Risk Evaluation and Mitigation Strategies for Real-Scene 3D Construction Projects in ZC

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Abstract: This paper focuses on real-scene 3D construction projects, emphasizing their significant applications across various fields and the associated risks. The study conducts risk evaluation and strategy formulation through literature review, field surveys, and expert consultations, identifying risk factors related to safety, environment, quality, schedule, management, and finance, and develops a risk indicator system. Using the fuzzy analytic hierarchy process for risk evaluation, the study determines the impact and severity of each risk factor. Based on the evaluation results, targeted risk mitigation measures are formulated, accompanied by the establishment of a risk monitoring mechanism. The research provides a scientific basis for risk management in real-scene 3D construction projects, aiding in the smooth implementation and broader application of this technology.

Keywords: Real-Scene 3D Construction Projects; Risk Evaluation; Fuzzy Analytic Hierarchy Process; Risk Mitigation

1. Introduction

1.1 Research Background and Significance

In the digital era, real-scene 3D technology, which integrates advanced multidisciplinary innovations, provides a vivid representation of geographical entities and spatial environments. It plays a crucial role in industries such as urban planning, cultural heritage preservation, and tourism development. Despite its potential, real-scene 3D construction projects are emerging fields that encounter numerous risks during implementation. These projects are characterized by their extensive scope, lengthy timelines, and significant investment, involving multiple domains, processes, and stakeholders, which complicates risk management. Ineffective risk management could result in projects not meeting expected outcomes. Presently, there is a paucity of Chinese research on risk evaluation for these projects, and this paper seeks to address this gap by offering project managers a scientific basis for decision-making, thus ensuring successful project execution.

The study is vital both theoretically and practically. Theoretically, it develops a risk evaluation framework tailored to real-scene 3D construction projects, offering an in-depth analysis of the interconnections and mechanisms of risk factors. This contributes new insights and methods for advancing the theoretical framework of geographic information project risk management. Practically, it aids project investors, developers, and operational managers in devising proactive risk management strategies, thereby reducing potential losses and ensuring project continuity. Additionally, it provides a reference model for the ZC region and similar projects, promoting the widespread and sustainable development of real-scene 3D technology.

1.2 Literature Review in China and Internationally

Since the publication of *Risk Management for Enterprises* in 1963, research in risk management has gradually become systematic and specialized. Scholars from around the world have extensively explored definitions, processes, and methods of risk management.

Chatterjee [1] described risk identification as a systematic and dynamic process. Murphy and Gardoni [2] developed a capability-based analytical framework to identify risks in large-scale projects. Javid and Prianka [3] employed theories such as fuzzy linear programming to construct risk identification models. Tang [4] used a combination of Fault Tree Analysis (FTA) and the Analytic Hierarchy Process (AHP) to identify risk factors in construction projects. Fan highlighted the dynamic nature of risk management and emphasized dynamic analysis to establish risk evolution models for comprehensive and precise risk management. Samantra et al. [6] developed a risk evaluation system based on fuzzy set theory. Zhang and Shang [7] proposed a model combining conventional cloud models and entropy weight methods to assess risks in underwater shield tunnel construction. Famiyeh and Bassaw [8] devised an integrated predictive safety risk evaluation model for assessing occupational health and safety risks of construction site workers. Zhou and Liu [9] employed cluster analysis to dissect risk factors affecting information technology projects, addressing both internal and external factors, and developed a risk evaluation method suitable for such projects. Zhao [10] focused on wind power project risk evaluation and innovatively proposed a support vector algorithm, applying it to wind power projects to provide accurate risk evaluation for investment decision-making.

1.3 Research Content and Methodology

The primary focus of this study includes the identification, assessment, and response strategies for risks in the 3D construction project in ZC. During the risk identification phase, methods such as literature review, field research, and expert surveys are employed to gather potential risk factors at various project phases and to establish a risk indicator system. In the risk evaluation phase, the Fuzzy Analytic Hierarchy Process (FAHP) is used to calculate the weights of risk indicators, determine evaluation sets, conduct expert scoring, construct a fuzzy matrix, and compute the membership degree of each indicator to obtain the risk evaluation results. For the risk response strategy phase, specific measures are devised for different risk factors, based on risk response principles, and a risk monitoring mechanism is established.

The research methods primarily include literature analysis, which involves collecting and comparatively analyzing Chinese and international literature on risk identification and assessment methods; the WBS decomposition method, which breaks down the project into sub-projects and tasks during the preliminary risk identification phase to analyze potential risks; expert interviews, which involve engaging industry experts to participate in risk identification and assessment and gather professional opinions; and the AHP-Fuzzy comprehensive evaluation model, which synthesizes the Analytic Hierarchy Process and fuzzy comprehensive evaluation methods to achieve both qualitative and quantitative evaluation of project risks.

1.4 Technical Route and Innovation

The technical route of this study involves first clarifying the research background and significance, along with organizing relevant theories. Next, risk identification for the 3D construction project in ZC is conducted, and a risk indicator system is established. This is followed by employing the Fuzzy Analytic Hierarchy Process for risk evaluation. Finally, based on the assessment results, risk response strategies are formulated and a risk monitoring mechanism is established.

The innovations in the research are primarily in two areas: first, constructing a comprehensive and systematic risk evaluation system, innovatively using the WBS decomposition method and literature analysis for risk identification, and developing a unique risk evaluation model to achieve thorough and precise project risk evaluation; second, closely integrating theory and empirical analysis by using the 3D construction project in ZC as a case study to develop practical response strategies.

2. Overview of Relevant Theories

2.1 Introduction to Risk and Project Risk

Risk refers to the uncertainty of future outcomes of events. This study adopts a narrow definition of risk, focusing on the uncertainty of loss occurrence. Mathematically, risk can be expressed as $R = f(P, C)$, where R denotes risk, P represents the probability of an adverse event, and C signifies the consequences of the adverse event. Risk exhibits characteristics such as objectivity, uncertainty, adversity, relativity, and symmetry. It can be categorized into various types, including pure risk, speculative risk, natural risk, and man-made risk, depending on the classification criteria.

Project risk involves uncertainty factors during project execution that may negatively impact project objectives. It mainly includes three key attributes: risk factors, risk events, and risk losses, characterized by phasing, gradual progression, predictability, and randomness.

2.2 Knowledge Related to Risk Identification

Risk identification is the initial step in risk management, involving the assessment, classification, and clarification of the nature of risk sources and factors a project may face. Methods include literature analysis, expert surveys, WBS decomposition, fault tree analysis, and SWOT analysis. The process encompasses personnel and resource analysis and classification, risk prediction and identification, and analysis of consequences and loss patterns. It requires ongoing and institutionalized efforts.

2.3 Knowledge Related to Risk Evaluation

Risk evaluation involves integrating identified risk factors with quantitative analysis results to build a risk evaluation model based on project objectives and determine the project's risk level. The research content includes reviewing project risk background information, defining risk evaluation benchmarks, applying risk evaluation methods to construct the model, ranking the impact of risks to identify critical risks, and determining the project's risk status with a comprehensive assessment.

Common methods of risk evaluation include quantitative, qualitative, and combined qualitative-quantitative approaches. Quantitative methods such as the Fuzzy Comprehensive Evaluation Method, Attribute Mathematics, and Monte Carlo Simulation describe risk in quantifiable terms. Qualitative methods like Subjective Scoring, Analytic Hierarchy Process, LEC Method, and Decision Tree evaluate risk based on severity. Combined methods, such as Analytic Hierarchy Process-Fuzzy Comprehensive Evaluation, Bayesian Network Modeling, and Risk Ordering and Screening (ROS), consider both qualitative and quantitative factors for a more comprehensive and accurate risk evaluation.

2.4 Concepts Related to Real-Scene 3D Construction Projects

Real-scene 3D construction is a systematic project utilizing modern surveying and geographic information technology for comprehensive, accurate 3D spatial data collection, modeling, and integration across China's land and marine areas. The goal is to build a three-dimensional spatial framework to serve multiple fields. Key technological supports include data acquisition, data processing and modeling, and data fusion and updating technologies. Application areas encompass natural resource management and monitoring, urban and rural planning and construction, emergency management, and disaster prevention. Data standards involved in real-scene 3D construction projects include data formats, coordinate systems, accuracy requirements, with quality control extending throughout the data acquisition, processing, fusion, and updating processes.

3. Construction of the Risk Indicator System for Real-Scene 3D Projects in ZC

3.1 Project Overview and Current Risk Management Status

The Real-Scene 3D construction project is located in the western region of Zibo City, Shandong Province, encompassing the Zhoucun District, Wenchang Lake Area, Wangcun Town, and two specific zones in the Southern Suburb. Covering a total area of 90.86 square kilometers, the project aims to provide high-precision 3D geospatial models for urban planning, cultural heritage protection, and tourism development, scheduled from September 2023 to December 2026.

Prior to project initiation, the company identified risks such as personnel safety, technical operations, external environmental factors, and time management. Measures like safety training, developing technical response strategies, coordination with stakeholders, and schedule planning have been implemented, yet numerous challenges persist. Thus, there's an urgent need for risk evaluation to devise more effective counterstrategies.

3.2 Selection of Risk Identification Methods

Considering the project complexity and uniqueness, a combination of literature analysis, expert surveys, and the Work Breakdown Structure (WBS) method is selected for risk identification. Literature analysis provides theoretical foundations and practical experiences through professional sources. Expert surveys engage industry specialists, leveraging their expertise for comprehensive and accurate risk identification. The WBS method decomposes the project according to intrinsic logic and implementation processes, ensuring comprehensive and systematic risk identification. These methods complement each other, securing accurate risk identification for the project.

3.3 Construction and Selection of the Risk Indicator System

The WBS method divides the Real-Scene 3D construction project in ZC into planning, implementation, and maintenance phases, further breaking them down into subprojects and tasks. Initial risk indicators are selected through literature research, constructing a preliminary risk indicator system, which includes primary indicators such as safety, environmental, quality, schedule, management, and financial risks, along with various secondary indicators.

3.4 Determination of Risk Indicators for the Real-Scene 3D Construction Project in ZC

Using expert interviews, a deeper exploration of the initially selected risk indicators is conducted. Twenty experienced experts in the field of surveying are invited to rate the importance of the risk indicators and identify any overlooked risk factors. Through expert evaluation and discussion, the final risk indicator system for the Real-Scene 3D construction project in ZC is established, which is crucial for subsequent risk evaluation and strategy formulation.

4. Risk Evaluation of Real-Scene 3D Construction Project in ZC

4.1 Introduction and Selection of Risk Evaluation Methods

To address the risk indicators in the Real-Scene 3D construction project in ZC, we employ a combination of the AHP and the Fuzzy Comprehensive Evaluation Method. AHP decomposes decision-related elements into multiple levels, such as goals, criteria, and alternatives, for both qualitative and quantitative analysis to determine the relative importance of each factor. The Fuzzy Comprehensive Evaluation Method converts qualitative indicators into quantitative data using the concept of membership degree, employing the fuzzy relation synthesis principle for quantification. The synergy of these methods allows for a more scientific and rational evaluation of project risks.

4.2 Establishment of the AHP–Fuzzy Comprehensive Evaluation Model

The steps in the Fuzzy Analytic Hierarchy Process (FAHP) include determining the factor set and weights, defining the comment set, having experts score the evaluations, constructing the fuzzy matrix R, and calculating the membership degree for each indicator to finalize the evaluation results. In this study, the factor set comprises fundamental indicators influencing the risks of the Real-Scene 3D project in ZC, with AHP determining the weight of each risk factor. The comment set linguistically describes project risk issues. Experts familiar with the project provide scores, constructing the fuzzy matrix R. A weighted average fuzzy operator then calculates each indicator's membership degree to ultimately determine the evaluation outcome.

4.3 Construction of the Real-Scene 3D Project Risk Evaluation Model in ZC

Based on the identification and determination of risk indicators, a risk evaluation system for the Real-Scene 3D construction project in ZC is established. This includes primary indicators such as safety, environmental, quality, schedule, management, and financial risks, along with corresponding secondary indicators.

Using AHP, the risk factor weights are calculated by forming judgment matrices, computing geometric averages of disparate elements, and normalizing them to derive each indicator's weight. Consistency checks ensure the rationality of the judgment matrices. The results reveal weightings of 0.381 for safety risks, 0.064 for environmental risks, 0.101 for quality risks, 0.042 for schedule risks, 0.160 for management risks, and 0.252 for financial risks.

The comment set is defined as {High, Relatively High, Average, Relatively Low, Low}. Twenty experts from various fields evaluate the project risk factors, and upon data normalization, a fuzzy membership matrix R is constructed. Each indicator's membership degree is calculated based on its weight and the fuzzy matrix, e.g., the membership vector for safety risks is (0.037, 0.216, 0.299, 0.440, 0.008).

4.4 Risk Evaluation Results for the Real-Scene 3D Construction Project in ZC

The calculation results facilitate an analysis of risk levels for each indicator. Most experts assess safety risks as relatively low, environmental risks as relatively low, quality risks and schedule risks as average, management risks and financial risks as relatively high.

By multiplying the membership degree by the comment scores and summing them, the final score for each indicator is computed. The results indicate that management risks carry the highest weight, with environmental risks the lowest. This provides a clear direction for project risk management, suggesting that the project team should prioritize addressing management risks and simultaneously develop management strategies for other risk factors.

5. Risk Mitigation Strategies for Real-Scene 3D Construction Projects in ZC

5.1 Analysis of Project Risk Factors

Safety risks involve transportation hazards for survey personnel, on-site operational dangers, safety threats posed by measuring near power distribution equipment, and data security risks during processing and utilization. Environmental risks include wind variations affecting aerial surveys, risks from extensive water bodies, and challenges posed by flight regulations on surveying activities. Quality risks relate to implementation plans, surveying instruments, technical proficiency of personnel, quality control protocols, and software reliability. Schedule risks are influenced by adverse weather conditions, major events or holidays, and the availability of hardware, software, and staffing resources. Management risks encompass inadequate leadership coordination, poor data management, lack of risk management awareness, and ineffective coordination between field and office operations. Financial risks are largely due to delays in fund disbursement and rising costs of surveying instruments and hardware/software facilities.

5.2 Risk Mitigation Measures for the Project

Risk management should adhere to principles like tailoring measures to project specifics, balancing costs and benefits, adapting to changing circumstances, and clarifying responsibilities. Different strategies should be employed for various risk factors.

Management Risk Mitigation: Risks of data mismanagement leading to loss or damage could be reduced by assigning dedicated personnel to manage server folders and restricting employee access. Inadequate leadership coordination might be addressed by appointing specialized staff for communication. Risk management awareness may be enhanced through organizing training sessions to sensitize employees. Poor coordination between field and office operations could be improved by forming project teams with clear responsibilities.

Financial Risk Mitigation: Ensuring prompt fund disbursement might involve including prepayment clauses in contracts and optimizing internal processes. Increased costs for equipment and software could be managed by procuring or leasing based on actual needs.

Quality Risk Mitigation: Implementation plan risks could be addressed by consulting experts and adjusting plans according to project specifics. Risks in quality control and software might be mitigated by assigning lead parties to develop plans and update software in real-time. Unskilled personnel concerns could be counteracted by ensuring supplier training and organizing internal knowledge sharing. Surveying instruments like drones and GPS may benefit from thorough testing.

Schedule Risk Mitigation: Resource risks might be mitigated by increasing investments to ensure timely project completion. Planning around adverse weather might help, along with creating emergency plans. For major events or holidays, arranging schedules thoughtfully and accommodating overtime based on employee preference could be beneficial.

Safety Risk Mitigation: Transportation safety for survey personnel might improve with dedicated drivers. On-site safety might be enhanced through safety training and commitment agreements. Risks near power equipment could be mitigated by procuring insulated clothing and conducting demonstration training. To prevent data security breaches during handling, promoting confidentiality awareness and obtaining confidentiality agreements might prove effective.

Environmental Risk Mitigation: Suitable flying conditions might help manage wind variability during aerial surveys, with frequent checks of photo quality. Coordination with flight schools might determine appropriate flying times. Strategic planning of flight times and routes could address the impact of large water bodies on aerial surveys.

5.3 Monitoring of Project Risks

Risk monitoring is a crucial aspect of project risk management, employing methods such as audit inspections, risk checklist methodologies, earned value analysis, and project risk reporting to track and monitor risks effectively. Audit inspections can be conducted at specific times post-implementation in the form of audits or review meetings. The risk checklist methodology records the nature of risk factors, response measures, and responsible parties, enabling dynamic management. Earned value analysis takes into account cost and schedule risks. Project risk reports communicate risk information to stakeholders.

The risk monitoring process includes risk identification, risk evaluation, the development and execution of risk response plans, monitoring risk status, and adjusting response strategies, forming a closed-loop dynamic management process.

A risk management team is established within the company, with clearly defined member responsibilities. The team leader, appointed from the company's vice president, oversees comprehensive management. The deputy leader, typically the project manager, handles risk-related tasks in various project phases. Different risk factors are managed by the field operations leader, quality management department, project technical leader, project deputy manager, and commercial department, ensuring accountability in risk monitoring.

6. Conclusion and Outlook

6.1 Research Conclusions

This study on real-scene 3D construction projects employs a variety of methods to identify key risk factors, establishing a comprehensive and systematic risk indicator system in the risk identification phase. During the risk evaluation phase, the fuzzy analytic hierarchy process delivers scientifically accurate risk evaluations, clarifying the impact levels and risk grades of different factors. Based on these evaluations, an in-depth analysis of risk factors are conducted, leading to the formulation of highly targeted and feasible risk response measures and the establishment of a robust risk monitoring mechanism. These research findings provide strong support for risk management in real-scene 3D construction projects, helping to ensure successful project execution.

6.2 Outlook

Despite achieving significant outcomes, this study has some limitations. In China, research on risk in surveying projects is still evolving, and the identification of risk factors in real-scene 3D construction projects requires greater completeness. Future studies should expand their scope and use advanced technologies to enhance the risk identification system. The use of the analytic hierarchy process introduces subjectivity, so future research could benefit from integrating objective data and quantitative metrics to improve the evaluation model’s objectivity and reliability. Additionally, the general applicability of this study’s methods and findings to other surveying projects needs further validation. Exploring the unique characteristics and risk patterns of different surveying projects will help optimize methodologies and improve the practical value of the research.

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