Fuzzy Evaluation of Construction Risk of Urban Integrated Pipe Gallery

Based on Shapley Empowerment

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**Keywords:** urban integrated pipe gallery; Shapley value; construction risk; fuzzy evaluation;

**Abstract.** Based on the risk identification of urban integrated pipe gallery construction, a comprehensive risk assessment index system for manholes, including technology, management, and environment is established. The basic principle of Shapley value is used to calculate the cost based on the cost. The weights of each index were combined with the fuzzy theory to construct a risk assessment model for urban integrated pipe gallery construction. Finally, the evaluation and analysis of a real project construction risk in Qingdao was carried out, and the key factors affecting the construction risk of the integrated pipe gallery were determined. The improvement suggestions were put forward and the feasibility of the model was verified.

**Introduction**

The urban integrated pipe gallery integrates various underground pipelines such as electric power, energy, communication and gas, which are independently buried in the ground, into a common underground pipe gallery for unified management and maintenance, which is conducive to solving the unreasonable and improved layout of urban underground space. It is beneficial to solve the unreasonable layout of urban underground space, improve the utilization of urban underground space, and reduce the occurrence of pipeline accidents. At present, China's comprehensive pipe corridor project is large in scale, high in starting point and fast in speed. In the process of construction, The urban integrated pipe gallery project will often face a series of construction safety problems, and the integrated pipe corridor project is mostly PPP mode, which requires high construction schedule and quality. The construction unit has strong construction risk management capability, so it has a high research significance for the risk analysis of urban integrated pipe corridor.

At present, many domestic scholars have made in-depth theoretical research on urban integrated pipe corridor construction projects. Sun Yongchao\textsuperscript{1} and Cao Jiantao\textsuperscript{2} have studied the application of BIM technology in the life cycle of collaborative design and construction management; Zhang Ailin\textsuperscript{3} used the improved AHP-entropy weight method to carry out fuzzy evaluation research on the construction progress of integrated pipe gallery, and the key factors affecting the construction progress are obtained. Sun Hao\textsuperscript{4} studied the whole life cycle risk assessment system of urban underground pipe gallery and analyzed each The risk of stage construction, Wei Haimin\textsuperscript{5} used the HHM method to analyze the risk factors of integrated pipe gallery construction; Wang Shuhong\textsuperscript{6} analyzed the risk of integrated pipe gallery from the perspective of coupling disaster, and proposed the more types of disasters, the coupling degree The lower the probability of a disaster, the higher the risk of any single disaster. Han Lihong\textsuperscript{7}
used C-OWA operator and fuzzy clustering to study the investment risk evaluation of urban integrated pipe corridor of PPP project. Based on the above research, it is known that the construction risk analysis and identification of urban integrated pipe corridor projects have achieved many achievements and formed a relatively mature system, and the focus of research is mostly on the risk and operation analysis of new technologies and methods such as PPP projects or BIM technologies. The theoretical research on the construction risk of urban integrated pipe gallery still uses the theory and knowledge of underground engineering construction, and the evaluation and research on the construction risk of urban integrated pipe gallery still needs further research. Constructing the index system through scientific mathematical model and carrying out construction risk assessment is an urgent need to effectively improve the risk control of urban integrated pipe gallery construction.

This paper takes the urban integrated pipe gallery project as the object, combines the characteristics of the integrated pipe gallery construction, summarizes the risk factors of the urban integrated pipe gallery construction, and constructs the construction risk evaluation index system. Based on the Shapley value, the risk factors of urban integrated pipe gallery construction are selected. By introducing the fuzzy comprehensive evaluation method, the risk assessment model of urban integrated pipe gallery construction is established. Through the model, the comprehensive pipe corridor project of a city is analyzed, and the management countermeasures are given according to the evaluation results to improve the safety management level of the urban integrated pipe gallery construction.

Overview of Shapley Value Evaluation Methods

Basic overview of Shapley values. In order to solve the problem of profit or risk allocation under multi-person cooperation, LS Shapley proposed the concept of cooperative countermeasures that satisfies validity axioms, symmetry axioms, and addifiable axioms in 1953, and proved its uniqueness. The solution is called the Shapley value. The basic expression is that in a coalition with economic interests in which n members participate, each member will receive a certain profit or risk. The total profit of the alliance of n members is greater than the sum of the profits of the members engaged in activities alone. It is not a simple addition of the risks of each member, but is influenced by the mutual relationship of the members. The Shapley value is a method to solve the problem of cooperative alliance risk risk distribution by the relative importance of each member to the whole. It is essentially an empowerment method.

Adaptability of Shapley value. The core of the risk assessment of urban integrated pipe gallery construction is to empower and evaluate the index system. Due to the wide range of construction areas, mutual interference of external environment, wide and complicated construction technology, tight construction period, poor construction conditions and temporary protection difficulties, etc. The internal system complex and the external system are changeable. Therefore, the construction safety accident is not caused by a single risk factor, but is caused by the coupling of various factors. It is necessary to consider the combination of various factors and various risks. The effect of the combination of factors on the target is not equal to the sum of the effects of each factor alone. Therefore, the weight of the combination is weighted using the Shapley value, and the risk impact of the more objective indicators on the superior and the overall target is calculated according to the combined weight. Therefore, a more objective evaluation of the risk of integrated pipe gallery construction.

Urban Comprehensive Pipe Gallery Construction Risk Evaluation Model

Construction of risk index system for urban integrated pipe corridor construction. The construction of the indicator system needs to fully consider the internal elements of the objective system of the integrated pipe corridor, and ensure that the indicators can reflect the actual situation of the system from different aspects, and reflect the intention of the evaluation activities
to a large extent. This paper constructs the construction risk index system of urban integrated pipe corridor project from four aspects: personnel factor, technical factor, management factor and environmental factor. Figure 1:

Fig.1. Risk assessment index system for urban integrated pipe gallery construction.

**Combination weight calculation based on Shapley value.** The construction of urban integrated pipe gallery is a complex system. Any change of any factor in the system will cause other factors to change. Therefore, it is necessary to consider the combined weight between construction risk factors. This requires the introduction of Shapley value to calculate the non-additive weight of each indicator. According to the combined weights, it is more objective to obtain the degree of impact of each indicator on the higher-level indicators and the overall target, that is, the comprehensive weight.

Specifically, it is realized by the following model: let the set \( N = \{1, 2, 3, \ldots, n\} \), any subset of which is \( S \) (any combination of \( n \) factors), \([N, V]\) is a combination of risk factors, \( V(S) \) is the corresponding real value function, that is, the risk coefficient value of the corresponding factor combination, \( V(\phi) = 0 \). Then based on the non-additive measure of the risk factor weight value, that is, the comprehensive weight calculated based on the risk factor combination weight - Shapley value:

\[
\psi(N,V) = \sum_{e \in E} w(e) [V(\{\phi\}) - V(\{e\})]
\]

(1)

\[
\psi(e) = \frac{1}{n!} [V(\{\phi\}) - V(\{e\})]
\]

(2)
Where \( W(S) \) is the weighting factor, i.e., the probability of the corresponding combination of risk factors; \( s \) is the number of elements in subset \( S \), i.e., the number of risk factors in the combination; \( S/i \) is the combination after \( i \) is removed.

**Fuzzy comprehensive evaluation.** Based on the comprehensive construction of urban comprehensive pipe gallery construction risk index system and the use of Shapley value to give comprehensive weight, the fuzzy theory is introduced to construct a fuzzy evaluation model for urban integrated pipe gallery construction based on Shapley value composite weight. Specifically implemented by the following model:

1. Establishing a safety management evaluation comment set: Define a comprehensive evaluation comment set \( U=\{U_1, U_2, U_3, U_4\} \), indicating that the evaluation result is \{excellent, good, pass, and poor\} 4 levels as the evaluation criteria.
2. Constructing a fuzzy evaluation matrix: Inviting experts and engineering-related staff to obtain \( B_1, B_2, B_3, B_4 \), fuzzy evaluation matrices through construction site survey and scoring.
3. According to the fuzzy theory, the comprehensive weight vector and the fuzzy evaluation matrix are used to perform the fuzzy matrix synthesis operation \((\land, \lor)\), and the comprehensive evaluation is obtained.

**Case Analysis**

An underground comprehensive pipe gallery project of Qingdao Ocean High-tech Zone is located at Binhai Avenue to FengHuangShan Road. The estimated total investment of the project is about 176 million, and the total length of the pipe gallery is about 1.63km. It is a double-cabin pipe gallery. The pipe gallery contains five types of pipelines, such as water supply, electric power, heat, communication, and reclaimed water. The communication pipeline includes four types of pipelines, including radio and television, mobile, telecommunications, and Unicom. The auxiliary systems mainly include ventilation systems, monitoring and alarm systems, fire protection systems, and logos. Systems, power and lighting systems, drainage systems, etc.

**Determine weight based on Shapley.** According to the accident causal statistics, expert research and construction site questionnaire survey, the combined safety management values of various factors are obtained, as shown in Table 1.

<table>
<thead>
<tr>
<th>((N, V))</th>
<th>(V(s))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V1)</td>
<td>0.419</td>
</tr>
<tr>
<td>(V2)</td>
<td>0.319</td>
</tr>
<tr>
<td>(V3)</td>
<td>0.235</td>
</tr>
<tr>
<td>(V(1,2))</td>
<td>0.617</td>
</tr>
<tr>
<td>(V(1,3))</td>
<td>0.576</td>
</tr>
<tr>
<td>(V(2,3))</td>
<td>0.553</td>
</tr>
<tr>
<td>(V(1,2,3))</td>
<td>1</td>
</tr>
</tbody>
</table>

Take the calculation of the \(sh\) indicator as an example. The specific calculation process is as follows:

\[
\phi_{sh}(N,V) = \sum_{i=1}^{n} \frac{\sum_{j \in I \setminus \{i\}} |I|! |I_2|!}{|I|! |I_2|!} [v(2) - v(1)]
\]

\[
\phi_{sh}(N,V) = \frac{1}{3!} [v(V1) - v(\{V1\})] \cdot \frac{1}{3!} [v(V2) - v(\{V2\})] \cdot \frac{1}{3!} [v(V3) - v(\{V3\})] = 0.3952
\]
In the same way, the weights of the other 15 risk factors are calculated in turn. Then calculate the combined weights of $B_1$, $B_2$, $B_3$, and $B_4$ for $A$. The security management values of each secondary indicator are shown in Table 2.

**Table 2. A subordinates indicators and safety management values**

<table>
<thead>
<tr>
<th></th>
<th>$V(N, V)$</th>
<th>$V(s)$</th>
<th>$V(N, V)$</th>
<th>$V(s)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>v1</td>
<td>0.207</td>
<td>v(2,4)</td>
<td>0.501</td>
<td></td>
</tr>
<tr>
<td>v2</td>
<td>0.195</td>
<td>v(3,4)</td>
<td>0.319</td>
<td></td>
</tr>
<tr>
<td>v3</td>
<td>0.314</td>
<td>v(1,2,3)</td>
<td>0.819</td>
<td></td>
</tr>
<tr>
<td>v4</td>
<td>0.284</td>
<td>v(1,2,4)</td>
<td>0.726</td>
<td></td>
</tr>
<tr>
<td>v(1,2)</td>
<td>0.471</td>
<td>v(1,3,4)</td>
<td>0.718</td>
<td></td>
</tr>
<tr>
<td>v(1,3)</td>
<td>0.436</td>
<td>v(2,3,4)</td>
<td>0.709</td>
<td></td>
</tr>
<tr>
<td>v(1,4)</td>
<td>0.512</td>
<td>v(1,2,3,4)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>v(2,3)</td>
<td>0.451</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Taking the $B_1$ index calculation as an example, the specific calculation process is as follows:

$$s_{B_2(N,V)} = \sum_{s \in N} \left( \sum_{g=1}^{n} \frac{(s-1)!((n-s))!}{n!} \left[ V(3) - V(1) \right] \right) = 0.2193$$

In order to facilitate the calculation, the weights of the indicators in each part of the indicator system are expressed in the form of vectors:

$$\overrightarrow{A} = (0.2193, 0.2238, 0.3251, 0.3541)$$

$$\overrightarrow{B_1} = (0.3952, 0.3337, 0.2717)$$

$$\overrightarrow{B_2} = (0.274, 0.1501, 0.1836, 0.1785, 0.2178)$$

$$\overrightarrow{B_3} = (0.4656, 0.2648, 0.2696)$$

$$\overrightarrow{B_4} = (0.3656, 0.1381, 0.1794, 0.3414)$$

**Fuzzy comprehensive evaluation.** This paper invites experts and engineering related personnel to conduct on-the-spot investigations on the project. According to the evaluation comments, the fuzzy evaluation matrices of $A$, $B_1$, $B_2$, $B_3$, and $B_4$ are as follows:

$$M_1 = \begin{bmatrix} 0.37 & 0.28 & 0.18 & 0.17 \\ 0.36 & 0.28 & 0.21 & 0.15 \\ 0.35 & 0.33 & 0.22 & 0.10 \end{bmatrix}$$

$$M_2 = \begin{bmatrix} 0.38 & 0.23 & 0.19 & 0.20 \\ 0.35 & 0.27 & 0.18 & 0.20 \\ 0.24 & 0.30 & 0.21 & 0.15 \end{bmatrix}$$

$$M_3 = \begin{bmatrix} 0.31 & 0.37 & 0.22 & 0.10 \\ 0.21 & 0.37 & 0.22 & 0.20 \end{bmatrix}$$

$$M_4 = \begin{bmatrix} 0.37 & 0.25 & 0.18 & 0.20 \\ 0.36 & 0.31 & 0.22 & 0.10 \\ 0.36 & 0.28 & 0.21 & 0.15 \end{bmatrix}$$

$$M_5 = \begin{bmatrix} 0.37 & 0.26 & 0.20 & 0.17 \end{bmatrix}$$
According to the fuzzy evaluation matrix and the comprehensive weight, the fuzzy comprehensive evaluation of each secondary index is calculated. The specific calculation is as follows:

\[ B_2 = B \cdot M_2 \]

\[ B_2 = \begin{bmatrix} 0.30 & 0.23 & 0.19 & 0.20 \\\n0.35 & 0.27 & 0.19 & 0.20 \\
0.24 & 0.40 & 0.21 & 0.19 \\
0.31 & 0.37 & 0.22 & 0.18 \\
0.21 & 0.37 & 0.22 & 0.20 \end{bmatrix} \]

\[ B_2 = (0.2741, 0.1501, 0.1836, 0.1785, 0.2178) \]

Normalized processing:

\[ \overline{B}_2 = \begin{bmatrix} 0.2763, 0.3109, 0.2073, 0.2055 \end{bmatrix} \]

According to the principle of maximum membership:

\[ U_2 = \max \{ a \} = \max \{ 0.2763, 0.3109, 0.2073, 0.2055 \} = 0.3109 \]

Similarly, the fuzzy synthesis results for B1, B3, and B4 are as follows:

\[ \overline{B}_1 = (0.2861, 0.2697, 0.2221, 0.2221) \]
\[ \overline{B}_3 = (0.3045, 0.2349, 0.2303, 0.2303) \]
\[ \overline{B}_4 = (0.3643, 0.2834, 0.2125, 0.1398) \]

Safety management level analysis and improvement suggestions. According to the above calculation results, it can be known from the principle of maximum membership degree that the project is excellent in terms of B1 personnel factors, B3 management factors, and B4 environmental factors, while the B2 technical factors are evaluated as good.

According to the evaluation of the mathematical model, the reason for the good B2 is that the weights of C6 and C8 are large and the actual evaluation is low. According to the analysis of the actual situation of the project, the project is located in the hilly area of Ludong. The soil is gneiss and quartzite. The soil is hard and not suitable for construction. The average depth of the pipe gallery is 1.69m; the stable water is 1.04-1.39, m. The average elevation is 1.30m, and the groundwater level is higher than the buried depth of the integrated pipe gallery. Therefore, the stability of the support system and the impermeability of the support system are relatively high. At the same time, the project is integrated into a double cabin pipe gallery, one side is a thermal pipeline and a regenerative water tank cabin, and the other side is a communication, electric power, water supply, and reserved pipeline cabins. The concrete impermeability, compressive strength and strength requirements of the cabin are high. In the absence of sufficient support system as a support, the slow-setting concrete formwork system will lose stable and reliable support points, which will not only seriously affect the quality of concrete pouring, but also cause serious construction safety accidents such as template collapse. Has a higher risk.

According to the analysis results, the improvement suggestions are put forward, that is, by strengthening the strength of the supporting protection system by using steel structure support, the supporting system combined with various supporting structures is used to enhance the impermeability of the supporting structure and avoid the water leakage collapse of the foundation pit, further Strengthen the standardization of scaffolding and formwork installation, ensure the stability of concrete formwork preloading, strictly control the concrete mix ratio and curing time, etc., in order to improve the structural strength of the pipe cabin and ensure the safe construction of the pipe tank during the later pipeline installation. Conditions, which ultimately improve the risk management capabilities of integrated pipe gallery construction.

Final evaluation to determine the level of safety management evaluation. Based on the improvement suggestions given above, after strengthening and adjusting the engineering safety
management work, based on the improvement and adjustment, the final evaluation of A:

\[ A = \hat{A}N_0 \]

\[ = (0.2193, 0.2239, 0.3251, 0.3541) \]

\[ = (0.35, 0.24, 0.239, 0.2193) \]

Normalized processing:

\[ \hat{A} = (0.3388, 0.2323, 0.2166, 0.2123) \]

According to the principle of maximum membership:

\[ U = \max (a) = \max \{0.3388, 0.2323, 0.2166, 0.2123\} = 0.3388 \]

It can be seen from the final evaluation results that although the project has high risk in technical factors, the construction unit has strong risk management capability, so the overall evaluation of the project is excellent.

**Conclusion**

(1) With the gradual promotion of the integrated pipe corridor project, it faces more and more construction risks. This paper comprehensively constructs a comprehensive pipe gallery construction index system including people, technology, management and environment to make the index system. The construction is more scientific and it is also easy to quantify the indicators.

(2) Considering risk management as an interrelated overall system, through the Shapley value non-measurable weighting method, it reflects the interaction and interaction between various construction risks, which is more in line with the actual situation.

(3) Through the case study, the fuzzy comprehensive evaluation of a comprehensive pipe corridor project in Qingdao was obtained, and the key influencing factors were determined. The reasons were analyzed in combination with the project, and the improvement suggestions were put forward to improve the risk management level of the enterprise.

**References**


