1		
Factor D				1	
Factor E					1

After calculating the weight of the risk factors through the above steps, the fuzzy-DEMATEL method was used to calculate the degree of influence between the risks. First of all, the 20 experts were given the risk factor influence degree score table, which compared all risk factors in the indicator layer pairwise. The evaluation of the influence degree from weak to strong was divided into five levels, and a triangular fuzzy number was set for each level. After that, equation (2) was used to deblur the rating table, and the average score of the influence degree was calculated. A direct influence matrix was constructed according to the average score of the influence degree in the score table, and then the centrality degree of each risk factor was calculated following the steps mentioned above.

The weight of the risk factor obtained by the AHP method was adjusted accordingly.

Finally, a questionnaire was designed according to the indicator layer in the hierarchical structure given by the AHP method, and the score of each indicator was set from 0 to 10 according to the risk degree from low to high. Then, the 20 experts scored the risk factor indicators in the questionnaire.

IV. ANALYSIS OF RESULTS

This paper used the fuzzy-DEMATEL method to analyze the degree of mutual influence of risk factors in the geological exploration project. After a series of calculations, comprehensive influence matrix D of risk factors in the geological exploration project is shown in Table II. The causal relationship diagram of risk factors drawn according to Table III is shown in Fig. 3. Matrix D reflects the comprehensive influence of a risk factor on other risk factors. A scatter plot of the distribution of risk factors in a plane was obtained by using the centrality degree as the x-axis and cause degree as the y-axis. After introducing the average centrality degree of risk factors, the plane was divided into four quadrants. It can be seen that meteorological risk A1, management mechanism and awareness risk D1, and construction supervision unit’s qualification risk D2 were in the second quadrant, belonging to driving risk factors. Drilling technique risk B1, risk of coordination with the government E1, and risk of coordination with port and shipping enterprises were in the third quadrant, belonging to conclusion risk factors. Navigation risk A2, ship operation risk B2, construction personnel risk C1, and traffic organization risk C2 were in the fourth quadrant, belonging to transitional risk factors.

TABLE II. COMPREHENSIVE INFLUENCE MATRIX D OF RISK FACTORS IN THE GEOLOGICAL EXPLORATION PROJECT

	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2
A1	0.148	0.493	0.308	0.510	0.570	0.504	0.272	0.210	0.257	0.339
A2	0.111	0.274	0.261	0.336	0.353	0.331	0.198	0.164	0.189	0.350
B1	0.086	0.228	0.229	0.360	0.415	0.316	0.203	0.156	0.183	0.227
B2	0.107	0.408	0.340	0.375	0.501	0.477	0.246	0.193	0.230	0.373
C1	0.099	0.264	0.332	0.378	0.392	0.413	0.353	0.204	0.308	0.287
C2	0.115	0.463	0.294	0.514	0.522	0.420	0.262	0.247	0.267	0.424
D1	0.086	0.221	0.206	0.384	0.443	0.317	0.214	0.150	0.175	0.218
D2	0.119	0.330	0.444	0.550	0.617	0.501	0.351	0.231	0.310	0.359
E1	0.064	0.181	0.130	0.190	0.199	0.316	0.117	0.101	0.144	0.155
E2	0.079	0.347	0.169	0.259	0.253	0.363	0.146	0.124	0.141	0.236

TABLE III. MEASUREMENT OF THE COMPREHENSIVE INFLUENCE DEGREE OF VARIOUS RISK FACTORS IN THE GEOLOGICAL EXPLORATION PROJECT

	Influence degree	Influenced degree	Centrality degree	Degree of cause	Ranking of centrality degree
A1	3.610	1.014	4.624	2.596	9
A2	2.567	3.209	5.776	0.642	4
B1	2.401	2.713	5.114	0.312	6
B2	3.252	3.855	7.107	0.603	3
C1	3.028	4.265	7.293	1.237	2
C2	3.528	3.958	7.486	0.430	1
D1	2.413	2.361	4.774	0.052	8
D2	3.811	1.779	5.590	2.032	5
E1	1.597	2.203	3.800	0.606	10
E2	2.117	2.967	5.084	0.850	7

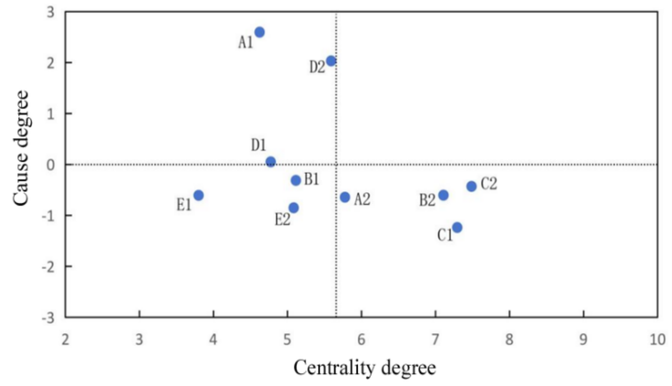

Fig. 3. Causal relationship diagram of risk factors in the geological exploration project.

Then, the AHP method was used to carry out hierarchical analysis on the risk of the geological exploration project, and the weight of risk indicators was calculated and adjusted using the centrality degree. The results and the scores of each risk indicator collected by questionnaire are shown in Table IV. After the adjustment, the weight distribution of risk indicators changed, among which construction supervision unit’s qualification risk D2 had the highest weight, management mechanism and awareness risk D1 had the second-highest weight, and risk of coordination with the government E1 had the lowest weight. After combining the adjusted weight with the average score of the corresponding risk indicators, the overall risk score of the geological exploration project risk was 2.1, indicating that the overall risk of the geological exploration project was low.

TABLE IV. THE HIERARCHICAL ANALYSIS STRUCTURE OF THE RISK OF THE GEOLOGICAL EXPLORATION PROJECT AND THE WEIGHT DISTRIBUTION AND AVERAGE SCORES OF INDICATORS BEFORE AND AFTER ADJUSTMENT

Destination layer	Criterion layer	Indicator layer	Initial weight	Centrality degree	Weight after adjustment	Average score
The risk of the geological exploration project	A	A1	0.180	4.624	0.154	1.2
		A2	0.120	5.776	0.128	1.3
	B	B1	0.040	5.114	0.038	1.2
		B2	0.060	7.107	0.079	1.3
	C	C1	0.050	7.293	0.067	1.1
		C2	0.050	7.486	0.069	1.1
	D	D1	0.200	4.774	0.176	3.6
		D2	0.200	5.590	0.206	3.5
	E	E1	0.045	3.800	0.032	1.1
		E2	0.055	5.084	0.052	1.0

V. DISCUSSION

During the construction of infrastructure, it is common to conduct a geological survey of areas where the facility will be constructed in order to ensure the safety of the building facility as well as the construction personnel [21]. Geological survey projects often face many risk factors due to complicated technology, long period, large investment, and changing environment [22]. In order to ensure the safe implementation of geological exploration projects, it is necessary to evaluate and analyze the risk factors involved in these projects. Some studies related to risk assessment are reviewed. Lin et al. [23] analyzed the risk of heavy metal pollution in the Beibu Gulf. The results of the analysis using principal component analysis, positive matrix factor model, and mercury isotope method showed that heavy metal pollution mainly came from industrial pollution sources, including petrochemical, coal combustion, metal and metalloid processing, leather tanning, and human activities, among which anthropogenic pollution sources accounted for approximately 70% of all pollution. Pan [24] established a wind power output power model based on the output characteristics of wind power and established probability models of generating units, lines, and loads considering the uncertainty of other system components to evaluate system operation risks. Based on the “source-sink” landscape theory, Zhao et al. [25] established the location-weighted landscape contrast index and non-point source pollution risk index, in order to study the pollution risk of Baihua Lake in Guiyang City. The evaluation results were compared with the measured water quality data and field investigation results to verify the reliability of this method. This paper used the AHP method to perform qualitative and quantitative analysis of the risk factors in geological exploration projects. Firstly, through the analysis of the risk sources of projects, the hierarchical structure of the risk of projects was constructed, experts were invited to score the importance between two indicators in the hierarchy, and the weight of these indicators was calculated. In addition, in order to reduce the subjectivity brought by the expert score, this paper used the fuzzy-DEMATEL method to calculate the degree of mutual influence between the risk factors and adjusted the weight of the risk factor indicators in the AHP method. Then, a case study was conducted using the geological exploration project of an undersea tunnel project in Qingdao, Shandong province as the subject. The fuzzy-DEMATEL method analyzed the influence degree between the risk factors and the types of risk factors in the project, and then the AHP method divided the risk factors and calculated their weight. Finally, the influence parameters calculated by the fuzzy-DEMATEL method were used to adjust the weight of the indicators in the AHP method, and moreover, the risk level of the project was scored.

Case analysis results showed that meteorological risk A1, management mechanism and awareness risk D1, and construction supervision unit’s qualification risk D2 belonged to the driving risk factors, of which A1 and D2 had high cause degree but low centrality degree. Meteorological risk and construction supervision unit’s qualification risk were external risks, and D1 could affect the factors in the project, but the influence was small. Drilling technique risk B1, risk of coordination with the government E1, and risk of coordination with port and shipping enterprises E2 belonged to the conclusion risk factors, which had low cause and centrality degrees. These risk factors were the internal risks of the project, which were easy to be affected by other factors, but not easy to influence other factors. Navigation risk A2, ship operation risk B2, construction personnel risk C1, and traffic organization risk C2 belonged to transitional risk factors. These risk factors had low cause degree but high centrality degree, indicating that these internal factors of the project were susceptible to the influence of other factors and not easy to impact other factors.

In the analysis results of the AHP method, the construction supervision unit’ qualification risk D2 had the highest weight, followed by management mechanism and awareness risk D1, and risk of coordination with the government had the lowest weight, indicating that the risk caused by the construction supervision unit’ qualification, management mechanism and awareness had the greatest impact on the risk of the entire project. Moreover, the risk score of the project was calculated by combining the score given by the experts for the risk indicators with the corresponding weight, and the result was 2.1, suggesting that this project was at a relatively low risk level.

VI. CONCLUSION

This paper briefly introduces the AHP method and uses the fuzzy-DEMATEL method to adjust the indicator weight in the AHP method. A case study was performed using the geological exploration project of an undersea tunnel project in Qingdao, Shandong Province. Firstly, the fuzzy-DEMATEL method was employed to analyze the influence degree between different risk factors and the types of risk factors in the project. Then, the AHP method divided the risk factors and calculated their weight. Eventually, the indicator weight in the AHP method was regulated using the influence parameters calculated by the fuzzy-DEMATEL method. Meteorological risk A1, management mechanism and awareness risk D1, and construction supervision unit’s qualification risk D2 belonged to the driving risk factors, drilling technique risk B1, risk of coordination with the government E1, and risk of coordination with port and shipping enterprises E2 belonged to the conclusion risk factors. Navigation risk A2, ship operation risk B2, construction personnel risk C1, and traffic organization risk C2 belonged to the transitional risk factors. In the analysis results of the AHP method, the construction supervision unit's qualification risk (D2) had the highest weight, the management mechanism and awareness risk (D1) was the second, and the risk of coordination with the government (E1) had the lowest weight. The score of the overall risk level of the project was 2.1.

REFERENCES

[1] Yin, L. Pan, and X. Li, "A Novel Multi-Criteria Decision-Making Approach for Intellectual Property Risk Assessment in Crowdsourcing Design," J. Circuits Syst. Comp., vol. 31, pp. 1-25, 2022.

[2] M. Khalilzadeh, H. Shakeri, and S. Zohrehvandi, "Risk identification and assessment with the fuzzy DEMATEL-ANP method in oil and gas projects under uncertainty," *Proc. Comput. Sci*., vol. 181, pp. 277-284, 2021.

[3] O. Ahmadi, S. B. Mortazavi, H. A. Mahabadi, and M. Hosseinpouri, "Development of a dynamic quantitative risk assessment methodology using fuzzy DEMATEL-BN and leading indicators," *Process Saf. Environ*., vol. 142, pp. 15-44, 2020.

[4] M. Sága, I. Kuric, I. Klačková, and D. Więcek, "Comparison of risk assessment approaches and analyzes used in technical transport systems," *Transp. Res. Proc.*, vol. 74, pp. 516-521, 2023.

[5] M. Li, S. Tian, C. Huang, W. Wu, and S. Xin, "Risk Assessment of Highway in the Upper Reaches of Minjiang River under the Stress of Debris Flow," *J. Geosci. Environ. Protect.*, vol. 09, pp. 21-34, 2021.

[6] S. Dhulipala, "Gaussian Kernel Methods for Seismic Fragility and Risk Assessment of Mid-Rise Buildings," *Sustainability*, vol. 13, pp. 1-25, 2021.

[7] H. C. Liu, J. X. You, Q. L. Lin, and H. Li, "Risk assessment in system FMEA combining fuzzy weighted average with fuzzy decision-making trial and evaluation laboratory," *Int. J. Comput. Integ. M*., vol. 28, pp. 701-714, 2015.

[8] A. Mentes, H. Akyildiz, M. Yetkin, and N. Turkoglu, "A FSA based fuzzy DEMATEL approach for risk assessment of cargo ships at coasts and open seas of Turkey," *Safety Sci*., vol. 79, pp. 1-10, 2015.

[9] A. K. Sangaiah, O. W. Samuel, X. Li, M. Abdel-Basset, and H. Wang, "Towards an efficient risk assessment in software projects–Fuzzy reinforcement paradigm," *Comput. Electr. Eng*., vol. 71, pp. 833-846, 2018.

[10] X. Li, R. Wan, B. Wu, G. Meng, and H. Chen, "Risk Assessment of the construction of metro stations with open cut method based on fuzzy comprehensive evaluation method," *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 636, pp. 1-7, 2021.

[11] T. Hao, X. Zheng, H. Wang, K. Xu, and Y. Yu, "Development of a method for weight determination of disaster-causing factors and quantitative risk assessment for tailings dams based on causal coupling relationships," *Stoch. Env. Res. Risk A*., vol. 37, pp. 749-775, 2023.

[12] G. F. Can, and P. Toktaş, "A novel fuzzy risk matrix based risk assessment approach," *Kybernetes*, vol. 47, pp. 1721-1751, 2018.

[13] S. M. Hatefi, and J. Tamoaitien, "An integrated fuzzy dematel-fuzzy anp model for evaluating construction projects by considering interrelationships among risk factors," *J. Civ. Eng. Manag*., vol. 25, pp. 114-131, 2019.

[14] S. Liu, X. Guo, and L. Zhang, "An Improved Assessment Method for FMEA for a Shipboard Integrated Electric Propulsion System Using Fuzzy Logic and DEMATEL Theory," *Energies*, vol. 12, pp. 1-18, 2019.

[15] S. Sharifi, R. Shahoei, B. Nouri, R. Almvik, and S. Valiee, "Effect of an education program, risk assessment checklist and prevention protocol on violence against emergency department nurses: A single center before and after study," *Int. Emerg. Nurs.*, vol. 50, pp. 1-6, 2020.

[16] Y. Sun, T. Zhang, S. Ding, Z. Yuan, and S. Yang, "Risk assessment of high-speed railway CTC system based on improved game theory and cloud model," *Railw. Sci*., vol. 3, pp. 388-410, 2024.

[17] Y. Q. Sang, H. Li, and H. H. Jin, "Safety risk assessment of aircraft EWIS based on the improved combined weight and cloud model," *Aircr. Eng. Aerosp. Tec*., vol. 95, pp. 1470-1482, 2023.

[18] Z. Huang, F. Gao, X. Li, and M. Jiang, "Static and dynamic fuzzy assessment methods for the collapse risk of mountain tunnel construction," *J. Intell. Fuzzy Syst*., vol. 45, pp. 7975-7999, 2023.

[19] J. Li, and K. Xu, "A combined fuzzy DEMATEL and cloud model approach for risk assessment in process industries to improve system reliability," *Qual. Reliab. Eng. In*t., vol. 37, pp. 2110-2133, 2021.

[20] R. Deb, and S. Roy, "A Software Defined Network information security risk assessment based on Pythagorean fuzzy sets," *Expert Syst. Appl*., vol. 183, pp. 1-17, 2021.

[21] A. Tokai, and T. Nakakubo, "Risk Assessment and Management Methodologies for Applying Unusual Chemical Releases Derived from Disaster and Accident," *Jpn. J. Risk Anal*., vol. 29, pp. 195-197.

[22] K. Pang, C. Cheng, H. Zhao, Y. Ma, B. Dong, and J. Hu, "Simultaneous Analysis and Risk assessment of Quizalofop, Acifluorfen, Bentazone and Its Metabolites residues in Peanut and Straw under field conditions of China," *Microchem. J.*, vol. 164, pp. 1-9, 2021.

[23] H. Lin, W. Lan, Q. Feng, X. Zhu, T. Li, R. Zhang, H. Song, Y. Zhu, and B. Zhao, "Pollution and ecological risk assessment, and source identification of heavy metals in sediment from the Beibu Gulf, South China Sea," *Mar. Pollut. Bull.*, vol. 168, pp. 112403, 2021.

[24] W. Pan, "Research on power system risk assessment considering large-scale wind and solar access," *J. Phys.: Conf. Ser.,* vol. 2215, pp. 012024, 2022.

[25] W. Zhao, Z. Zhou, and L. Q. Li, "Risk assessment of non-point source pollution in karst reservoirs based on 'source﹣sink' landscape theory," *Water Sci. Technol.*, vol. 22, pp. 6094-6110, 2022.