Risk assessment model of underground engineering based on Delphi-AHP

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Abstract. Underground engineering is an extremely complex system engineering, with many uncertain factors and extremely many complex risk factors. In order to ensure the smooth completion of the organization and construction of the whole underground engineering, risk management is bound to be carried out, and in the process of risk management, risk analysis and assessment undoubtedly plays a crucial role. This paper on the study of underground engineering construction risk scholars both at home and abroad are reviewed, and then briefly summarizes of underground engineering risk analysis evaluation model at home and abroad, sum up experience, to establish universal underground engineering construction risk to risk factors to choose his own table, proposed a based on Delphi-AHP fast universal model of quantitative analysis for underground engineering construction risk to provide the basis for decision-makers quickly.

1. Introduction
Underground engineering construction is an extremely complex system engineering. There are huge uncertainties and safety risks in the construction and operation process. The risk factors are numerous and complex, and there are many potential factors in the construction of underground engineering that are not easy to identify. It is very necessary to manage the safety risk of underground engineering.

In the 1970s, the application research of underground engineering risk analysis and management has achieved certain results. Einstein. HH [1] of MIT in the United States is a representative person engaged in risk analysis of tunnel engineering. He has written many valuable documents [2, 3, 4], pointed out the characteristics of tunnel engineering risk analysis and the concepts that should be followed, introduced the concept of uncertainty into engineering estimation and proposed a tunnel cost model. Professor Faber. M. H [5] in Switzerland systematically elaborated risk analysis and response methods. JReilly [6] put forward the view that the construction process of tunnel engineering is a process of comprehensive risk management and risk sharing, which enables the rapid application of risk analysis in tunnel engineering [7, 8, 9]. The International Association of Tunnels and Underground Space also issued guidance on risk management [10]: The British Tunnel Association and the Insurance Industry Association jointly issued the "United Kingdom Tunnel Engineering Construction Risk Management Joint Specification"; the International Tunnel Engineering Insurance Group (ITIG) released the "Tunnel "Practice Rules for Engineering Risk Management"; Rimu has prepared "Guidelines for Safety Evaluation of Tunnel Construction". The Italian GeoDATA company
launched the GDMS information management platform for underground construction risk management.

Compared with developed countries, China's engineering risk management is still in its infancy. Due to the relatively short time of engineering research and practice, although the application of China's safety risk management in underground engineering started relatively late, in recent years China's safety risk. The application of management in the field of underground engineering has developed rapidly. Tongji University Li Yuanhai [11] and Zhu Hehua developed the “Geotechnical Construction Monitoring Information System” to assist in geotechnical construction management decision-making. The PLA University of Science and Technology carried out research and practice of safety risk management in Nanjing subway construction on the basis of its advanced risk management experience and information system through cooperation with Italian Geodata company. It can be said that China’s underground engineering safety risk management research and practice has been substantial progress has been made [12].

In the process of risk management, risk analysis and assessment play a vital role without a doubt. There are various risk assessment models for domestic and foreign experts, but they are generally cumbersome. This article first briefly summarizes many risk analysis models of underground engineering at home and abroad, analysis models, in-depth learning, and sums up experience, and proposes a universal model for rapid analysis of underground engineering construction risks, that is, the use of early establishment of universal underground engineering construction risks. The factor selection table is used by Delphi’s expert scoring method, and then combined with AHP modeling to quantitatively analyze the construction risk of universal underground engineering, and based on this, the risk level is fuzzy estimated to provide a basis for decision makers to quickly make risk control decisions. Finally, combined with the example of the Panlongshan tunnel project in Tai'an, Shandong, this universal model for rapid analysis of underground construction risk was used to quickly analyze and evaluate the level of construction risk. The decision-maker can take risk control measures for different risks to guide Risk Management.

2. Underground engineering risk analysis and assessment

Underground engineering projects, such as tunnels, subways, etc have a large number of sudden and accidental uncertainties during construction and operation. To reduce the adverse effects of such risk factors, effective risk research should be conducted on the underground engineering design system. In order to identify risk sources and uncertain factors, and take corresponding safety measures in time to ensure engineering safety. The “Management Guidelines for Subway and Underground Engineering Construction Risks” issued by the Ministry of Construction defines engineering risks as: if there are losses or adverse consequences that are contrary to the expected benefits, or losses caused by various uncertainties to all parties involved in construction, both are called engineering risks [13]. Engineering risk management mainly includes five main steps: risk definition, risk identification, risk analysis, and risk control. The risk management process of underground engineering is shown in Figure 1.
Combined with the underground project risk management process, it can be seen that risk analysis and evaluation are located in risk identification and risk control, and play an important role in the process of risk management. On the one hand, risk analysis provides a reference for deciding whether to deal with risks; on the other hand, risk analysis enables decision makers to deal with risks in the most appropriate and economically effective strategy. Risk analysis and assessment includes considering the source, consequence and possibility of occurrence of these risks, and analyzing and evaluating it by combining its possibility and consequence. The key to the accuracy of risk analysis and evaluation is the selection and application of the model. The second part of this article will briefly summarize the existing risk analysis and evaluation model of underground engineering. A universal model for rapid analysis of underground construction risks provides experience and theoretical support.

3. Underground engineering risk analysis and evaluation model
Risk analysis and evaluation play a very important role in the risk management process of underground engineering. Various models of domestic and foreign scholars studying underground engineering risk analysis and evaluation are divided into qualitative model, semi-quantitative model and quantitative model. The following is a brief overview of some risk analysis and assessment tools commonly used in large underground projects such as geotechnical engineering and tunnel engineering.
3.1. Fault tree analysis + event tree analysis model
Fault tree analysis (FTA) identifies, quantifies, and represents faults and fault combinations that may cause major dangers or events in the form of a graph. Event tree analysis (ETA) systematically maps the actual event scenarios that may lead to major events and the relationship between events and time dependence and potential escalation. It can also provide a numerical estimate of the probability of component events and upgrade events. “Fault tree analysis + event tree analysis” is the superposition of the above two models, and the result is a graph showing the relationship between the cause and consequence of the event. Since the graph combining the fault tree and the event tree becomes very complicated, this technique is most commonly used only when the fault logic is very simple. Figure 2 shows the general risk assessment process of Stacey et al. underground mine face using simple event trees and fault trees. The possible failure types are shown in the left column, and the probability of each failure is determined. The middle column shows an event tree that is used to determine several types of risks and their impact or consequences, such as economic loss, reputation loss, or impact on workers. The right column shows the final assessment of the acceptability or other aspects of these risks. This method was originally used for rock slope engineering [14, 15], and can be well used for underground civil engineering excavation.

![Figure 2](image)

**Fig. 2** A risk evaluation process combining fault and event trees (Stacey et al., 2006)

3.2. Bow tie graph analysis model
Bow tie graph analysis shows how a series of control measures can eliminate or minimize the possibility of a specific initiating event that may pose a risk, or reduce its consequences after an event occurs. The bow tie graph analysis method was originally a technique for analyzing security incidents,
but it is also useful for analyzing other types of complex risks and communicating critical risks and critical controls [16].

3.3. Probabilistic risk analysis model
Probabilistic risk analysis (PRA) includes other types of simulations such as Monte Carlo. In the past 30 or 40 years, probabilistic risk analysis (PRA) may be the most widely used quantitative risk analysis method in geotechnical engineering [17, 18], usually applied to failure risk [19, 20], construction time and cost estimation [21] and project management in a wide range of engineering and other fields [22]. However, this simple probabilistic method does not take into account spatial variability, uncertainty, the impact of pre-event or post-event control, and the dependence between design parameters and variables.

3.4. AHP model
AHP is a mathematical method for multi-criteria decision-making. It is often used to solve the problems of unclear definition and unreasonable structure in decision-making and risk assessment. The principle is to divide the risk factors related to the project decision into three levels: the target level, the criterion level, and the plan level. Through the calculation and comparison of each risk factor, the weights of different risk factors are obtained to select the most The best plan provides an important quantitative reference basis [23, 24]. This method is widely used in the field of construction in China, and sometimes used in combination with other methods [25, 26].

3.5. Bayesian network model
Bayesian network is a probability-based graphical and mathematical tool used to display the causal relationship between system components. They allow conditional dependence between variables, provide a method of reasoning in uncertain situations, and allow the probability table to be updated as more information becomes available. In practice, it is usually combined with some form of decision analysis. In wider geotechnical engineering, Bayesian network models are most commonly used to update probability tables, model parameters, analysis and design curves [27, 28]. With the advancement of computer technology and the accumulation of more engineering data, various future underground engineering projects have great potential.

3.6. Decision analysis model
Decision analysis (including decision tree analysis) is a structured format used to analyze or evaluate the results of decisions or choices based on available information. Many decisions in the construction of underground projects involve significant uncertainty. Decision analysis is usually combined with AHP and Bayesian network method.

3.7. Multi-risk analysis
Multi-risk analysis is an approximate calculation method used to calculate multiple statistically independent risks or hazards, each of which is considered a random variable. It provides a method to deal with uncertainty and can be used to estimate the cost of tunnel construction [29].

In addition to the above models, fuzzy logic models, artificial intelligence (AI) methods or related models have also been used in rock engineering risk analysis and evaluation [30], and sometimes combined with other method models [31]. It should be noted that the risk analysis and evaluation often carried out in engineering practice is qualitative or semi-quantitative. Therefore, this article will focus on the development and application of quantitative method models [32].

4. Establishment of safety risk assessment model for underground engineering based on analytic hierarchy process
Among the many models mentioned above for underground engineering risk analysis and evaluation, the analytic hierarchy process is widely used in the construction field in China. In addition, we know
that the construction risk of underground engineering is complex and the structure is unreasonable, which is exactly in line with the application of the analytic hierarchy process direction. Therefore, in order to establish a universal model of quantitative and rapid underground construction risk, the AHP and Delphi expert scoring method are combined to achieve the purpose of professional quantitative rapid analysis and assessment of risk. In order to be more convenient and fast, based on a large number of engineering data and rich engineering experience, a universal underground project risk factor selection table is established for Delphi expert scoring method. After scoring by experts, Yaahp software was used to carry out AHP modeling and quantitative analysis, and the fuzzy assessment of risk level was carried out accordingly, so as to achieve the purpose of rapid analysis and evaluation of construction risk level. Decision makers can use this model to take corresponding risk control measures for different underground engineering risks, so as to better achieve risk management.

4.1. Selection table of universal risk factors for underground engineering
Based on a large amount of engineering data and rich engineering experience, establish a universal risk factor structure for underground engineering as shown in Figure 3 [12]:

4.2. Delphi-AHP underground engineering risk assessment model
According to the above universal project universal risk factor table, use Excel to generate the corresponding expert score sheet questionnaire and distribute it to the project-related expert group. Experts can directly click the score in Excel, the process is rapid and efficient; the expert score sheet is recovered using Yaahp software to establish the original basic universal model based on the universal risk factor table for underground engineering construction for subsequent projects to select the appropriate risk factors based on their own engineering data and perform AHP analysis. The analytic hierarchy process method can be divided into six steps: the establishment of a hierarchical evaluation model, the construction of a suitable judgment matrix, the determination of appropriate evaluation criteria, the determination of hierarchy weights and total weights, the consistency test, and the final decision [33].
Fig. 3 General risk factor structure of underground engineering
Using Yaahp software can automatically achieve these six steps, accurately and quickly, to achieve the purpose of quantitative and rapid analysis and evaluation of underground engineering risks, and then the risk weight analysis results of each risk fuzzy estimation of risk levels, to provide a basis for decision makers to quickly make risk control decisions.

The specific risks and risk factors are classified as shown in Table 1-6 below:

**Table 1 Environmental risk**

| Environmental risk          | Changes in national policies and regulations | Adjustment of industry development plan |
|----------------------------|---------------------------------------------|----------------------------------------|
| Political and economic policy | Adjustment of industry development plan     | Industry-oriented changes              |
| Natural risk               | Financial crisis, inflation                 | Continuous rain or freezing            |
| Environmental risk          | Force majeure such as earthquakes and floods|                                        |
| Engineering tunnel features| Engineering Geology                         | Hydrogeology                           |
| Environmental conditions for construction operations | Tunnel depth | Section size |
|                             | Tunnel length                               | Tunnel slope                           |
|                             | Auxiliary tunnel situation                  | Surrounding rock type and its stability|
|                             | Lighting during construction                | Working space size                     |
|                             | Temperature during construction             | Homework schedule                      |

**Table 2 Technical risk**

| Technical risk | Design          | Geological survey situation | Construction preparation |
|----------------|-----------------|------------------------------|--------------------------|
| Design         | Design difficulty| Hydrogeological survey | Investigation of laws and regulations related to construction |
|                | Optimization degree of construction plan | Mechanical parameters | Organizational design of implementation construction |
|                | The maturity of the technology used in the design | Soil layer structure survey | Checking the design completion documents |
|                | Matching degree between design scheme and engineering reality | Advance geological forecast |                           |
|                | Completeness of data collection |                           |                           |
| Technical risk | Geological survey situation |                           |                           |
|               | Hydrogeological survey |                           |                           |
|               | Mechanical parameters |                           |                           |
|               | Soil layer structure survey |                           |                           |
|               | Advance geological forecast |                           |                           |
|               | Investigation of laws and regulations related to construction |                           |                           |
|               | Organizational design of implementation construction |                           |                           |
|               | Checking the design completion documents |                           |                           |
### Table 3 Construction risk

| Engineering excavation       | Excavation method                  |
|                              | Loop footage                       |
|                              | Reserve deformation                |
|                              | Tunnel over-excavitation           |
|                              | Section change                     |
|                              | Groundwater treatment              |
|                              | Stress relief measures             |
|                              | Into the hole                      |
|                              | Fall                               |
|                              | Pick                               |
|                              | Palm decompression measures        |
|                              | Gas pre-drainage                   |
|                              | Blasting method                    |
|                              | Blasting safety limit              |
| Construction risk            | Engineering blasting               |
|                              | Blasting equipment safety inspection|
|                              | Charge and blasting regulations    |
|                              | Vibration or long-distance blasting|
|                              | Master of construction experience  |
|                              | Advanced support                   |
|                              | Supporting rigidity                |
|                              | Reinforcement and improvement of stratum |
|                              | Support timing                     |
|                              | Support method                     |
|                              | Support quality                    |
|                              | Closed loop cycle                  |
|                              | Waterproof measures                |
| Waterproofing and drainage of the project | Precipitation measures          |
|                              | Drainage measures                  |

### Table 4 Construction management risk

| Construction quality management | Construction staff status |
|                                 | Construction personnel training |
| Protection situation            | Master and application of construction experience |
| Ventilation                     | Project quality inspection implementation |
| Construction equipment and facilities | Personal protection |
| Fire control situation          | Mechanical equipment protection |
|                                 | Ventilation equipment            |
|                                 | Choice of ventilation method     |
|                                 | ventilation system               |
|                                 | Ventilation quality              |
|                                 | Air supply and demand ratio      |
|                                 | Fire source inspection at tunnel entrance |
|                                 | Dress code for entry personnel   |
|                                 | Regulations and implementation of dangerous operations such as welding |
|                                 | Fire prevention and fire protection facilities |
|                                 | Supporting equipment             |
|                                 | Communication equipment          |
|                                 | Drainage equipment               |
|                                 | Selection of cables and equipment |
|                                 | Protection of electrical appliances and equipment |
|                                 | Construction machinery selection |
|                                 | other                            |
Table 5 Management personnel risk

| Managerial risk | Organizational structure | Human resources status | Core member mobility | Direct connection between internal and external Project members' work enthusiasm and work efficiency |
|-----------------|--------------------------|------------------------|----------------------|-----------------------------------------------|
| Participating parties |                          | Designer risk          | Supervision risk     | Owner risk (payment risk, credit risk, financing risk, management ability risk, etc.) |
|                  |                          |                        |                      | Subcontractor risk (qualification risk, labor productivity, quality risk, etc.) |

Table 6 Safety management risk

| Security management risk | On-site safety management | Installation situation of security agencies | Work safety responsibility system |
|-------------------------|---------------------------|---------------------------------------------|----------------------------------|
|                         |                           | Safety promotion and education               | Incident management               |
| Monitoring and measurement during construction | Management of dangerous equipment such as blasting equipment | Monitoring and measurement system |
|                         |                           | Norms require monitoring projects           | Monitoring instruments and layout |
|                         |                           | Monitoring frequency                        | Monitoring frequency              |
|                         |                           | Information feedback and processing        |                                  |

5. Engineering applications

5.1. Project Overview
Panlongshan Tunnel is located in Tai’an City, Shandong Province, China. The tunnel is 2885 meters long and has 6 lanes in both directions. The entrance of Panlong Mountain Tunnel is about 100 meters. The entrance and geographical location of Panlong Mountain Tunnel are shown in Figure 4 [34].

![Fig. 4 Panlongshan tunnel and geographical position of Tai’an city](image)

The entrance of the tunnel is located at the foot of the mountain, with a gentle slope of about 5-12°, and the soil thickness of the Quaternary varies from 0.40m to 1.20m. Analysis of the exposed part of the entrance part of the YK78 + 410 tunnel from the late Cambrian limestone, part of the frame thin
layer of marl, layered structure, stratum dip angle, rock strike and hole axis oblique, no entrance fracture structure, joints and fractures. It is development, development of local dissolution of fractures. Drilling shows that small filling holes, dissolution cracks and pore erosion are developed locally, and the filling is muddy with poor stability. The uniaxial saturated compressive strength of the rock is 13.2-18.6 MPa, the basic mass of the rock is 195, the longitudinal wave velocity of the rock is 500 (m/s), and the rock is classified as grade V. Due to the poor quality of the surrounding rock at the entrance of the tunnel, the central crossing diagram method was used to excavate the entrance of the tunnel. Based on the project overview, the risk factors that meet this project were selected from the universal risk factors for underground engineering construction above to establish the underground project The risk hierarchy model diagram is to be used, and the model is established by Yaahp.

5.2. Engineering application of Delphi-AHP underground engineering risk assessment model

Distribute the Excel scoring questionnaire to the panel of experts, collect the scores and recycle them, and import the results into Yaahp software for grading. The six steps of the analysis, the ranking weights of the various evaluation indicators obtained are shown in Table 7 below:

| Options                                          | proportion |
|--------------------------------------------------|------------|
| Support quality and timing                       | 0.1068     |
| Surrounding rock type and its stability          | 0.0810     |
| Blasting method                                  | 0.0578     |
| Closed loop cycle                                | 0.0483     |
| Tunnel depth, length, slope                      | 0.0469     |
| Personal protection                              | 0.0356     |
| Monitoring frequency                             | 0.0355     |
| Engineering Hydrogeology                         | 0.0351     |
| Excavation method                                | 0.0328     |
| Working dust situation                           | 0.0285     |
| Working space size                               | 0.0255     |
| Welding dangerous work                           | 0.0237     |
| Waterproof measures                              | 0.0233     |
| Charge and blasting regulations                  | 0.0228     |
| Tunnel over-excavation                           | 0.0196     |
| Emergency incident management                    | 0.0194     |
| Support method                                   | 0.0192     |
| Blasting safety limit                            | 0.0179     |
| Information feedback processing                  | 0.0177     |
| Stress relief measures                           | 0.0162     |
| Working lighting conditions                      | 0.0157     |
| Fire and fire protection facilities              | 0.0151     |
| Drainage measures                                | 0.0148     |
| Engineering quality inspection implementation    | 0.0142     |
| Blasting equipment safety inspection              | 0.0138     |
| Reserve deformation                              | 0.0135     |
| Auxiliary tunnel situation                       | 0.0126     |
| Section size                                     | 0.0126     |
| Continuous precipitation or freezing system      | 0.0100     |
| Reinforcement and improvement of stratum         | 0.0097     |
According to the scoring results of the expert team, a paired comparison matrix is established to check the consistency of the matrix. The judgment matrix between the target layer A and the criterion layer B, and the judgment matrix between the criterion layer B and the scheme layer C are not shown here.

### 5.3. Delphi-AHP underground engineering risk assessment model engineering results

According to the calculation results of the consistency test, the consistency ratio C.R. of the A-B and B-C judgment matrices is less than 0.1, indicating that the closer the judgment matrix is to complete consistency, the risk factor can be used to quantitatively describe the decision [35].

Through Delphi-AHP underground engineering risk assessment model analysis, the quality and timing of the support, the type and stability of the surrounding rock, and the blasting method of the Panlongshan Tunnel in Tai’an City, Shandong Province, China are the three main risk sources in the construction of the project. The risk analysis weight of the timing exceeds 0.1, and the highest risk of the project is the highest. The risk level is advanced. Therefore, in the construction design and construction process of the project, special attention should be paid to the quality and timing risks of the support; secondly, due to the surrounding rock conditions of the project Poor, so attention should be paid to the surrounding rock types and stability risks. This project uses the central cross diagram method to excavate the tunnel entrance section. Finally, blasting is very important for underground engineering.
engineering construction, and its risks are numerous and complicated, so the contractor should choose a suitable blasting method to reduce the overall risk of the underground project.

6. Conclusion

According to the data of underground engineering data and experience of underground engineering, this paper proposes a universal model for rapid analysis of construction risk of underground engineering, that is, the selection table of risk factors for the construction of universal underground engineering is established for the Delphi expert scoring method. Then combined with analytic hierarchy process modeling to quantitatively analyze the construction risk of pervasive underground engineering, and based on this, the risk level is estimated fuzzily to provide a basis for decision makers to quickly make risk control decisions. Finally, combined with the Panlongshan Tunnel Project in Tai'an City, Shandong Province, using the above universal model for rapid analysis of construction risk of underground engineering, the model quickly analyzed and evaluated the construction risk level, and obtained the support quality and timing, surrounding rock type and stability. The blasting method is the three major risks of the construction safety of the underground project. The decision-makers of the participating parties can take corresponding risk control measures for the risk factors obtained by analysis and evaluation, which reduces the safety risk of the project.

Of course, underground engineering problems are intricate and complex, and specific problems should be analyzed concretely. The environment of underground engineering is different, and the risk factors are also different. Only the local conditions can be identified and analyzed, and all aspects of information are integrated. The risk factor selection table selects the risk factors that meet different underground projects, and then uses Delphi expert scoring-hierarchical analysis of the underground project risk assessment model to better and quickly carry out quantitative analysis and assessment of underground project risk, and then for the underground project risk Management provides new ideas. In the long run, after accumulating a large amount of quantitative data, establishing a special database will also help reduce the possibility of accidents. Through risk management, the risks that may exist in the project can be predicted and evaluated. According to the evaluation results, early measures can be taken to effectively reduce or eliminate the possibility of safety accidents and make underground construction safer.

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