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A Review of Risk Identification & Risk Assessment on Urban Utility Tunnel Construction

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Abstract: With the rapid development of urban utility tunnel construction in China, the risks encountered during construction are becoming increasingly prominent, necessitating more robust and systematic risk-assessment. This study aims to improve the risk assessment system for the construction of urban utility tunnels and provide theoretical support for engineering practice.

This study critically examines current practices in risk identification and risk assessment in both China and international contexts by reviewing existing literature from year 2013 to 2023. The review reveals that existing research and engineering applications predominantly rely on traditional risk-assessment models, which are generally static and expert-driven. These approaches exhibit notable limitations, particularly in their inability to support dynamic risk monitoring, multi-source data integration, and intelligent early-warning functions. Furthermore, the current risk-assessment systems demonstrate insufficient interdisciplinary integration, limited real-time performance, and constrained practical operability in complex construction environments. Based on these findings, there is the need for a paradigm shift towards dynamic and data-driven risk-assessment approaches which focus on integrating big-data analytics, artificial intelligence, and intelligent sensing technologies to enhance the adaptability, timeliness, and predictive capability of risk management systems. Such advancements are essential to promote the intelligent and systematic development of risk control strategies and to improve the overall effectiveness and foresight of risk management in urban utility tunnel construction.

Keywords: Underground Engineering; Urban Utility Tunnel; Risk Assessment; Risk Indicators; Research Status

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1.Introduction

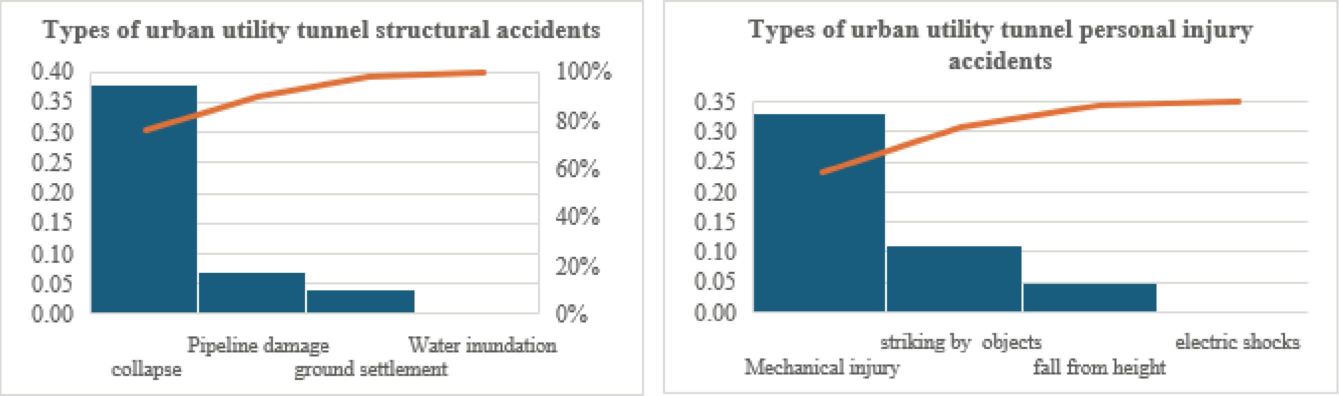
Urban utility tunnels, are an advanced form of infrastructure network. These tunnels are used as an important measure for utilizing underground space and promoting sustainable urban development. In China, the construction of urban utility tunnels has entered a stage of rapid development with the strong campaign on national policies in 2015 (Zhao Yongzhi, 2019). However, due to the complex structure of utility tunnels and high requirements for construction technologies, various risk factors interact with each other during construction, resulting in great difficulties in safety management and control.

Currently, more than fifty cities across China are promoting construction of urban utility tunnels. With the cluster and network development of projects, construction risks are further amplified and aggravated. The overlapping of multiple operation faces and the mutual influence of underground spaces make the risk situation more complex. Through an investigation into the number of accidents involving China's urban utility tunnels over the past decade (2013-2023), the study finds that with the annual expansion of tunnel construction volume, risk accidents have shown an overall upward trend. From 2020 to 2022, due to the global COVID-19 pandemic, construction projects were largely suspended and the number of accidents dropped accordingly. It was not until 2023, when projects resumed successively, that the number of accidents rose again, as detailed in Figure 1.

Figure 1: Statistical Table of Accidents in utility tunnel over the past decade

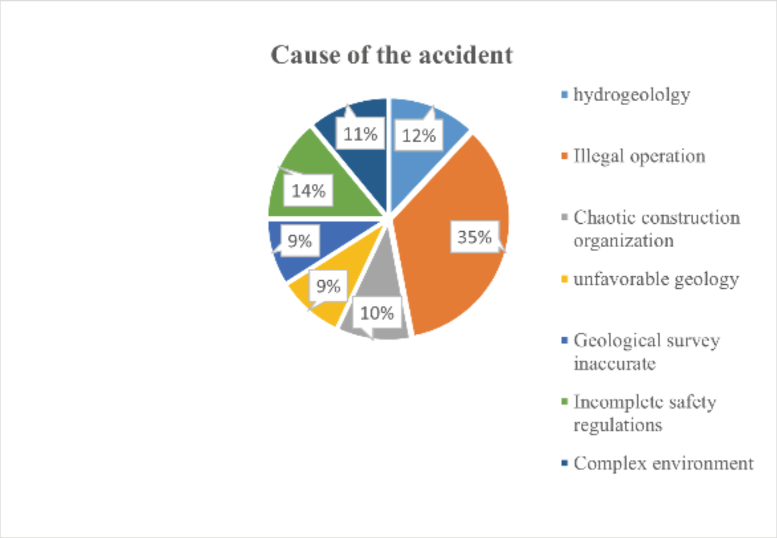
Urban utility tunnel construction involves a variety of accident types. Further analysis reveals that structural accidents such as collapses, pipeline damage, ground settlement and water inundation cause massive property losses. Personal injury accidents including mechanical injuries, falls from height and striking by objects frequently occur during construction, leading to severe casualties. Specific accident types are shown in Figure 2.

Figure 2 Types of utility tunnel accidents



Based on the accident type, an in-depth analysis of its underlying causes was conducted. The accident was mainly attributed to improper personnel operation, complex geological conditions, inadequate safety management and other factors. Specific causes are shown in Figure 3.

Figure 3 Analysis of the Causes of utility tunnel Accidents



It can be seen from Figures 1 to 3 that systematic identification and evaluation of construction risks of utility tunnels, as well as proper risk management, are of great significance to improving the construction safety of utility tunnels.

Construction risks in urban utility tunnels permeate every stage, and the type and severity of these risks dynamically change with variations in personnel, environment, processes, and management measures. The construction of utility tunnels in China started relatively late, and the relevant theoretical system is not yet perfect. Especially in terms of risk assessment, a systematic and scientific methodological system has not been formed. At present, research on risk evaluation of utility tunnels mainly focuses on the operation and maintenance stage, with few studies conducted for the construction stage（Chen Kan, 2021）.

How to construct a risk assessment model suitable for practical engineering projects, and how to effectively classify and control construction risks through appropriate risk identification and evaluation methods, has become a critical issue urgently needing resolution in current engineering practice.

Therefore, this study first systematically analysis the current state of research on risk assessment in urban utility tunnel construction, summarizes existing identification and assessment methods and systems, and points out the shortcomings and development trends of existing research, thus laying a theoretical foundation for constructing a more reasonable risk assessment model.

2.Risk Identification in Utility Tunnels Construction

Risk management can be divided into three parts: risk identification, risk analysis, and risk assessment (Li Chunhua, 2023).

Risk identification refers to the analysis and research of the time, location, quantity, and type of risk occurrence from multiple perspectives, including premonition, identification of risk symptoms, analysis of risk sources, and determination of risk events. Usually, risk analysis and identification are collectively referred to as risk identification（Li Chunhua, 2023）.

Risk assessment refers to the judgment of the probability of risk occurrence, the expected degree of loss, and the ability to withstand the risk through risk analysis, in order to evaluate the possibility of risk occurrence and the harm it brings, and to formulate strategies to reduce risks and losses based on the situation（Yan Lixin, 2024）.

The goal of risk identification in utility tunnel construction is to establish a suitable risk indicator system. At present, most scholars adopt the method of initial knowledge and screening.

2.1 Conventional Risk Identification Frameworks

The most common method for initial identification of risks in utility tunnel is to use the 4M1E method to identify indicators based on existing literature, national standards and regulations, and utility tunnel construction accident cases (Anon, 2020).

4M method is a commonly used tool in problem solving and change management, which is based on four core elements: man, machine and material, management, and method for analysis. Usually, it also includes “1E”: environments. So, it is collectively referred to as the 4M1E method. That is to say, the five elements of man, machine and material, management, method, and environments are commonly referred to.

This method serves as a basic qualitative framework for risk identification with clear logic and ease of application, yet it is inclined to qualitative description and unable to quantify the correlation among risk factors.

Later, researchers combined the 4M1E method with other theories to form a new risk identification technique in order to make the identified indicators as comprehensive as possible.

The basic idea of the Hierarchical Holographic Model (HHM) is to identify risks in a system by analyzing it from multiple perspectives and dimensions based on the fundamental principles of systems engineering (Liu Yukexin, 2022). Firstly, determine the HHM framework of the research object. The HHM framework can collect information through various channels and continue to decompose and derive new sub model graphs through continuous improvement. After the risk identification work of all levels and subsystems is completed, an overall risk list of the project can be generated.

This method is a systematic integration approach suitable for complex systems, which can explore the relationships between different system levels. However, it requires strong support from basic data, involves complex modeling and heavy workload, is not applicable to preliminary risk identification, and generally needs to be used in conjunction with other methods.

In addition, some scholars have applied new theories from other disciplines to the risk identification of utility tunnel construction.

2.2 Integration of Project Decomposition and Causal Analysis Methods

The Work Breakdown Structure-Risk Breakdown Structure(WBS-RBS）is to break down the project into WBS tasks and use RBS to classify potential risks（Li Fangzhen, 2017）. This can systematically identify the risk categories that each work package may face, such as technical risks, management risks, external risks, etc.

This method enables comprehensive and non-omissive risk identification and accurate localization of specific risk occurrence nodes. However, it focuses on process flows and is insufficient in identifying non-technical risks such as management and economic ones, thus it is generally not used alone.

Fishbone analysis method, also known as causal analysis method, is a method of discovering the “root cause” of problems. It was developed by Japanese management master Mr. Ishikawa Shinobu and is therefore also known as Ishikawa diagram. It can also be called a ‘ cause and effect diagram’（Liu Lei, 2020）.

This method is result-oriented, tracing the root causes layer by layer with strong visualization, which facilitates team discussion. However, it is not applicable to preliminary risk identification and only suitable for the cause analysis of well-defined risk problems.

2.3 Data-Driven and Interdisciplinary Identification Approaches

Grounded Theory (GT) was jointly proposed by Anselm Strauss and Barney Laser from Columbia University, it is a method of using a systematic process to induce a phenomenon layer by layer to guide the theory (Chen Wei, 2022). Its main purpose is to abstract new concepts and ideas from empirical data through inductive analysis and comparison. The GT research method achieves hierarchical induction through coding, with the most critical step being the step-by-step coding of the data, which includes three levels: open coding, spindle coding, and core coding. The purpose of open coding is to discover conceptual categories from data and form initial categories. Spindle coding is used to discover and establish various connections between conceptual categories and based on these relationships, encode them again on the basis of the initial category to form the main category. Core coding refers to the discovery of core categories based on comparative analysis of the main category, and the concatenation of all other categories into a whole to construct a theory (Chen Wei, 2022).

This method is a research approach based on data coding and analysis. It has high data requirements and is time-consuming for coding and analysis, making it unsuitable for projects with tight schedules and limited data.

Nowadays, scholars generally use a combination of Expert investigation method and data statistical software for secondary screening based on initial identification of indicators.

The Expert investigation method, was founded and implemented by the Rand Corporation in 1946 (Xu Jingwei, 2020). Essentially, it is a feedback anonymous inquiry method. The general process is to obtain the opinions of experts on the problems to be predicted, organize, summarize, and statistically analyze them, and then anonymously provide feedback to each expert.

After soliciting opinions again, the process is concentrated, and feedback is given again until a consensus is reached.

Statistical Package for the Social Sciences (SPSS) is a statistical analysis software used for data processing, data analysis, and data visualization(Chen Bo, 2020）. It provides a range of statistical analysis tools that facilitate researchers and analysts in extracting information, making decisions, and discovering patterns from data. While this combination improves indicator reliability and consensus, it does not fundamentally resolve the issue of subjectivity, as expert judgment remains the dominant source of decision-making.

The research results of nearly 10 years in this study have been summarized and organized, as shown in Table 1.

Table 1: Research Progress on the Construction of Risk Indicator System

Author **time**	**Initial identification of risk factors**	**Risk factor screening**	**Risk factor database**
Liu Yukexin （2022）	HHM 4M1E method Fishbone diagram	Expert investigation method SPSS	5 level 1 indicators 24 level 2 indicators
Wei Haimin （2017）	Work Experience HHM	Expert investigation method Risk probability impact matrix	4 level 1 indicators 18 level 2 indicators
Chen Shengfa （2023）	Fishbone diagram 4M1E method HHM	Expert investigation method	5 level 1 indicators 33 level 2 indicators
Chen Wei （2022）	Grounded Theory	Expert investigation method SPSS	5 level 1 indicators 22 level 2 indicators
Zhang Shuai （2022）	4M method	Expert investigation method	4 level 1 indicators 25 level 2 indicators
Duan Leting (2022)	4M1E method	Expert investigation method	5 level 1 indicators 28 level 2 indicators
Liu Keru （2018）	Expert investigation method		3 level 1 indicators 15 level 2 indicators
Qiu Shi （2019）	4M1E method		4 level 1 indicators
Ruan's Zhizhuang （2019）	4M1E method		3 level 1 indicators
Zhang Xiaolong （2020）	Expert investigation method		4 level 1 indicators
Zhao Hui （2020）	Expert investigation method		5 level 1 indicators 18 level 2 indicators
Cai Menglong （2020）	Expert investigation method		5 level 1 indicators
Zhang Yong (2020)	4M1E method		5 level 1 indicators 28 level 2 indicators
Liu Lei （2020）	4M1E method Fishbone diagram		3 level 1 indicators
Xu Haiyan （2020）	4M1E method Expert investigation method		3 level 1 indicators 12 level 2 indicators 57 level 3 indicators
Jiang Hao （2023）	4M1E method		6 level 1 indicators 31 level 2 indicators
Zhang Zhicheng （2024）	4M1E method		5 level 1 indicators 18 level 2 indicators
Li Fangzhen （2017）	WBS-RBS matrix	Expert investigation method	2 level 1 indicators 6 level 2 indicators 23 level 3 indicators
Chen Bo （2020）	Risk impact mechanism	Expert investigation method SPSS	5 level 1 indicators

Author time	Initial identification of risk factors	Risk factor screening	Risk factor database
Ma Huigan (2021)	4M1E method	Expert investigation method	5 level 1 indicators 25 level 2 indicators
Hu Yihuan (2023)	Expert investigation method	Field research	5 level 1 indicators 25 level 2 indicators
Huang Huijun (2020)	Fishbone diagram 4M1E method	Expert investigation method SPSS	5 level 1 indicators 18 level 2 indicators
Chen Zeming (2020)	4M1E method	Expert investigation method	5 level 1 indicators 18 level 2 indicators
Han Yuhong (2024)	4M1E method	Expert investigation method	5 level 1 indicators 17 level 2 indicators
Xu Jingwei (2020)	4M1E method	Expert investigation method	5 level 1 indicators 20 level 2 indicators
Qin Huali (2022)	4M1E method	RF Random Forest	5 level 1 indicators 22 level 2 indicators

2.4 Critical Evaluation and Research Gaps

As shown in Table 1, current risk analysis is primarily based on the 4M1E method of accident causation theory. The risk identification process still relies heavily on qualitative descriptions from available documents, standards, and accidents, neglecting in-depth exploration of the engineering substance of the constructed indicator system. This leads to a disconnect between risks and the specific technological, geological, and management scenarios of utility tunnel construction, resulting in risk indicator databases that are more general than specific.

Based on the systematic identification and preliminary analysis of risk factors in utility tunnel construction, the core decision-making step in risk management becomes how to scientifically assess and prioritize the potential impact of these risks. Therefore, the following section will focus on examining the application logic, evolution path, and inherent limitations of various risk assessment methods.

3.Research Progress of Risk Assessment

In recent years, the construction risks of urban utility tunnels have become a focus of attention for scholars. Researchers have conducted a series of studies on the proactive prevention, risk assessment, and management of construction risks in urban utility tunnels, establishing various improved risk assessment models, as detailed in Table 2.

This study summarizes existing construction risk assessment methods into three main categories: qualitative, quantitative, and comprehensive evaluation, in order to further promote the application of construction risk assessment systems in the construction of urban utility tunnels.

Seo et al. (2019) conducted accident scenario analysis on potential hazards during the construction process, providing a theoretical basis for reducing the occurrence of fire accidents during the construction of urban utility tunnel.

The qualitative method played a crucial role in the initial stages of utility tunnel risk assessment, particularly in complex engineering scenarios where data was scarce. However, their limitations have become increasingly apparent with the development of practice. These methods rely heavily on expert experience, and their evaluation results are easily influenced by the composition of the expert group, cognitive biases, and “groupthink,” leading to subjective uncertainties that are difficult to quantify and control.

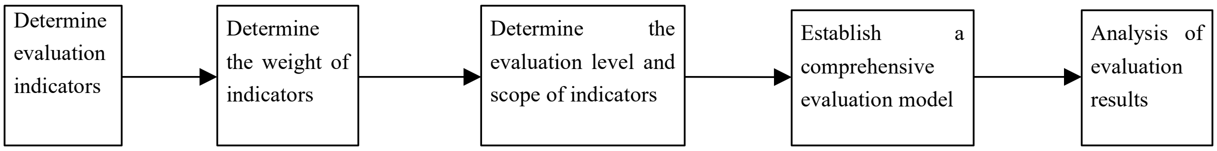
Seong J H (2018) et al. derived hazards related to the utility tunnel, screened key safety hazards, and conducted risk assessment using matrix method.

While risk matrices are intuitive, simply dividing the probability of risk occurrence and the severity of its consequences into a finite number of levels and then discretely combining them often obscures the subtle differences within a continuous risk spectrum, potentially leading to an underestimation of key risks or resource misallocation. Most studies of this kind stop at risk ranking, failing to further reveal the complex coupling and transmission mechanisms between risk factors, thus weakening the predictability and targeted nature of management strategies.

Recognizing the respective shortcomings of qualitative and quantitative methods, comprehensive methods have become the current mainstream research trend, attempting to achieve complementary advantages through method hybridization.

In recent years, Chinese scholars have mostly used the comprehensive evaluation method in the risk assessment research of integrated utility tunnel, and its general process is shown in Figure 4.

Figure 4: General Process of Comprehensive Evaluation



3.1 Weight Calculation

There are various methods for calculating weights, and the most commonly used method by scholars is the Analytic Hierarchy Process (AHP), which mainly conducts importance analysis through expert scoring. With the deepening of research, various evaluation methods have emerged to avoid the subjective judgment of experts affecting the results, making the weights closer to the actual situation.

AHP, refers to a decision-making method that decomposes elements related to decision-making into levels such as objectives, criteria, and plans, and conducts qualitative and quantitative analysis based on these levels (NGUYEN Thi Thuy Trang ,2019). This method is a hierarchical weight decision analysis method proposed by Professor Sati of the University of Pittsburgh, an American operations researcher, in the early 1970s when researching the topic of “electricity distribution based on the contribution of various industrial sectors to national welfare” for the US Department of Defense.

G1 weighting method is based on the AHP for improvement, allocating weights by quantifying the relative importance of different indicators (Zhao Hui, 2020).

Decision making Trial and Evaluation Laboratory (DEMATEL) was conducted by scholar from Battelle Laboratory in the United States Gabus (Duan Le ting ,2020). This method starts with the mutual influence between factors, identifies causal relationships between factors, and can obtain causal and outcome factors. By establishing a direct impact matrix, the influence degree, affected degree, cause degree, and centrality of each factor are calculated to determine the causal relationship between risk factors and the importance of risk factors in the indicator system.

Information entropy is also known as entropy weight method. According to the definition of information entropy, for a certain indicator, the entropy value can be used to determine the degree of dispersion of the indicator (Zhang Shuai, 2022). The smaller the information entropy value, the greater the degree of dispersion of the indicator, and the greater the impact of the indicator on the comprehensive evaluation. If the values of a certain indicator are all equal, then the indicator does not play a role in the comprehensive evaluation.

Criteria Importance Through Intercriteria Correlation is also known as CRITIC. It is an objective weight weighting method proposed by Diakoulaki (Zhao Hui, 2022). Determine the weight of each indicator by comprehensively considering its comparative strength and degree of conflict.

Combination Ordered Weighted Averaging is also called COWA. The OWA operator is the most fundamental research on information integration methods, proposed by American scholar Yager. Its purpose is to weaken the negative effects of extreme values to a certain extent by reordering and weighting the original data. There are numerous changes to the OWA operator, and Chinese scholars have conducted research from the perspective of improving data aggregation forms, believing that COWA can process data more efficiently and simply (Cai Menglong, 2020).

Combination weighting in game theory is a commonly used method for analyzing game problems. It transformed the game problem into a combinatorial problem, and then introduced weights based on the combinatorial problem to reflect the interests and strategies of each participant in the game (Han Yuhong, 2024). Also known as Method of Least Squares combined weighting.

3.2 Evaluate Model

At present, the most commonly used method by scholars is the fuzzy comprehensive evaluation method, on which many models have been developed.

In 1965, Professor L.A. Zadeh, an American expert in automatic control, proposed fuzzy sets concept to express the uncertainty of things. It is a comprehensive evaluation method based on fuzzy mathematics (Chen Wei, 2022). This comprehensive evaluation method transforms qualitative evaluation into quantitative evaluation based on the membership theory of fuzzy mathematics, that is, using fuzzy mathematics to make an overall evaluation of things or objects that are constrained by multiple factors.

The coupling degree model is a model that represents the interaction dependencies of system components. Charles Perrow proposed the concept of risk coupling in the 1970s and pointed out that the cause of accidents is the uncertainty and coupling of two vulnerable points in the system (Zhang Shuai, 2022). It describes the relationships between system components and the tasks they are responsible for. The coupling degree model is divided into three types: coupling type, coupling degree, and coupling details. Coupling type refers to the relationship type between components in a system, which can be classified as cohesive, strongly coupled, lightly coupled, and uncoupled. Coupling degree refers to the interdependence between system components, manifested as low coupling degree, medium coupling degree, and high coupling degree. Coupling details refer to the detailed associations between different components of a system. If there are many coupling details, it indicates that there are more connections between the components in the system, while if there are fewer, it indicates that there are fewer connections between the components in the system.

Grey Relational Analysis is a type of grey system analysis method. It is a method of measuring the degree of correlation between factors based on the similarity or dissimilarity of their development trends (Liu Ruke, 2018), also known as "grey correlation degree".

Matter element extension method is a powerful tool for resolving secondary contradictions, primary contradictions, and critical problems in complex systems (Zhao Hui, 2020). It is based on the comparison and optimization of multiple known general decisions, by grasping key strategies and maximizing the conversion of incompatible contradictions into compatible relationships, thus achieving the global optimal decision-making goal.

In 1995, Support Vector Machine (SVM) was proposed by Corinna Cortes and Vapnik to solve pattern recognition problems. Based on statistics, it is used to handle classification and regression problems (Chen Bo, 2020). The selected training set is trained continuously to obtain the corresponding relationships between variables for prediction and classification.

System dynamics simulation model (SD) is a model that applies the principles of system dynamics to analyze the structure, behavior, and causal relationships of a system, and simulates the dynamic changes of the system (Duan Leting, 2020). The model establishes a structural model and performs computer simulation operations under different assumptions to predict the dynamic behavior of the system in various situations.

The uncertain measurement evaluation model is a mathematical model proposed to quantify the true quantitative relationships in a system and solve the problem of uncertain information (Zhang Shuai, 2022). By making judgments about the uncertainty contained in uncertain state things by decision-makers and converting this level of cognition into proportional magnitude.

Convolutional Neural Networks is also called CNN. The research began in the 1980s and 1990s, and it is a type of feedforward neural network that includes convolutional computation and has deep structure (Qin Huali, 2022). It is one of the representative algorithms of deep learning.

Interaction matrix analysis method is also known as cross probability method. A method of using the mutual influence matrix to solve the problem of interaction and mutual influence among various predicted events, in order to make accurate predictions (Jiang Hao, 2023). This law was first studied by the United States in the 1960s.

Social Network Analysis (SNA) is a quantitative analysis method developed by humanities and social scientists based on graph theory and other related theoretical foundations. Thomas first applied this method as a tool for describing social relationships between people, used as a research method for analyzing the relationship structure and attributes of social networks (Chen Shengfa, 2023). Compared to traditional analysis methods, social network analysis focuses more on the relationship characteristics of individuals in the network.

Bayesian Network model (BN) is a probability graph model that uses directed acyclic graphs to represent random variables and their conditional dependencies (Zhang Zhicheng, 2024). Nodes represent variables, edges represent conditional dependencies, and unconnected nodes represent conditional independence. Each node is associated with a probability function, which gives the probability of the node based on the variable values of the parent node.

Genetic Algorithm-Back Propagation is also called GA-BP. The GA-BP algorithm refers to the use of genetic algorithms to optimize backpropagation neural networks for improving their performance and efficiency. This method combines the evolution of genetic algorithms and the learning ability of backpropagation neural networks to achieve better optimization results (Xu Jingwei, 2020). Through this process, genetic algorithms can search the parameter space of neural networks, find the optimal parameter combination, and optimize the performance and generalization ability of neural networks. This method is commonly used to handle complex optimization problems, especially when neural networks have a large number of parameters.

Cloud model theory is a concept proposed by Li Deyi, academician of the CAE Member in 1995, is an uncertainty transformation model that deals with qualitative concepts and quantitative descriptions. It can represent the process from qualitative concepts to quantitative representations (forward cloud generator), or it can represent the process from quantitative representations to qualitative concepts (reverse cloud generator). The cloud model represents the primitives in natural language - language values, and uses the numerical features of clouds - expected Ex, entropy En, and super entropy He-to represent the mathematical properties of language values (Liu Yukexin, 2022). The research progress in the past 10 years has been investigated and summarized in Table 2.

Table 2: Summary of Research Progress on utility tunnel Risk Assessment Model

Reference / **Time**	**weight**	**assessment**
Chen Wei （2022）	DEMATEL Direct impact matrix	Fuzzy comprehensive evaluation
Li Fangzhen （2017）	AHP	Fuzzy comprehensive evaluation
Xu Hanyan （2020）	AHP	Fuzzy comprehensive evaluation
Ma Huigan （2021）	AHP	Fuzzy comprehensive evaluation
Hu Yihuan （2023）	Fuzzy analytical hierarchy process	Fuzzy comprehensive evaluation
Chen Bo （2020）	AHP Entropy method Minimum deviation and Combination weighting	Improving SVM Theory
Han Yuhong （2024）	AHP Entropy method Game theory	Bayesian network model
Cai Menglong （2020）	C-OWA	D-S synthesis algorithm
Zhao Hui （2020）	CRITIC GI weighting method	Improved Extended Matter Element Theory
Qiu Shi （2019）	Entropy method	coupling model
Zhang Yong （2020）	Entropy method DEMATEL	coupling model Vensim PLE software
Zhuang Shuai （2022）	Entropy method	uncertainty measurement theory
Huang Huijun （2020）	C-OWA	Grey correlation degree
Jiang Hao （2023）	C-OWA	interaction matrix

Reference Time	weight	assessment
Chen Zeming （2020）	AHP	Grey correlation degree
Chen Shengfa （2023）	Social Network Analysis Method	Net draw software Ucinet6.0 software
Huang Ping （2020）	Static subtree Dynamic Accident Tree	Meta decision diagram markov chain model
Liu Yukexin （2022）	AHP	Cloud model Fuzzy comprehensive evaluation
Liu Keru （2018）	Grey correlation degree	
NGUYEN Thi Thuy Trang （2020）	AHP	
Qin Huali （2022）	1D-CNN	
Zhang Zhicheng （2024）	Bayesian network model	
Xu Jingwei （2020）	GA-BP	

3.3 Critical Synthesis and Methodological Limitations

As shown in Table 2, to overcome the subjectivity of qualitative analysis, quantitative models such as Bayesian Networks, and fuzzy mathematics have been introduced into the field of utility tunnel risk assessment. This combination of qualitative and quantitative methods significantly improves the objectivity of the assessment process and the accuracy of the results. However, the overemphasis on these methods has also brought new problems.

Some methods have extremely high requirements for the quality and quantity of basic data. Given the current reality of insufficient standardization of engineering data and incomplete historical databases, their complex calculations may simply be “precisely calculating inaccurate data,” leading to a “garbage in, garbage out” dilemma.

Methods such as While Bayesian Networks can dynamically update probabilities and express causal relationships, the construction of their network structure and the assignment of conditional probability tables still largely depend on expert judgment, failing to completely eliminate subjectivity. Furthermore, the model complexity increases exponentially with the increase of risk factors, leading to decreased interpretability.

Therefore, while this type of research makes significant methodological contributions, a large amount of literature exhibits a technology-oriented phenomenon of “synthesis for the sake of synthesis.” Many studies focus on improving weight calculations or membership functions, but neglect to delve into the engineering essence of the constructed indicator systems. This leads to a disconnect between the evaluation models and the specific technological, geological, and management scenarios of utility tunnel construction. There are more generalized models than specialized ones, and their foundations still cannot completely escape subjective qualitative inputs. Furthermore, most comprehensive models remain ‘static snapshots,’ failing to simulate the dynamic process of construction risks evolving as the project progresses.

Conclusion

In recent years, with the continuous expansion of the scale of integrated utility tunnel construction, construction safety accidents have occurred frequently, and construction risks have increasingly become a focus of attention for academic circles both domestically and internationally. Regarding risk assessment methods, an increasing number of studies are attempting to introduce new assessment models into the risk assessment system for utility tunnel construction. Some of these studies have built risk assessment models based on qualitative and quantitative indicators, demonstrating good results in engineering risk prediction and prevention.

However, overall, existing risk assessment models for utility tunnel construction still largely rely on qualitative descriptions of engineering geology, hydrology, and construction conditions, lacking in the quantitative processing of evaluation factors and the analysis of interaction mechanisms between indicators.

Overall, current research has made phased progress in promoting the development of risk assessment from qualitative to quantitative methods, but significant shortcomings remain in dynamic risk monitoring, multi-source information fusion, intelligent early warning, and interdisciplinary system integration. Future research needs to further integrate big data and artificial intelligence technologies to develop a more real-time, interactive, and operable dynamic risk assessment system to comprehensively improve the scientific rigor and proactiveness of integrated utility tunnel construction risk management.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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