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Research Article

Risk Evaluation of Urban Integrated Pipe Corridor Operation and Maintenance Based on Improved AHP-CIM Model

Shuai Wang and Shaochuan Fu

School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China

Correspondence should be addressed to Shuai Wang; 16113139@bjtu.edu.cn

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In order to scientifically and objectively evaluate the risk in the operation and maintenance process of the urban integrated pipe corridor, and then prevent the occurrence of urban integrated pipe corridor operation and maintenance accidents, this paper combines AHP analysis and CIM model to propose a new model for the risk assessment of pipe corridors: AHP-CIM model, and uses the model to conduct a verification of the operation and maintenance risk evaluation of the Beijing Tongzhou Canal Core Area North Ring Tunnel Integrated Pipe Corridor. Using a combination of qualitative and quantitative methods, the risk factors in the operation and maintenance process of the integrated urban pipe corridor were first identified and their weights determined, and then the CIM model was used to calculate the probability distribution of the levels of risk factors at each level of the hierarchical model, and finally the risk assessment set of the risk probability distribution of this integrated pipe corridor was obtained. The results show that the overall O&M risk level of this integrated pipe corridor is high, and its probability is 69.47%.

1. Introduction

In recent years, due to the increasing scarcity of land resources, integrated pipe corridors have gradually become the main choice for the construction of municipal facilities in cities due to their superiority in terms of resource integration and convenient maintenance. With the policy support of the State Council, the construction scale of urban underground integrated pipeline corridors in China is also gradually expanding.

A comprehensive urban underground pipeline corridor is a municipal underground pipeline complex that integrates municipal pipelines such as electric power, communication, gas, water supply and drainage, heating and other engineering pipelines in a common underground tunnel space, and achieves its unified planning, operation, maintenance and management by setting up special lifting, maintenance ports, control and testing supporting systems, etc. As a public service infrastructure for cities, the construction of underground integrated urban corridors is of great significance in solving urban diseases, promoting the improvement of the carrying capacity of cities and meeting the needs of people's livelihood.

However, in general, the construction of urban underground integrated corridors in China is still in its infancy, and although the level of control of China's corridor operation and maintenance contractors has improved considerably in recent years, the level of operation and maintenance management of integrated corridors is still inadequate, and the risk assessment methods for corridor operation and maintenance are not yet perfect, with disasters and accidents occurring from time to time. There is still a lack of more scientific and objective methods to evaluate the overall risk of integrated corridor operation and maintenance.

In this paper, based on the analysis of risk factors of urban underground integrated pipeline corridors, a new risk evaluation of integrated pipeline corridor O&M will be established using the improved AHP analysis method and CIM model, and applied to practical cases.

2. Literature Review

At present, underground integrated pipeline corridors are under construction or in operation in several cities in China. Safety issues are crucial in the operation and maintenance of integrated pipe corridors, and in recent years, scholars at home and abroad have conducted a lot of research on this.

2.1. Current Status of Domestic Research. More ideas have been put forward by domestic scholars on the risk evaluation of integrated pipeline corridors, covering various stages such as investment, construction, operation and maintenance, and the whole life cycle. The existing literature is categorized into three types: specialized disaster and accident risk evaluation studies, coupled risk evaluation studies, and comprehensive risk evaluation studies.

Specialized disaster-incident risk evaluation research: Zhao [1] and Wang [2] conducted a comprehensive risk identification and evaluation of natural gas leakage accidents in integrated pipeline corridors using the accident tree analysis method as well as the Kent method, respectively; Xiangling et al. selected five aspects based on hierarchical analysis and fuzzy comprehensive evaluation method, including integrated pipeline corridor situation, firefighting facilities, evacuation facilities, safety management, and escape personnel skills, as the main influencing factors affecting the fire risk of integrated pipeline corridors, and evaluated the fire risk of integrated pipeline corridors [3]; Huang and Lin established a fire safety evaluation index system for integrated pipeline corridors and proposed to evaluate the fire safety level of integrated pipeline corridors using an evaluation model based on AHP-evidence theory [4]; Shen used the fuzzy fault tree analysis method to assess, from the perspective of risk research The failure probability of gas pipeline leakage in urban integrated pipeline corridors, identified the main risk points in them, developed a dedicated emergency plan and evaluated its completeness [5].

Coupled risk evaluation study. Wang et al. established hazard evaluation indicators for a single disaster that may occur in the integrated pipeline corridor, and applied fuzzy mathematical methods to establish a coupling degree model so as to obtain the coupling relationship between multiple disasters, and finally proposed a risk evaluation method for the coupling of disasters caused by multiple disasters in the integrated pipeline corridor [6]; Qiu et al. proposed a coupled evaluation method for the construction safety risk of the integrated pipeline corridor based on CM and information entropy method, using information entropy to quantify the weight of each index, and quantitatively evaluated the safety risk state of integrated pipe corridor construction based on coupling degree model with coupling degree value [7]; Chai and Liu designed a multi-hazard coupled prediction model of integrated pipe corridor based on fuzzy clustering analysis, implemented clustering based on variable fuzzy clustering method, and then applied the use of fuzzy mathematics to obtain the coupling relationship between multiple hazards, and finally The multi-hazard coupled prediction of integrated pipeline corridor was realized [8].

Comprehensive risk evaluation research: Chen et al. constructed a fuzzy comprehensive assessment model for disaster risk of comprehensive pipeline corridors based on Bayesian networks and achieved ratings for disaster risk [9]; Liu et al. constructed an evaluation model based on grey clustering method to evaluate the operational risk of underground comprehensive pipeline corridor projects [10]. Zhang and Zhang established a whole-life cycle risk assessment index system and applied fuzzy hierarchical analysis to risk assessment [11]; Lu et al. constructed a risk evaluation model for operation and maintenance of underground integrated pipeline corridor projects based on information entropy combination of empowerment and topologizability theory [12]; Cai et al. established a construction safety risk based on improved D-S evidence theory evaluation model for a comprehensive evaluation of the first phase of the construction of the comprehensive pipe corridor in Kaizhou, Chongqing [13]; meanwhile, literature [14] and literature [15] also made relevant studies on comprehensive risk evaluation of underground comprehensive pipe corridors from different perspectives, involving issues such as the comparison of comprehensive pipe corridor operation and maintenance in different regions and comprehensive pipe corridor operation and maintenance disasters.

2.2. Status of Research abroad. Although the construction of foreign integrated pipe corridor compared to the domestic advancement, foreign scholars on the integrated pipe corridor risk evaluation research is relatively mature, but simply for the integrated pipe corridor risk evaluation research literature compared to the domestic is less, involving there are related domain tube tunnel risk evaluation more. Therefore, the existing literature is grouped into two categories: risk evaluation studies of integrated pipeline corridors, and other related risk evaluation studies.

Canto-Perello et al. proposed an expert system combining colour-coded, Delphi and hierarchical analysis methods to analyse the criticality and threat of integrated pipe corridors, which was used to support the planning of safety policies for urban underground facilities [16]; Jang and Jung investigated gas leaks and unknown ignitions in integrated pipe corridors due to gas explosions [17]; Wang and Fang constructed a risk evaluation model for integrated pipe corridor PPP projects, identified risk factors for utility based on a questionnaire survey, and then designed a risk evaluation index system and used an optimized fuzzy integrated rating method for risk evaluation [18]; He et al. proposed a new fire risk assessment method within integrated pipe corridors in In the absence of historical cable fire data, fuzzy theory was used to calculate the failure probability of the main events of cable fires, and fuzzy inference was performed using a weighted fuzzy Petri net, and a numerical simulation method was used to quantify the losses caused by cable fires so as to quantify the risk of cable fires [19]; Ding et al. applied a fault tree model to influence the urban underground integrated pipeline corridor project PPP model risks were analyzed, resulting in factors that have a greater impact on project risks, and found that the application of the PPP model in integrated underground corridors is more suitable for developed regions [20]; while the literature [21, 22] analyzed the key risks of urban integrated corridors and their ratings from the actual situation of Chinese as well as Korean cities, respectively.

Other related risk rating studies: as early as 2011, Rita and Herbert proposed a method to systematically assess and manage tunnel-related risks by combining a geological prediction model with a construction strategy decision model to predict the geology prior to tunnel construction to select the least risky construction strategy among different construction strategies [23]; Golam et al. proposed a Bayesian belief network for assessing the risk of failure of metal water pipes model that can rank water supply trunk pipes in distribution networks to identify vulnerable and sensitive pipes for rational water supply management [24]; Zhang et al. proposed a method for tunnel fire safety risk analysis based on fuzzy Bayesian networks [25]; Khwaja Mateen et al. proposed a new public-private partnership based on fuzzy integral infrastructure project (PPP project) risk assessment method to help stakeholders make risk management decisions [26]; Wu et al. developed a cloud model-based risk assessment model for metro tunnel shield construction, which effectively addressed the stochastic uncertainty and fuzzy uncertainty of indicator factors [27]; in addition to these, Kang, Marian et al. Martinka et al. have also implemented dynamic analysis of risks in underground tunnels, sub-sea tunnels, and cables, respectively [28–30]. Han et al. through the combination of the classical AHP method and DSM method effectively manage its risks in operation and maintenance management [31].

2.3. Shortcomings of Existing Studies

(1) The existing studies are more concerned with the impact of these special disasters such as gas leaks and fires in urban integrated pipeline corridors and their prevention and control, and there are relatively few studies on the overall risk assessment of the operation and maintenance of urban integrated pipeline corridors

(2) Existing research is relatively more focused on the investment, design and construction of integrated pipeline corridors, and relatively less on the analysis and study of the operation and maintenance risks of integrated pipeline corridors

(3) In the process of research on the operation and maintenance risks of integrated pipeline corridors, most of the studies tend to be qualitative, and there is a lack of reliable quantitative and comprehensive evaluation methods for operation and maintenance risks

(4) In the process of ranking the importance of risks, subjective weighting methods such as hierarchical analysis are mostly used, which makes it difficult to fully consider the information contained in the risk evaluation indicators and has certain limitations

3. Research Methodology

3.1. Improving the AHP Hierarchical Analysis. The AHP hierarchical analysis method is an effective approach to complex problems proposed by American scholar T. L. Saaty. It is the process of decomposing a complex problem into multiple influencing factors, establishing a hierarchy based on the logical relationship between the factors, calculating qualitative and quantitative calculations for each level, and finally summing up the levels according to the weights to achieve a comprehensive decision-making process. The specific steps of the application of the method are as follows:

(1) Establish a hierarchical structure model. According to different attributes, each factor is decomposed into target layer, criterion layer, and indicator layer.

(2) Construct a comparative judgement matrix. Starting from the second level of the hierarchical model, the comparison method and the scaling method are used to compare the importance of factors between the same levels, so as to construct a comparison matrix, as

$$\left(B_{ij}\right)_{n\times n}=\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix}. \tag{1}$$

At present, the improvement of the AHP method by domestic scholars mainly focuses on the comparison matrix, the construction of the scale and the solution of the weights of the feature vectors, among which the scale is the focus of the research on the construction problem. In this paper, we choose to improve the AHP method in terms of the design of the scale.

Table 1 below shows the assignment rules of the traditional "nine-scale method" for constructing the comparison matrix. The analysis shows that the method is highly subjective and inconvenient in practice, and requires the use of seat differences between words, such as "slightly important", "more important", "extremely important" and "extremely important" " and "extremely important" to construct a comparison matrix. This is particularly difficult in practice for sets of factors that are less distinct in terms of impact and have a larger base.

In view of the shortcomings of the "nine-scale method," a new "five-scale method" is established to make judgments, converting the nine numbers from 1 to 9 in the nine-scale method into five numbers of 1/4, 1/2, 1, 2 and 4, thus constructing a new judgement matrix as shown in Table 2 below. The new judgement matrix is shown in Table 2. The

Table 1: Two-by-two comparison of the "nine-scale method."

Numerical values	Level of importance
1	Element i and element j are more important than equally
3	The i and j elements are slightly more important than the
5	Element i is more important than element j
7	The i element is much more important than the j element
9	Element i is significantly more important than element j
2, 4, 6, 8	The mutual importance of elements i and j lies between the two adjacent judgement scales above

Table 2: Two-by-two comparison of the improved "five-scale method."

Numerical values	Level of importance
4	Factor i is absolutely more important than factor j
2	Factor i is marginally more important than factor j
1	Factor i is equally important than factor j
1/2	Factor j is slightly more important than factor i
1/4	The j-factor is definitely more important than the i-factor

improved "five-scale method" distinguishes to a certain extent from the vague expressions in the text of the "nine-scale method" by not focusing on "slightly," "obviously," "very" and so on. and "very," which reduces the subjectivity of the artificiality and makes it less difficult and more efficient to implement. In addition to this, because the five numbers are chosen in proportion to each other, the final weight allocation ratio can be quickly obtained without the need for a consistency test

(3) Normalize the comparison matrix to obtain the standard two-by-two comparison matrix, as

$$\left(\overline{B}_{ij}\right)_{n\times n} = \begin{bmatrix} \overline{b}_{11} & \overline{b}_{12} & \cdots & \overline{b}_{1n} \\ \overline{b}_{21} & \overline{b}_{22} & \cdots & \overline{b}_{2n} \\ \vdots & \vdots & \vdots & \\ \overline{b}_{n1} & \overline{b}_{n2} & \cdots & \overline{b}_{nn} \end{bmatrix}. \tag{2}$$

Calculation of risk factor weights for the criterion level as well as the indicator level. The elements of each row of the standard two-by-two comparison matrix are summed to obtain a sum value, and each element of that row is divided by this sum value separately to calculate the weight of that element, as

$$w_i = \frac{\overline{b_i}}{\sum_{i=1}^{n} b_i}. \tag{3}$$

A weight matrix is constructed from the weight values of each indicator layer, as

$$W = \left(w_1 \;\; w_2 \;\; \cdots \;\; w_1 \right). \tag{4}$$

3.2. CIM Model. The CIM model is a memory assessment model for control intervals, divided into 2 types of series corresponding models and parallel corresponding models, and is an effective method for analyzing the superposition of complex risk factor probability distributions. It replaces the integral of the risk factor probability function directly with the sum of the histograms of the risk factor probability distribution, which simplifies the calculation of the risk factor probability and has significant advantages in handling complex and variable information.

In the urban integrated pipeline corridor operation and maintenance safety risk, the probability of accidental risk is greater, the emergence of risk factors levels is random, and there are more uncertainty factors, and they interact and influence each other, resulting in diversified influences between risk factors, when the factors causing risk change, it will inevitably lead to changes in the risk itself or associated factors, at this time, the risk factors at the same level can be simplified to parallel relationship, so this paper selects the probability superposition method of multiplication to apply the CIM parallel response model for research.

In the calculation of the probability of risk superposition, we set the decision target as X, there are n randomly occurring risk factors that affect each other, noted as $X_1, X_2, \ldots, X_n$, then its combined response probability calculation formula is as follows:

$$\begin{aligned} P\left(X_a = x_a\right) = {} & \sum_{i=1}^{n} P\left(X_1 = x_a, X_2 \le x_a\right) \\ & + \sum_{i=1}^{n} P\left(X_1 < x_a, X_2 = x_a\right), \end{aligned} \tag{5}$$

where $a = 1, 2, \ldots, n$, x_a denotes the interval being divided into groups of n.

When there are two or more risk factors, we apply the model to the probability distribution superposition calculation, as shown in Figure 1 for the CIM parallel response model risk specific superposition process: the first and second risk factor probability distribution is superimposed to obtain the new probability distribution superposition value, this superposition value and the third risk factor probability distribution for the second probability distribution superposition, and so on, after n - 1 superposition

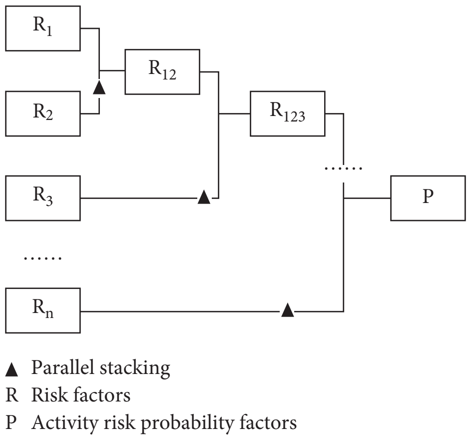

Figure 1: Risk overlay process for the CIM parallel response model.

calculation, until the last factor probability distribution superposition value, that is, the main risk level of the probability distribution.

3.3. Improved AHP-CIM Model Construction. The AHP hierarchical analysis method is systematic, concise and practical, and is able to analyse things qualitatively, but its subjectivity affects the accuracy of decision making problems. By combining AHP-CIM, the qualitative indicators in the CIM model are quantified by the AHP analysis method, which overcomes the problem of the CIM model not being able to deal with qualitative indicators well when applied alone, while compensating for the shortcomings of the AHP model being influenced by subjective factors and realising the combination of qualitative and quantitative.

The specific procedure for evaluating the O&M risk of the integrated corridor using the improved AHP-CIM model is shown in Figure 2 below:

4. Case Study

In this paper, the Beijing Tongzhou Canal Core Area North Ring Ring Tunnel Integrated Corridor is chosen as an example to analyse and validate the constructed model.

The Beijing Tongzhou Canal Core Area Beiruan Tunnel Integrated Corridor is located underneath the Tongzhou Canal Beiruan Traffic Ring Tunnel and is the first underground three-level ring corridor in Beijing that combines urban road traffic and municipal functions. The Beiluan Ring Tunnel is buried deep beneath Beiguan North Street, Xinhua East Road, Yongshun South Street and Beiguan Middle Road in Tongzhou District. The main tunnel is 1.5 km long, with a total structural width of 16.55 m and a height of 12.9 m, containing a carriageway layer, an equipment mezzanine layer and a comprehensive pipe corridor layer. The integrated pipe corridor is a double-layered structure, coconstructed with the circular tunnel. The section of the pipe corridor is arranged in three compartments, electric, water letter and thermal, with a total length of approximately 2.3 km.

4.1. Building an Integrated Corridor Operation and Maintenance Risk Evaluation Index System. As there are relatively few studies on the risks in the operation and maintenance of integrated pipeline corridors, in order to obtain a more comprehensive picture of the risk factors in the process of operation and maintenance of integrated pipeline corridors, we used the literature analysis method to read and combine the existing literature and information data in the literature review section to summarize and identify the risk factors in the process of operation and maintenance of integrated pipeline corridors.

Initially, six risk sources were identified: management factors, corridor body, corridor pipelines, infrastructure, internal and external environment and information technology, with a focus on the causes of accidents that have occurred in natural gas pipelines, water supply and drainage pipelines, electricity pipelines, oil pipelines and corridor bodies. The preliminary list of risks is shown in Table 3, based on a review of such literature and the relevant standards and regulations in each region of China.

Based on the preliminary list of risk factors for further generalization, a comprehensive evaluation index system for the operation and maintenance risks of urban integrated pipeline corridors is established in accordance with the basic principles of the hierarchical analysis method, and the system is divided into three layers according to the model construction principles of the AHP hierarchical analysis method, namely the target layer, the criterion layer and the indicator layer, as shown in Figure 3.

4.2. Determining the Weighting of Risk Factors. Combined with the actual situation of the Beijing Tongzhou Canal Core Area North Ring Tunnel, Figure 3 above was used as the risk factor hierarchy model for the comprehensive evaluation system of the operation and maintenance risk of the integrated pipeline corridor, and in accordance with the “five

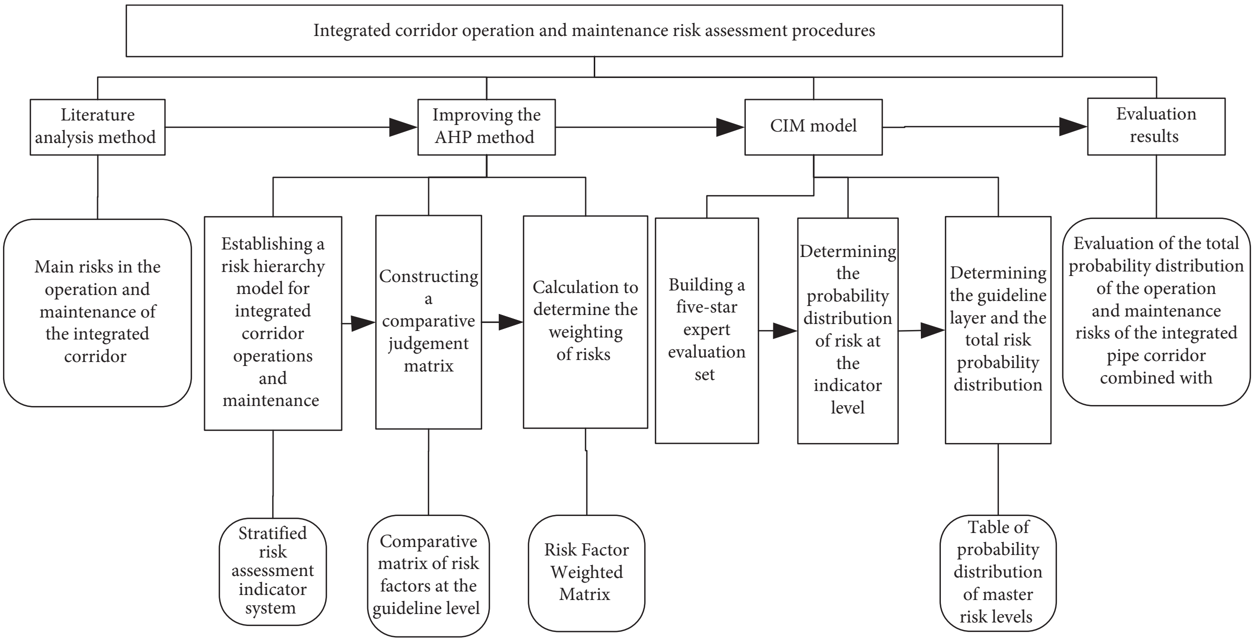

Figure 2: AHP-CIM model evaluation procedure.

Table 3: Literature collection on the main risk factors of the integrated corridor O&M management process.

Serial number	Risk category	Literature sources
1	Unclear management responsibilities and poor safety awareness	Literature [10]
2	The many management units make coordination difficult	Literature [11, 12]
3	File management in disarray	Literature [12]
4	Inadequate and unregulated management standards	Literature [13, 14]
5	Improper handling by personnel	Literature [14]
6	Invasion by persons, theft	Literature [14]
7	Inadequate routine maintenance	Literature [32]
8	Poor O&M equipment and facilities	Literature [32]
9	Technical immaturity	Literature [33]
10	External forces, third party construction damage	Literature [34]
11	Corroded pipes, substandard pipe welding	Literature [35]
12	Leaking pipes	Literature [34, 35]
13	Quality of products and installations such as valves and fittings	Literature [36]
14	Uneven settlement of pipe corridor, structural stability	Literature [37]
15	Interaction between pipelines and dangerous pipeline build-up	Literature [37]
16	Fires, explosions, etc. caused by oil, gas, etc.	Literature [38]
17	Natural disasters such as earthquakes, floods and mudslides	Literature [39]
18	Urban construction, road excavation	Literature [40, 41]
19	Air humidity, oxygen and toxic gas levels inside the corridor	Literature [38, 41]
20	Waterproofing of pipe galleries, density of drainage outlets	Literature [42]
21	Inadequate ventilation, lighting and firefighting facilities	Literature [43]
22	Dynamic update of underground pipeline information is not timely	Literature [44, 45]
23	No linkage of information above and below ground	Literature [45]
24	Insufficient intelligent control	Literature [45]
25	Poor communication	Literature [45]

scale method" described in Table 2 above, the experts of the integrated pipeline corridor were asked to compare the degree of influence of each risk factor on the project at the criterion level to obtain the relative importance between them and give the corresponding scale values, so as to construct a two-by-two comparison matrix as shown in Table 4.

A two-by-two comparison matrix of the main risk factors for this integrated corridor is obtained from Table 3 and is

$$\begin{bmatrix} 1 & 2 & 2 & 4 & 2 \\ 0.5 & 1 & 0.5 & 2 & 0.5 \\ 0.5 & 2 & 1 & 2 & 0.5 \\ 0.25 & 0.5 & 0.5 & 1 & 0.5 \\ 0.5 & 2 & 2 & 2 & 1 \end{bmatrix}. \tag{6}$$

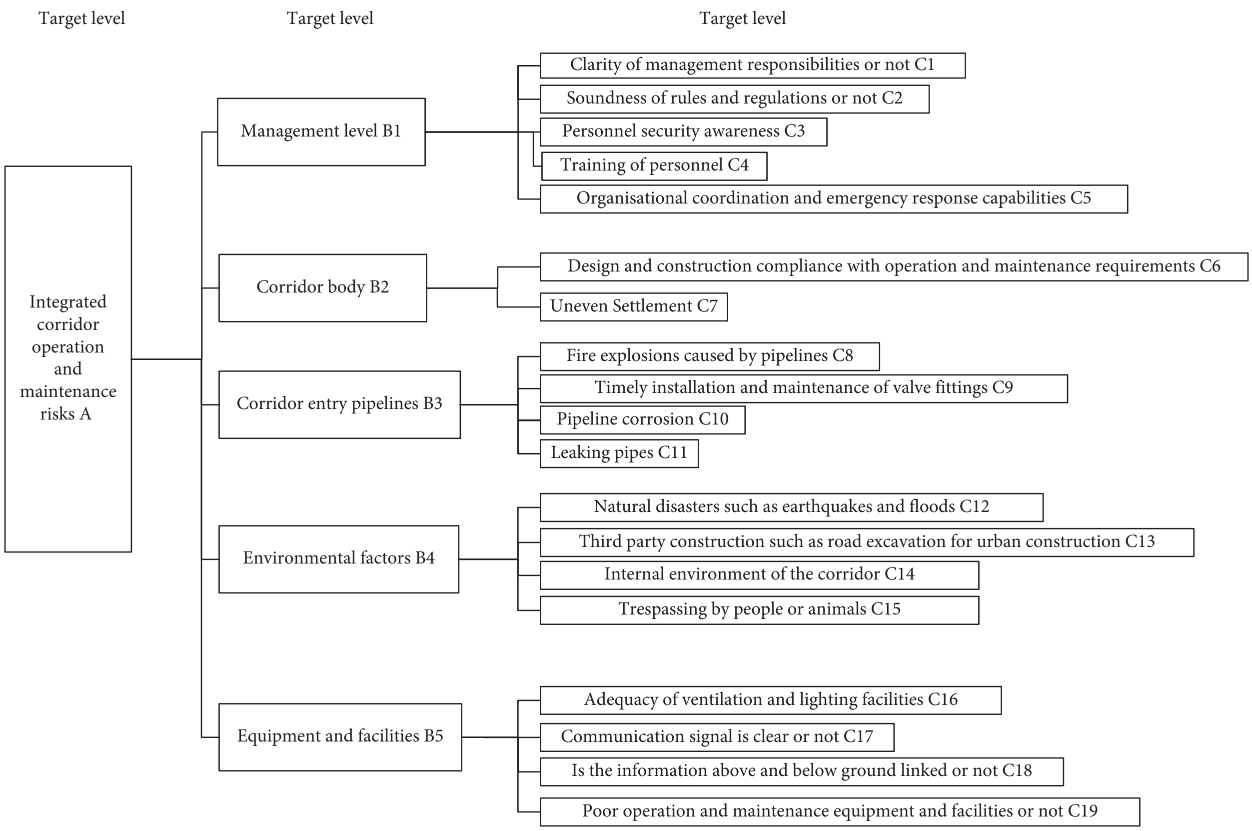

Figure 3: Integrated corridor operation and maintenance risk evaluation index system.

Table 4: Comparison matrix of risk factors for criterion level B.

A	B_1	B_2	B_3	B_4	B_5
B_1	1	2	2	4	2
B_2	1/2	1	1/2	2	1/2
B_3	1/2	2	1	2	1/2
B_4	1/4	1/2	1/2	1	1/2
B_5	1/2	2	2	2	1

Normalizing (6) gives the standard two-by-two comparison matrix:

$$\begin{bmatrix} 0.3636 & 0.2667 & 0.3333 & 0.3636 & 0.4444 \\ 0.1818 & 0.1333 & 0.0833 & 0.1818 & 0.1111 \\ 0.1818 & 0.2667 & 0.1667 & 0.1818 & 0.1111 \\ 0.0909 & 0.0667 & 0.0833 & 0.0909 & 0.1111 \\ 0.1818 & 0.2667 & 0.3333 & 0.1818 & 0.2222 \end{bmatrix}. \quad (7)$$

A modified five-scalar method was used, eliminating the need for consistency testing. The weights of the main risk factors at the criterion level are obtained according to (7) combined with the algorithm of (2) in MATLAB:

$$\begin{aligned} W &= \begin{pmatrix} w_1 & w_2 & w_3 & w_4 & w_5 \end{pmatrix} \\ &= \begin{pmatrix} 0.3543 & 0.1383 & 0.1816 & 0.0886 & 0.2372 \end{pmatrix}. \end{aligned} \quad (8)$$

4.3. Calculating the CIM Model Probability Distribution

4.3.1. Build an Expert Evaluation Set and Determine the Risk Probability Distribution for Indicator Layer C. Based on the hierarchical structure model given in Figure 1, the subrisk factors (i.e., the indicator layer) of each main risk are rated by 10 experts in five aspects: management level, corridor body, entry pipeline, environmental factors and equipment and facilities, and the evaluation results are in a five-level manner, namely high risk, relatively high risk, moderate risk, relatively low risk and low risk. Let the evaluation set be V, then it is expressed as

$$\begin{aligned} V &= \begin{pmatrix} V_1 & V_2 & V_3 & V_4 & V_5 \end{pmatrix} \\ &= ((large\ large\ moderate\ small\ small). \end{aligned} \quad (9)$$

We set the evaluation level given by an expert to the ith risk factor as *j*, the number of experts who give evaluation level *j* to risk factor *i* by N_j, and *N* is the total number of experts, then *Pij* denotes the probability of the risk level of that risk factor, which is calculated by

$$P_{ij} = \frac{N_j}{N}. \quad (10)$$

Accordingly, the rank probabilities for all subrisks of the indicator layer were obtained as shown in Table 5.

Table 5: Risk rating probability table for the operation and maintenance of the northern ring tunnel integrated corridor in the Tongzhou canal core area.

	Risk indicators	Risk level probability				
		Small	Smaller	Moderate	Larger	Large
Management levelB_1	Clarity of management responsibilitiesC_1	0.0	0.0	0.3	0.2	0.5
	Soundness of rules and regulationsC_2	0.0	0.0	0.2	0.5	0.3
	Personnel security awarenessC_3	0.0	0.0	0.2	0.4	0.4
	Training of personnelC_4	0.1	0.1	0.2	0.3	0.3
	Organizational coordination and emergency response capabilitiesC_5	0.0	0.0	0.3	0.3	0.4
Corridor bodyB_2	Compliance of design and construction with O&M requirementsC_6	0.0	0.1	0.1	0.3	0.5
	Uneven SettlementC_7	0.2	0.0	0.5	0.2	0.1
Corridor entry pipelinesB_3	Explosive fires caused by pipelinesC_8	0.3	0.1	0.3	0.2	0.1
	Timely installation and maintenance of valve fittingsC_9	0.1	0.0	0.1	0.2	0.6
	Pipeline corrosionC_{10}	0.1	0.1	0.4	0.2	0.2
	Leaking pipesC_{11}	0.2	0.1	0.5	0.1	0.1
Environmental factorsB_4	Natural disasters such as earthquakes, floods and mudslidesC_{12}	0.5	0.1	0.3	0.1	0.0
	Third party construction such as road excavation for urban constructionC_{13}	0.4	0.2	0.4	0.0	0.0
	Internal environment of the corridorC_{14}	0.0	0.1	0.6	0.2	0.1
	People, animals trespassingC_{15}	0.5	0.1	0.3	0.1	0.0
Equipment and facilitiesB_5	Adequacy of ventilation, lighting and fire-fighting facilitiesC_{16}	0.1	0.0	0.2	0.4	0.3
	Is the communication signal clear?C_{17}	0.1	0.0	0.5	0.2	0.2
	Is the information above and below ground linkedC_{18}	0.1	0.0	0.6	0.1	0.2
	Is the equipment and facilities poorC_{19}	0.0	0.1	0.4	0.3	0.2

4.3.2. Parallel Stacking Calculates the Probability Distribution of the Principal Risk Level of the Criterion Layer B. Using the parallel response model of CIM, the probability distribution of the main risk of the guideline layer is calculated for the probability of the subrisk levels of indicator layer C in the table above. The following is an example of the algorithmic process for the probability distribution of the occurrence of each of the risk levels for criterion layer B3 into the corridor pipeline risk with a moderate number of subrisks.

(1) 1st overlay: the B_3 subrisk C_8 and C_9 risk level probabilities of the primary risk are overlaid according to (5).

Lower risk level V1 probability stack: $0.3 \times 0.1 = 0.03$

Lower risk level V2 probability stack: $0.1 \times (0.1 + 0) + 0 \times 0.3 = 0.01$

Medium risk level V3 probability stack: $0.3 \times (0.1 + 0 + 0.1) + 0.1 \times (0.3 + 0.1) = 0.1$

Higher risk level V4 probability stack: $0.2 \times (0.1 + 0 + 0.1 + 0.2) + 0.2 \times (0.3 + 0.1 + 0.3) = 0.22$

High risk level V5 probability stack: $0.1 + 0.6 \times (0.3 + 0.1 + 0.3 + 0.2) = 0.64$

The results of the 1st overlay, C89, were concatenated with the subrisk C10 to obtain Table 6, ready for the 2nd overlay.

(2) 2nd overlay: calculated by overlaying the C_{89} and C_{10} risk class probabilities based on (5).

Lower risk level V1 probability overlay: $0.03 \times 0.1 = 0.003$

Lower risk level V2 probability overlay: $0.01 \times (0.1 + 0.1) + 0.1 \times 0.03 = 0.005$

medium risk level V3 probability stack: $0.1 \times (0.1 + 0.1 + 0.4) + 0.4 \times (0.03 + 0.01) = 0.076$

Higher risk level V4 probability overlay: $0.22 \times (0.1 + 0.1 + 0.4 + 0.2) + 0.2 \times (0.03 + 0.01 + 0.1) = 0.204$

High risk level V5 probability overlay: $0.64 + 0.2 \times (0.03 + 0.01 + 0.1 + 0.22) = 0.712$

The results of the 2nd overlay, C_{8910}, were concatenated with the subrisk C_{11} to obtain Table 7 below, ready for the 3rd overlay.

(3) 3rd overlay: calculated by overlaying the C_{8910} and C_{11} risk class probabilities based on (5).

Lower risk level V1 probability overlay: $0.003 \times 0.2 = 0.0006$

Lower risk level V2 probability overlay: $0.005 \times (0.2 + 0.1) + 0.1 \times 0.003 = 0.0018$

Medium risk level V3 probability stack: $0.076 \times (0.2 + 0.1 + 0.5) + 0.5 \times (0.003 + 0.005) = 0.0648$

Higher risk level V4 probability overlay: $0.204 \times (0.2 + 0.1 + 0.5 + 0.1) + 0.1 \times (0.003 + 0.005 + 0.076) = 0.192$

High risk level V5 probability overlay: $0.712 + 0.1 \times ((0.003 + 0.005 + 0.076 + 0.204) = 0.7408$

The probability distribution of the occurrence of each risk level of the main risk B_3 at the guideline level can be obtained by concatenating the results of the 3rd overlay calculation, as shown in Table 8.

Similarly, the risk level probability distributions for B_1, B_2, B_4 and B_5 are calculated by overlaying (5) in MATLAB to

Table 6: Probability distribution of the 1st superimposed parallel risk level.

Risk indicators		Overall rating				
		Small	Smaller	Moderate	Larger	Large
B_3	C_{89}	0.03	0.01	0.1	0.22	0.64
	C_{10}	0.1	0.1	0.4	0.2	0.2
	C_{11}	0.2	0.1	0.5	0.1	0.1

Table 7: Probability distribution of the 2nd superimposed parallel risk level.

Risk indicators		Overall rating				
		Small	Smaller	Moderate	Larger	Large
B_3	2nd superimposed valueC_{8910}	0.003	0.005	0.076	0.204	0.712
	C_{11}	0.2	0.1	0.5	0.1	0.1

Table 8: Probability distribution of risk level B3 for the main risk at the guideline level.

Primary risk	Overall rating				
	Small	Smaller	Moderate	Larger	Large
B_3	0.0006	0.0018	0.0648	0.192	0.7408

Table 9: Probability distribution of risk levels for master risk at guideline level.

Code level B risk factors	Comprehensive risk assessment rating				
	Small	Smaller	Moderate	Larger	Large
B_1	0.0000	0.0000	0.0014	0.0868	0.9118
B_2	0.0000	0.0200	0.1200	0.3100	0.5500
B_3	0.0006	0.0018	0.0648	0.1920	0.7408
B_4	0.0000	0.0216	0.5454	0.3330	0.1000
B_5	0.0001	0.0000	0.0629	0.2954	0.6416

obtain Table.9 below.9 From this table, the matrix B of the main risk level probability distribution for the guideline layer is constructed and is.

$$B = \begin{bmatrix} 0.0000 & 0.0000 & 0.0014 & 0.0868 & 0.9118 \\ 0.0000 & 0.0200 & 0.1200 & 0.3100 & 0.5500 \\ 0.0006 & 0.0018 & 0.0648 & 0.1920 & 0.7408 \\ 0.0000 & 0.0216 & 0.5454 & 0.3330 & 0.1000 \\ 0.0001 & 0.0000 & 0.0629 & 0.2954 & 0.6416 \end{bmatrix}. \tag{11}$$

Multiply this risk probability distribution matrix with the weight matrix to calculate the risk assessment set V for this integrated corridor O&M risk probability distribution.

$$V = B^T \times W^T = \begin{bmatrix} 0.0000 & 0.0000 & 0.0006 & 0.0000 & 0.0001 \\ 0.0000 & 0.0200 & 0.0018 & 0.0216 & 0.0000 \\ 0.0014 & 0.1200 & 0.0648 & 0.5454 & 0.0629 \\ 0.0868 & 0.3100 & 0.1920 & 0.3330 & 0.2954 \\ 0.9118 & 0.5500 & 0.7408 & 0.1000 & 0.6416 \end{bmatrix} \times \begin{bmatrix} 0.3543 \\ 0.1383 \\ 0.1816 \\ 0.0886 \\ 0.2372 \end{bmatrix},$$

$$V = \left(0.0001 \;\; 0.0050 \;\; 0.0921 \;\; 0.2081 \;\; 0.\,6947 \right). \tag{12}$$

From the results of this evaluation set, it can be seen that the ranking probability of the occurrence of risk in this urban integrated pipeline corridor is in the following order from high risk > higher risk > medium risk > lower risk > low risk, and the probability of occurrence of each risk level is 69.47%, 20.81%, 9.21%, 0.5% and 0.01% respectively, and the total risk level is mainly concentrated in the medium and high risk level.

Focusing on the main risk factors at the indicator level, it can be seen that the city's integrated pipeline corridor: management factors, corridor body factors, into the corridor pipeline factors, equipment and facilities factors risk level is high probability; corridor environmental factors risk level is moderate probability; the overall risk of corridor operation and maintenance is high.

5. Conclusions and Outlooks

In this paper, the AHP method is improved from the perspective of scalar design, and the CIM model is introduced to combine the advantages of both, and an improved AHP-CIM risk evaluation model is constructed to realize a qualitative and quantitative combined risk evaluation method for the operation and maintenance of the integrated pipeline corridor.

Based on the literature, a comprehensive analysis of the risk factors of the integrated pipeline corridor was carried out, and a hierarchical model consisting of 5 secondary and 19 tertiary indicators was established. The calculation results show that the probability of O&M risks in this integrated pipeline corridor is high that probability of 69.47%, and the focus is on four aspects: management level, corridor body, pipelines into the corridor, equipment and facilities.

In response to the findings of the study, several outlooks are given for the prevention and control of the O&M risks of the integrated pipe corridor.

(1) The government as well as the corridor O&M contractor should speed up the improvement of the regulations on the O&M of the integrated corridor, clarify the O&M content and technical requirements, unify and standardize the preparation and presentation of files and information, and speed up the standardization of O&M management.

(2) Clarify the allocation of responsibilities for O&M activities, strengthen training, improve the professional quality and safety awareness of management personnel, and try to cooperate with professional management and maintenance units or with the government to form more professional and reliable management and maintenance teams.

(3) Pay attention to and speed up the handling of emergency incidents in the corridor itself and in the part of the pipeline entering the corridor, further improve the regulations for handling emergency incidents, and reasonably allocate the composition of the personnel of the main construction body, the personnel of the pipeline entering the corridor unit and the operation and maintenance personnel in the management team.

(4) Improve the internal equipment and facilities of the integrated pipeline corridor, monitor and maintain valves, fittings and other products in a timely manner, regularly overhaul and update key infrastructure such as lighting, ventilation and fire-fighting, keep communication signals open, and pay attention to the density of water-proofing and drainage outlets in the corridor.

(5) Accelerate the construction and improvement of the information platform of the integrated pipe corridor to achieve intelligent operation and maintenance management, so as to link up information on the underground, achieve visualization of the urban underground integrated pipe corridor, and achieve intelligent control and emergency decision-making.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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