



# Risk Assessment Study of Underpassing Railway Turnout Area Using UBIT Method

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**Abstract.** With the rapid development of urban rail transit, the issue of level crossings between train access lines and ground roads has become increasingly prominent, leading to frequent occurrences of "dead-end roads" that severely impact citizens' travel experiences and urban traffic efficiency. To address this problem, this paper takes an underpass project in a railway switch area as an example, employing the Unified Bored Immersed Tube (UBIT) method for underpass construction and using the Fuzzy Comprehensive Evaluation (FCE) method to assess risks throughout the project. By establishing a hierarchical structure of risk factors and a quantitative index system, this paper identifies four major categories of risk factors: construction conditions, design plans, construction plans, and operational management. The Analytic Hierarchy Process (AHP) is used to determine the weights of each factor. The research results indicate that structural design and construction process control factors have the greatest impact on risk control, with a comprehensive risk assessment value of 4.26, classified as medium risk, necessitating corresponding control measures and emergency plans. This study provides a systematic risk assessment method and reference for similar projects.

**Keywords:** Unified Bored Immersed Tube, Rail Transit, risk assessment.

## 1 Introduction

The rapid development of urban rail transit has led to the issue of level crossings between train access lines and ground roads, resulting in road dead-ends or detours that severely impact citizens' travel experiences and urban traffic efficiency. As urban development and road network systems improve, these "dead-end roads" have increasingly become "blemishes" on urban quality. The construction of people-oriented cities urgently requires the opening of these "capillaries" to improve regional "microcirculation." The key to opening these "dead-end roads" at train access lines lies in crossing existing operational railway switch areas. Due to the high protection requirements for railway switch areas, there have been few related cases in the past. However, increasingly mature technologies in various professional fields, such as the pipe-roofing method, UBIT (Unified Bored Immersed Tube), and URT, provide possibilities for

opening these roads. However, underpass projects in railway switch areas face unprecedented challenges and risks, including structural risks, track risks, power supply risks, and signal risks. Therefore, it is crucial to comprehensively identify and assess various risk sources and establish a risk assessment system for the entire process of underpass projects in railway switch areas.

Underpass projects are essentially underground geotechnical engineering, and their stability is largely an uncertain issue. In actual projects, many parameters are fuzzy, uncertain, or difficult to quantify, making it challenging to determine their statistical laws and their respective impacts on risk assessment results. The Fuzzy Comprehensive Evaluation (FCE) method, based on fuzzy mathematics theory, uses fuzzy relationship synthesis principles to quantify fuzzy risk factors and make comprehensive evaluations. Applying the FCE method to the risk assessment of underpass projects in railway switch areas can effectively assess the fuzzy risks of project instability, formulate corresponding risk mitigation measures, and ensure construction safety.

In the application of fuzzy mathematics for risk assessment, scholars have achieved a series of research results<sup>[1][2]</sup>. However, research on the risks associated with the underpassing of railway switch areas using the pipe-roofing method is almost non-existent. This paper takes an underpass project in a railway switch area as an example, establishing a hierarchical analysis structure for risk factors and a quantitative index system suitable for the pipe-roofing method in underpassing railway switch areas. It introduces a comprehensive risk assessment framework based on the Fuzzy Comprehensive Evaluation (FCE) method, which is particularly well-suited for handling the fuzziness and uncertainty of underground geotechnical engineering risks. Compared to traditional methods, this approach provides a more systematic and quantitative assessment, offering valuable references for similar projects.

## 2 Project Overview

A certain city branch road is a north-south thoroughfare with good connectivity, but it is blocked by a rail transit parking lot. To improve the regional microcirculation road network structure and enhance community living quality, it is urgent to open this branch road node. Considering that the rail transit parking lot cannot be shut down and the underpass location is at the crossover switch area of the access lines, the recommended method for this underpass project is the UBIT (Unified Bored Immersed Tube) method. The UBIT method is an underground excavation construction technology mainly used for underground projects such as subway stations and tunnels. Its core idea is to use rectangular jacking pipes as the minimum unit of excavation. After the pipe roof is advanced, concrete is filled into the pipe sections, and transverse prestressing is applied to form a transversely load-bearing pipe roof structure.<sup>[3][4][5]</sup> The UBIT construction method has undergone both theoretical and practical research in the context of urban rail transit construction. Compared to traditional box jacking methods and pipe-roofing methods, the UBIT method offers several advantages, including better control of surface settlement, reduced environmental impact, and high efficiency in urban areas with heavy traffic or complex underground pipelines. These characteristics make the UBIT

method particularly suitable for underpass projects in railway switch areas, where high protection requirements and minimizing interference with existing operations are of paramount importance.

### 3 Hierarchical Analysis of System Risks in Underpassing Railway Switch Areas Using the UBIT Method

#### 3.1 Establishing the Hierarchical Structure of Risk Factors

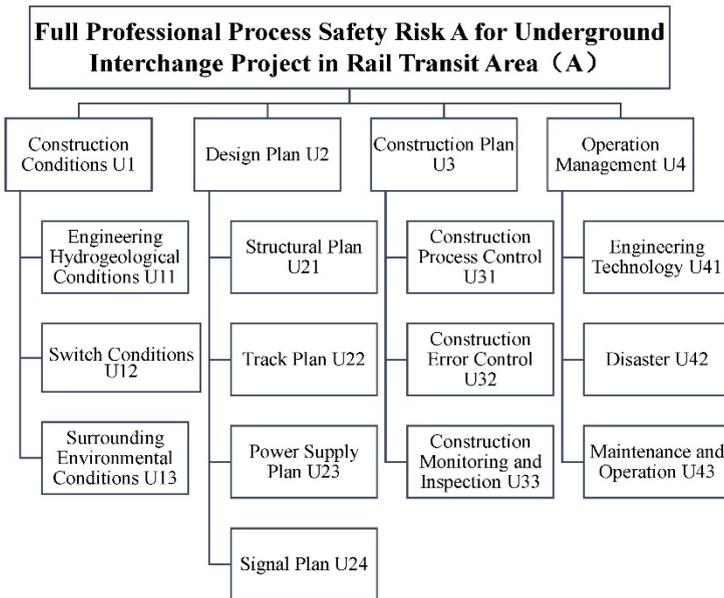


Fig. 1. Risk Factor Hierarchy Diagram.

Underpass projects in railway switch areas are multi-level, multi-criteria complex systems with numerous risk factors of varying degrees of impact. The Analytic Hierarchy Process (AHP) is a method that combines qualitative and quantitative analysis to solve complex multi-objective problems. Based on previous research results, standards, and empirical knowledge, combined with in-depth analysis of the actual project, a hierarchical structure of project risk factors is established. The first layer is the target layer, which is the safety risk of the entire project across all disciplines and processes. The second layer is the indicator layer, which includes the risk factors of project safety. The third layer is the sub-indicator layer, which further subdivides the risk factors in the indicator layer. The fourth layer is the operational layer, which further refines the sub-indicators to guide specific business execution or operations. This paper identifies four main risk factors in the indicator layer:  $U = \{U1, U2, U3, U4\}$ , where U1 is construction condition factors, including 3 sub-factors; U2 is design plan factors, including 4 sub-

factors; U3 is construction plan factors, including 3 sub-factors; and U4 is operational management factors, including 4 sub-factors. Figure 1 shows the hierarchical structure of risk factors for this project.

### 3.2 Weight Assessment of Each Risk Factor

The impact of risk factors in the same layer on the upper-level indicators is inconsistent. To reasonably determine the weight of risk factors, this paper uses the judgment matrix method to calculate the weight vector  $W = \{w_1, w_2, \dots, w_n\}$  of risk factors. The relative importance of factors in the judgment matrix is reflected using a 1-5 scale, and the scale values are determined using the expert survey method. The larger the scale, the more important the former is compared to the latter. The weighting of risk factors in the AHP process was determined using the judgment matrix method, with input from a panel of experts selected based on their extensive experience in rail transit and underground construction projects. To mitigate potential biases, multiple rounds of expert consultation were conducted, and consistency checks were performed to ensure the reliability of the judgment matrices. The selected experts' diverse backgrounds and expertise contributed to a more balanced and accurate assessment of risk factor weights.

First, calculate the weight ratio of the indicator layer to the target layer. As shown in Table 1, establish the evaluation matrix and use the square root method to calculate the weight vector. The calculation steps are as follows:

**Table 1.** Table captions should be placed above the tables.

A	U <sub>1</sub>	U <sub>2</sub>	U <sub>3</sub>	U <sub>4</sub>
U <sub>1</sub>	1.00	0.20	0.20	0.33
U <sub>2</sub>	5.00	1.00	1.00	3.00
U <sub>3</sub>	5.00	1.00	1.00	3.00
U <sub>4</sub>	3.00	0.33	0.33	1.00

- 1) Calculate the product of each row element in the judgment matrix A:

$$M_i = \prod_{j=1}^4 a_{ij} = [0.013, 15.0, 15.0, 0.327] \tag{1}$$

- 2) Calculate the 4th root of  $M_i$ :

$$\bar{W}_i = \sqrt[4]{M_i} = [0.339, 1.968, 1.968, 0.756] \tag{2}$$

- 3) Normalize to obtain the weight vector W:

$$W_i = \frac{\bar{W}_i}{\sum_{i=1}^n \bar{W}_i} = [0.067, 0.391, 0.391, 0.150] \tag{3}$$

4) Meet the consistency test requirements:

$$C.R. = CI/RI = 0.012 / 0.89 = 0.014 < 0.1 \tag{4}$$

Similarly, the weight of the sub-indicator layer to the indicator layer and the weight vector of the sub-indicator layer to the target layer can be calculated.

## 4 Establishing the Quantitative Index System of Risk Factors

### 4.1 Risk Level Division of Influencing Factors

**Table 2.** Risk Factor Level Classification Table for Construction Plan.

Construction Plan U3	Level I	Level II	Level III	Level IV
<b>Construction Process Control U31</b>				
Debris Treatment Between Pipe Sections	Backfill with Concrete After Washing	Grouting After Washing	Grouting Reinforcement	No Treatment
Concrete Density	>0.98	0.95~0.98	0.9~0.95	<0.9
Concrete Strength During Tension	>90%	80%~90%	75%~80%	<75%
Backfill Concrete Grade for Pipe Sections	C40	C35	C30	C25
Soil Reinforcement Strength	≥3.0 MPa	1.5~3.0 MPa	0.8~1.5 MPa	<0.8 MPa
Earth Excavation	Zoned and Layered Excavation	Zoned Symmetrical Excavation	Zoned Excavation	Full-Section Excavation
Structural Backfill	C40	C35	C30	C25
Anti-Corrosion and Anti-Rust	Double-Layer Coating	Single-Layer Coating	Surface Sandblasting Only	No Treatment
<b>Construction Error Control U32</b>				
Verticality of Soil Reinforcement	1/300	1/250	1/200	1/150
Pipe Jacking Accuracy	≤50 mm	100~50 mm	130~100 mm	>130 mm
Prestress Value Deviation	<±1%	±3%~±1%	±5%~±3%	>±5%
<b>Construction Monitoring and Testing U33</b>				
Monitoring Level	Level 1	Level 2	Level 3	No Monitoring
Monitoring System	Informatized Monitoring	Automated Monitoring	Manual Monitoring Raw Material	No Monitoring
Quality Testing	Full-Process Testing	Parallel Testing	Testing	No Testing
Emergency Measures	Combined Measures	Follow-Up Grouting	Passive Control	No Measures

There are many factors affecting the risk of underpass projects in railway switch areas, and there is limited research on risk evaluation indicators. Based on national standards

and industry norms, referring to fuzzy evaluation research results of similar projects, and combining the actual situation of this project, this paper proposes a system risk factor level division system for underpass projects using the UBIT method to cross the crossover switch area of the parking lot access lines. The evaluation index division for the construction plan is shown in Table 2.

## 4.2 Construction of Membership Functions

The risk factor level division table includes quantitative and qualitative indicators. This paper divides qualitative factors into four risk levels: excellent, good, medium, and poor. For quantitative indicators, the membership function of the semi-trapezoidal distribution is used. The critical values are calculated as follows:

1. Calculate the critical values:

$$b_{k,1} = a_{k,1} + (a_{k,2} - a_{k,1}) / 4 = 2.625 \quad (5)$$

$$b_{k,2} = a_{k,2} + (a_{k,3} - a_{k,2}) / 4 = 1.325 \quad (6)$$

2. Construct the triangular distribution membership function expression for soil reinforcement strength as follows, with the function curve shown in Figure 2.

$$v_1(x) = \begin{cases} 1 & x \geq 3.0 \\ \frac{3.375 - x}{0.375} & 2.625 < x < 3.0 \\ 0 & x \leq 2.625 \end{cases} \quad (7)$$

$$v_2(x) = \begin{cases} \frac{3 - x}{0.375} & 2.625 < x < 3.0 \\ \frac{x - 1.325}{1.3} & 1.325 < x \leq 2.625 \\ 0 & x \leq 1.325 ; x \geq 3.0 \end{cases} \quad (8)$$

$$v_3(x) = \begin{cases} \frac{2.625 - x}{1.3} & 1.325 < x < 2.625 \\ \frac{x - 0.8}{0.525} & 0.8 < x \leq 1.325 \\ 0 & x \leq 1.325 ; x \geq 0.8 \end{cases} \quad (9)$$

$$v_4(x) = \begin{cases} 0 & x \leq 1.325 \\ \frac{1.325 - x}{0.525} & 0.8 < x < 1.325 \\ 1 & x \leq 0.8 \end{cases} \quad (10)$$

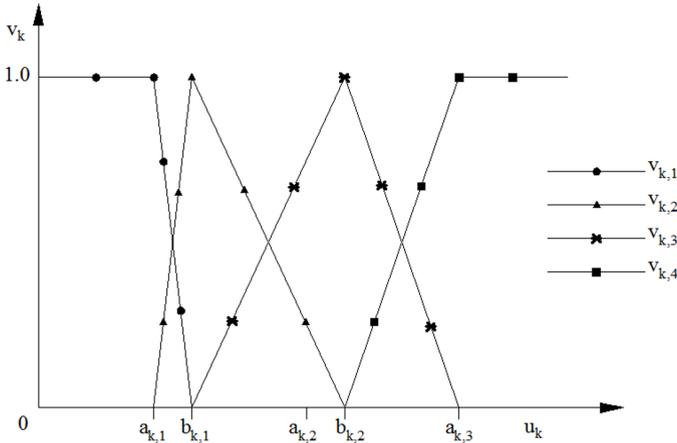


Fig. 2. Membership Function Curve.

## 5 Fuzzy Risk Assessment

### 5.1 Single Factor Evaluation

Single factor evaluation refers to the risk assessment of each risk factor separately. This paper defines the risk evaluation values corresponding to each risk level to reflect the evaluator's possible risk assessment results for each risk factor, as shown in Table 3.

Table 3. Rating Values for Each Risk Level.

Risk Level	I	II	III	IV
Rating Value	1.0	3.0	5.0	7.0

### 5.2 Fuzzy Comprehensive Evaluation

The comprehensive evaluation expression is  $F = W \circ R$ . According to the characteristics of this project, it is necessary to integrate all factors and reflect the impact of each factor's weight on the evaluation value. Therefore, the fuzzy operator "o" uses the weighted average type  $M(\bullet, \oplus)$  operator, with the calculation formula:

$$f_k = \sum_{j=1}^m w_j r_{jk}, k = (1, 2, \dots, m) \quad (11)$$

This operator can clearly reflect the role of weights and fully utilize the information in the evaluation value vector  $R$ , with strong comprehensive ability. Therefore, the comprehensive evaluation values of each risk factor in the sub-indicator layer can be calculated separately. Finally, based on the sub-indicator layer calculation results, the weighted average is used to obtain the comprehensive risk assessment value of the underpass project in the railway switch area.

### 5.3 Comprehensive Evaluation Conclusion

This paper divides the risk level of the underpass project in the railway switch area into four levels: safe, low risk, medium risk, and high risk. The risk level is divided according to the size of the comprehensive evaluation value  $F$ , as shown in Table 4.

**Table 4.** Response Measures for Each Risk

Risk Level	Evaluation Value	Risk Measures
Safe	[1.00,2.50]	The risk is negligible, and no additional avoidance measures are required.
Low Risk	(2.50,4.00]	The risk is within an acceptable range, and it is necessary to take avoidance measures.
Medium Risk	(4.00,5.50]	The risk is significant, and certain control measures and emergency response plans need to be prepared.
High Risk	(5.50,7.00]	The risk is very high and unacceptable, and measures must be taken at all costs to reduce the risk value.

According to calculations, before implementing effective reinforcement and construction guarantee measures, the comprehensive risk assessment value for this project using the Unified Bored Immersed Tube (UBIT) method to underpass the railway switch area is 5.67, which is classified as high risk. After taking practical and effective measures, a reanalysis was conducted, and the system risk level was reduced to 4.26, classified as medium risk. This necessitates the implementation of certain control measures and the preparation of emergency risk mitigation plans.

### 5.4 Propose Risk Control Measures and Recommendations

Based on the analysis above, the comprehensive risk level of this project using the pipe-roofing method to underpass the railway switch area is assessed as medium. Combining the actual conditions of the project, the following risk control measures and emergency response recommendations are proposed:

(1) Optimize the design scheme. The design should integrate multiple disciplines, including structures, tracks, power supply, and signaling, to propose the optimal solution. Particular attention should be paid to structural design optimization. For example, adopting stronger structural reinforcement methods may enhance construction safety but could also increase costs.

(2) Focus on construction process control and quality control. Factors such as concrete density, soil reinforcement strength, vertical alignment, and the accuracy of pipe

jacking significantly impact project risks. Issues such as substandard quality should be avoided.

(3) Strengthen construction safety monitoring. Establish a safety monitoring system for the railway switch during both the construction and operational phases. During construction, it is crucial to closely monitor switch deformation and surface settlement, prepare emergency plans, and issue timely warnings in case of abnormalities. The monitoring control values must comply with the relevant requirements of the rail transit management authorities.

## 6 Conclusion

This paper, based on a case study of an underpass project, establishes a hierarchical structure of system risk factors and a risk level classification system for the Unified Bored Immersed Tube (UBIT) method in underpassing railway switch areas. The Fuzzy Comprehensive Evaluation (FCE) method is employed to assess the system risks throughout the project. The conclusion indicates that after implementing reasonable measures in design and construction, the overall risk is classified as medium risk. This study provides a reference for on-site safety control in similar projects and offers insights for future research. The findings have broader implications for urban infrastructure and rail transit development, highlighting the importance of systematic risk management in complex engineering projects. Future improvements to the FCE-based risk assessment framework could include the integration of more advanced data analysis techniques and real-time monitoring systems to enhance risk prediction and management, paving the way for safer and more efficient urban infrastructure projects.

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