Risk Source Analysis and Key Control Technology Research of Subway Construction Based on Fuzzy Comprehensive Evaluation Method

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Abstract: at the present stage, the urbanization process in our country is accelerating and a large number of people are pouring into cities. As an important part of the urban transportation system, subway, with its advantages of convenience and high punctuality rate, can meet people's increasing traffic demand and occupies an important position. According to the basic principle of fuzzy comprehensive evaluation method and the basic factors affecting the construction period risk, this paper proposes to use fuzzy comprehensive evaluation method to analyze the construction period risk of the construction project, and to carry out fuzzy grade evaluation on the construction period risk of the project, so as to facilitate the decision makers of the project to take effective measures for the project. This paper proposes a fuzzy comprehensive evaluation method for risk assessment, in which ahp is used to determine the weight of influencing factors. An example is given to verify the practicability of the proposed method. The analysis results basically reflect the actual situation.

1. Introduction

The subway project has huge quantities, tight construction period, complex surrounding environment, narrow construction site, many construction difficulties and high risks. The construction cannot easily endanger the underground pipe network facilities, surrounding buildings and the normal life of residents. The construction of various subway tracks and light rail projects has become inevitable in the process of urbanization [1]. However, the construction of underground track is often affected by the underground hydrogeological environment, the ground is often accompanied by dense buildings, and the surrounding is accompanied by other complex underground facilities, which greatly increases the construction difficulty and construction risk. Subway stations are generally located in places with high passenger flow, such as commercial centers, cultural and entertainment centers and ground transportation hubs, in order to attract the maximum number of passengers and facilitate passengers. Delays in the construction period of the project will not only affect the cost increase and quality reduction of the project, but also lead to waste of manpower and material resources. Pan xiaoyu conducted a risk assessment on the construction risks of earth pressure shield tunneling in soft soil areas [2]. The fuzzy comprehensive evaluation method is a risk evaluation method with great development potential among underground engineering risk evaluation methods. Li ming et al [3] combined analytic hierarchy process and fuzzy evaluation to apply it to subway risk assessment. However, the implementation of risk assessment for subway projects can effectively reduce engineering risks and enhance the ability to cope with risks, so risk assessment has become an indispensable part in the subway construction process.

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2. Failure Mode and Evaluation Method Selection for Subway Construction

2.1 Analysis of Failure Modes in Construction

In the process of subway construction by shallow burying and underground excavation, there may be some dangerous influencing factors. Engineering and management personnel should analyze the failure modes caused by these influencing factors, determine their relative importance, and then reasonably allocate resources to monitor and prevent them to different degrees. Due to the advantages of simple construction, short construction period and low cost, cut and cover has always been the preferred method for subway construction. However, it has great impact on the urban road surface and environment, such as blocking traffic, generating noise, etc., so it is limited by the surrounding traffic and environmental conditions. Once a certain construction problem occurs, it will lead to the possibility of direct or indirect loss of the whole project. It is said that the project has risks, and the resulting consequences are called risk accidents [4]. The personnel, team or crew that bear risks are called risk subjects. The temporary support of the mid-span during excavation failed, and the two side spans squeezed toward the mid-span, causing the arch crown of the side span to crack. When repairing the mid-span, the mid-span center column foundation may sink, which is mainly due to the failure of the inverted arch to build in time and the insufficient bearing capacity of the center column foundation, resulting in cracking of the arch lining. There are many kinds of construction equipment and tools. Large transport vehicles, large excavators, cranes, pumping grouting machines, concrete tankers, shield machines, transformers, fans and many other mechanical equipment participate in the construction. The difference between the technology and method of urban subway construction design and the actual environment makes it necessary to make changes in urban subway construction, which leads to problems in the application of the method and technology.

2.2 Selection of Risk Research Methods

Subway station project is located in stratum, and the complexity of stratum makes it difficult to express some risks in underground construction with very accurate and quantitative data. Obviously, the risks in the construction process are uncertain, not only random, but also fuzzy. The combination of damage Chengdu of risk subject and probability of occurrence of damage is risk status, i.e. risk measurement. Risk factors refer to the attributes including contact time, contact place and contact conditions of subject and object. Thus, environmental factors are one of the major risk factors in subway construction accidents, and in these accidents, floods and poor geological conditions account for the majority. At present, existing engineering risk assessment methods such as risk multiplier method [5], fault tree method [6] are difficult to accurately express this. In addition, the risk multiplier method does not consider the correlation between failure indicators, and the establishment of fault tree is a rather complicated process, which makes quantitative analysis difficult. Fuzzy comprehensive evaluation method is based on fuzzy set theory and the principle of maximum membership degree to comprehensively evaluate the characteristics of multi-factor systems. The method has a wide range of applications and is an effective tool to solve multi-factor and complex problems. When there are many factors affecting things and there are strong uncertainties and fuzziness, it has obvious advantages to use this method for quantitative analysis [7].

3. A Fuzzy Comprehensive Evaluation Model is Established

3.1 Establish a Comprehensive Evaluation Set

For tunnel engineering, risk can be divided into economic risk, contract risk, natural disaster risk, construction risk, operation risk, environmental impact risk, etc. In terms of subway tunnel construction, it can also be classified according to the local subway construction process. Risk assessment indicators should be strictly screened to ensure that the indicators are true and effective, can objectively and accurately reflect the risks existing in the project, and increase the credibility of risk assessment. As the subway construction goes deeper and deeper, the scope expands continuously, and the surrounding buildings, roads, municipal underground pipelines, subway tunnels and other facilities are densely packed, the construction risks of foundation pit engineering are increasing day by day.

Set the focus factor set as

$$U=\{u_1\ \ u_2\ \ \cdots u_m\}\ (1)$$

The selection comments set is

$$V=\{V_1\ \ V_2\ \ \cdots V_m\}\ (2)$$

They are all finite sets.

In the process of subway station construction, this paper only considers three failure index factors for the time being: u_1 is the frequency of failure of each factor, u_2 is the severity of failure consequences of each factor, and u_3 is the degree to which failure causes of each factor are detected (hereinafter referred to as detection degree).

Risk assessment indicators need to consider a variety of risk factors, and select indicators that can represent these factors to reduce the complexity of the evaluation process. Geological aspects include different strata distribution; Physical and mechanical properties of geotechnical media materials; Liquidity, viscosity and deformation of geotechnical medium during construction. There are other obstacles such as building foundation; Pipeline facilities.

3.2 Determine the Membership Degree of Each Factor Related to the Evaluated Thing

Membership function is one of the keys of fuzzy comprehensive evaluation method. It is an expression of fuzzy statement of phenomena, laws and processes of things that cannot be accurately and quantitatively expressed. The membership degree thus determined is a measure of the closeness degree of fuzzy concepts. During the whole construction, different methods have different applicability. If there is no reasonable planning, a certain scheme is adopted rashly, which will inevitably bring great risks to the whole subway construction. There is a complex relationship between these factors. Therefore, when selecting risk indicators, we should straighten out the relationship and screen them step by step so as to make the indicator system clear in structure and level.

In order to make a single-factor judgment on $u_i(i=1,2,\cdots,m)$ in the factor set U, the factor ui is used to determine the degree of membership of the thing to the decision level $v_j(j=1,2,\cdots,n)$, and the u_i single-factor evaluation set $r_i=(r_{i1},r_{i2},\cdots,r_{in})$, which is a fuzzy subset on the choice review set V. From the evaluation set of m focusing factors, a fuzzy relation matrix R can be constructed:

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}\ (3)$$

It reflects the correlation between the sets U and V, where r_{ij} represents the degree of membership of factor u_i to the decision level v_j.

The hierarchical structure is established, and the comparison and judgment of the importance of each factor is quantified by using a scale of 1 to 9, and the judgment matrix of the comparison between each factor of the evaluation problem is constructed. At present, the method of determining membership function usually uses fuzzy statistical method or based on actual experience, while the following examples in this paper will determine the membership function needed in this paper according to the membership function construction method and principle [8] for several influencing factors considered in the subway construction process.

3.3 Determine the Weight of Each Evaluation Factor on the Evaluation Object

For the things to be judged, different conclusions may be drawn from different focus factors. Moreover, in many focus factors u_i, the degree of influence on the overall evaluation is different, and there are fuzzy preferred factors. The root method is used to calculate the maximum $\lambda_{\max}$ of the judgment matrix and the corresponding eigenvectors, and the normalized values are the weight values of the related factors of one layer relative to the related factors of the previous layer. At the same time, the consistency of the judgment matrix should be checked. The method for solving the weight not only avoids complicated consistency check, but also makes full use of the existing relevant data of subway construction risk factors, which is more reasonable than relying only on experts' subjective estimation.

Moreover, the weight vector can be adjusted by controlling parameter A to make it more reasonable. Therefore, the focus of evaluation can be regarded as a fuzzy subset A on factor set U. In the model, A is called the input fuzzy vector and is recorded as

$$A = \{a_1 \ \ a_2 \ \ \cdots a_m\} \quad (4)$$

Where a_i ($0 \leqslant a_i \leqslant 1$) is the membership of u_i to A and specifies, $\sum_{i=1}^{m} a_1 = 1$ is a measure of the influence of single factor u_i in the overall evaluation. The partial vector in A is called the importance degree coefficient of factor u_i, or weight.

Therefore, full restraint is imposed on the pile bottom in the simulation process. In this case, the soil friction has little influence on the settlement of underpinning system, and the soil friction is applied to the side of underpinning pile as external load. This requires better operability of indexes and simple quantification. The data are easy to be counted and processed.

3.4 Comprehensive Evaluation

The subway construction risk evaluation system is established on the basis of accident cause analysis, following the selection principle of evaluation indexes, sorting out the information of risk factors, consulting experts' opinions, and optimizing and screening by means of combination, elimination and replacement. If the structure has strength requirements in a specific direction, it is necessary to control the stress in this direction not to exceed the limit value [9]. The second-level fuzzy comprehensive evaluation is a comprehensive evaluation of various factors related to the evaluation object by applying the principles of fuzzy transformation and maximum membership degree. The evaluation of engineering risks is actually the evaluation of these five types of factors. Therefore, the first index under the target layer corresponds to human factors, mechanical factors, material factors, system factors and environmental factors respectively. After the fuzzy matrix R and fuzzy vector A are determined, the following fuzzy transformations can be used for comprehensive evaluation:

$$B = AR = \{b_1 \ \ b_2 \ \ \cdots b_n\} \quad (5)$$

Where b is called the output fuzzy vector, $b_j = \sum a_k r_{kj}$, $j = 1, 2, \cdots, n$. The fuzzy subset of the evaluation set V, i.e. the output fuzzy vector B, is thus obtained. The numerical value of its sub-vector will relatively reflect the risk degree of relevant factors in underground engineering construction.

4. Engineering Application Example

A underground subway station is a double-deck three-span two-column multi-arch structure. The construction method adopts the scheme of repairing both side spans first, and then repairing the middle span. During the construction, the arch, upright post, foundation, etc. are used. During construction, there may be risks such as cracking, sinking and failure of waterproof layer. According to experts' suggestions, the emergency response capability index is added to the professional skills and experience, the safety facility completeness index is added to the internal environment of the construction site, and the names of some indexes are modified. The absolute value of a single principal stress is controlled not to exceed the allowable stress. Similarly, the nephogram of stress intensity nodes can show the distribution of the third intensity equivalent stress on the overall structure. Among them, the principle for selecting the actual value of the index is to select the value of the index in the most dangerous section. Literature [10] has been analyzed according to the risk multiplier method, and this paper intends to use its basic data to evaluate and compare it according to the above fuzzy comprehensive evaluation method.

4.1 Select Failure Analysis Indicators

In the construction risk analysis, it is necessary to consider which hidden dangers exist in the engineering system, determine their failure modes, and carry out failure mechanism analysis. Through this cloud picture, the point where the equivalent stress of the third strength of the whole structure is the largest can be found. The hierarchical model reflects the subordination and domination relationship between adjacent hierarchical elements. According to this relationship, the upper and lower levels of elements are compared in pairs. The first-level fuzzy comprehensive evaluation is actually to deal with the fuzziness of the factor set. The contribution of each level of a factor to the value of the evaluation object is synthesized as a single-factor evaluation. In this paper, three indicators are set to characterize, namely, the degree of failure frequency (O), the severity of failure consequence (S), and the degree of failure cause being checked (D). According to the system failure records [3] which are similar to the inspected objects based on previous experience, the failure evaluation index (Table 1) is identified by 1 to 10 numbers. See Tables 1 and for the failure mode, mechanism and consequences of the project and the scoring results of quantitative indexes.

Table 1 Failure Factors And Risk Indexes of Subway Construction

Failure location	failure mode	Failure mechanism	Consequences of failure	O	S	D
Both sides straddle the vault	Cracking	Temporary support failure of mid-span during excavation after side span arching	Cause side span vault cracking	6	7	5
Center pillar foundation	Sink	The inverted arch was not built in time, and the bearing capacity of the center column foundation was low.	Cause arch lining cracking	5	6	6
Arch ring waterproof layer	Mass failure	Inappropriate process for laying waterproof layer on arch and poor joints	Cause arch leakage	8	4	6
inverted arch	Cracking	The bottom of inverted arch construction is not clear and the concrete quality is poor.	Cause the bottom to turn over and ooze mud	7	6	4
Surface stratum	Sink	The construction process is too long and the stratum is not pre-reinforced.	Endanger ground buildings (structures)	5	7	4

4.2 Select the Membership Function of Each Failure Analysis Index

For the evaluation of a certain class object, it often involves multiple factors or multiple indicators, which cannot be evaluated from a single factor, but needs to be comprehensively evaluated according to multiple factors, which is conducive to improving the scientificity and accuracy of evaluation. Through these nephograms, the point where the overall mechanical strain of the overall structure is the largest in these directions can be found. In some cases, it is necessary to control the overall mechanical strain in a certain direction of the structure, such as the hightemperature creep of steel bars in underpinning system. Each factor has M grades, and each factor grade has certain influence on the evaluation indexes of the evaluation set. According to Table 2, when the failure occurrence frequency degree is not more than 1, it can be regarded as the failure possibility grade is very small. When the frequency of failure is greater than 8, it can be regarded as the highest failure probability level. Therefore, the membership function $u_o(\chi)$ is taken as:

$$u_o(\chi) = u_s(\chi) = \begin{cases} 0, \chi \le 1 \\ 2(\frac{(\chi-1)}{7})^2, 1 < \chi \le 4 \\ 1-2(\frac{(8-\chi)}{7})^2, 4 < \chi \le 8 \\ 1, 8 < \chi \le 10 \end{cases} \quad (6)$$

As can be seen from Table 2, the higher the detection degree of failure causes, the lower the failure probability level. According to this rule, the membership function is a subtraction function of the detection degree. The nephogram of integral mechanical equivalent strain node of pile foundation underpinning shows that the maximum value of integral mechanical equivalent strain appears at the joint of underpinning beam and right underpinning pile under the action of overlying eccentric load. On the basis of comprehensive evaluation, the fuzzy comprehensive evaluation method uses the theory of fuzzy set to quantify the subjective judgment and qualitative description of the judge, and then substitutes them into the evaluation process to evaluate the whole system. This paper assumes that $u_D(\chi)=0$ when the failure cause detection degree is greater than 8, $u_D(\chi)=1$ when the failure cause detection degree is not greater than 2, and the intermediate region is analyzed by gamma distribution function. Therefore, the membership function $u_D(\chi)$ of the failure cause detection degree can be expressed as:

$$u_D(\chi) = \begin{matrix} 1, \chi \le 2 \\ e^{-(\chi-2)} \\ 0, 8 < \chi \le 10 \end{matrix} \quad (7)$$

The fuzzy concepts that are difficult to quantify can also be effectively analyzed, and the evaluation results are absolute and accurate. The risk of subway construction is a fuzzy concept, it does not have a clear risk limit, so the fuzzy comprehensive evaluation method combining qualitative and quantitative methods is a better choice.

Table 2 Failure Evaluation Scale

Failure probability level	O	S	D
No	-	-	10
Small	1	1	8-9
Afew	2-3	2-3	6-7
Medium	4-6	4-6	4-5
High	7-9	7-9	2-3
Very high	10	10	1

4.3 The Membership Degree of Each Failure Mode is Calculated

Because of its good algebraic properties, simple operation and easy to master, the operator of taking large and taking small is the most commonly used operator in fuzzy comprehensive evaluation. However, it only considers the most important factors and ignores some secondary factors. The degree of information utilization is not high, which is unfavorable to the accuracy of evaluation results. The values of O, S and D in Table 1 are substituted into the membership function formula (3) or formula (4), and the membership degree obtained is listed in Table 3. The fuzzy relation matrix of such failure modes is:

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$$R = \begin{bmatrix} 0.963 & 0.337 & 1.026 & 0.932 & 0.827 \\ 0.881 & 0.634 & 0.257 & 0.354 & 0.327 \\ 0.136 & 0.051 & 0.053 & 0.128 & 0.359 \end{bmatrix} \quad (8)$$

Table 3 Membership of Each Failure Mode

Failure factor	The vaults on both sides cracked.	Center pillar sinking	The waterproof layer of arch ring leaks water.	Inverted arch cracking	Surface subsidence
Frequency of occurrence	0.963	0.337	1.026	0.932	0.827
Severity of consequences	0.857	0.634	0.257	0.354	0.327
Degree of detection	0.136	0.051	0.053	0.128	0.359

4.5 Calculate the Output Fuzzy Vector and Evaluate the Construction Risk

The purpose of risk assessment is to control risks and minimize the probability of risks and losses caused by risks. At the same time, the nephogram of the second integral mechanical principal strain node for pile foundation underpinning can be extracted. From it, it can be seen that the maximum value of the second integral mechanical principal strain appears on the right-hand underpinning pile under the action of the overlying eccentric load on the underpinning beam and the underpinning piles on the left and right sides. Then, the pipe segment is drilled through through the orifice tube. The sealing device is fully packed with packing, and the sealing device is compressed by more than 3 screws. After drilling is completed, cement and sodium silicate double liquid slurry are used to seal the annular gap between the freezing pipe and the orifice pipe. After the matrices r and a are specifically determined, the output fuzzy vector can be obtained by using equation (2):

$$B = A \circ R = \{b_1 \ \ b_1 \ \ \cdots b_n\} = \{0.542 \ \ 0.334 \ \ 0.327 \ \ 0.351\, 0.668\} \quad (9)$$

According to the principle of relative size arrangement of element B, the primary risk of this example project is the subsidence of the surface strata due to the excessively long construction process and the lack of pre-reinforcement of the strata. In view of the specific risk points in interval shield construction, it mainly occurs in the process of shield entry and exit as well as in key sections of shield. Problems such as deformation of shield base and axial displacement of entry and exit often occur in shield entry and exit. The risk levels of typical risk sources for long-distance proximity construction are relatively high, of which the risks of foundation pit excavation and underpass overhead are more prominent, which should be paid enough attention. The following is the risk caused by water leakage in arch due to improper process of laying waterproof layer on arch and poor joints. Finally, the inverted arch was not built in time and the bearing capacity of the center pillar foundation was insufficient, resulting in risks caused by cracking of the arch lining. Therefore, in the prevention of risks, the probability of occurrence of personnel environmental risks and possible losses should be considered first, with emphasis on prevention.

5. Conclusion

When analyzing the construction period risk of a construction project, the method does not analyze the influence degree of a single factor, but analyzes the influence degree of comprehensive factors, establishes a fuzzy comprehensive evaluation model according to the specific situation of the construction project, and obtains the construction period risk grade of the construction project through analysis and calculation. According to the characteristics of numerous risk factors and distinct levels in subway construction, a subway construction risk evaluation model is established. AHP and fuzzy comprehensive evaluation method are used to evaluate the risk of subway construction. The risk level of the whole project is determined by the weight of each risk index and the single factor evaluation results of low-level indexes. The deformation analysis and research of the underpinning system with active underpinning are emphasized, and the general laws of its stress and deformation are obtained, which is of reference significance to the reinforcement of its weak links and the elimination of potential safety hazards.

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