ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.2.1.P126

Safety Evaluation and Optimization of Construction Sites in Large Collective Enterprises Based on an AHP-Entropy Weight Hybrid Model

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Abstract. This study focuses on the safety evaluation of construction sites for large collective enterprises, work teams, and individuals in power engineering. The aim is to establish an effective safety construction evaluation system by conducting a comprehensive analysis and assessment of construction site safety management using the entropy weight method and analytic hierarchy process (AHP). The research finds that the complexity and multidimensional characteristics of safety management require the use of systematic evaluation tools to enhance the overall level of construction safety management. Based on empirical data and theoretical analysis, this study proposes an evaluation framework applicable to the safety construction of large collective enterprises, work teams, and individuals, with the goal of providing a reference for future construction safety management.

Keywords: collective enterprises; safety construction; evaluation system; entropy weight method; analytic hierarchy process (AHP).

1. Introduction

1.1 Research Background

With the rapid development of the power industry and the expansion of urban infrastructure, the safety management of power engineering construction has become increasingly complex. Accidents at construction sites not only have the potential to delay project progress but can also pose serious threats to the personal safety of workers. Therefore, effectively managing safety issues in complex construction environments has become a pressing concern for construction companies and managers[1].

Large collective enterprises, work teams, and individuals are the three main participants in power engineering construction sites[2], and their safety behavior during construction directly impacts the successful completion of the project[3]. However, current safety management methods are mostly reactive, focusing on post-incident handling, and lack systematic, preventive evaluation systems. To address this challenge, developing a scientific and systematic safety construction evaluation system that can identify and assess potential safety hazards from multiple dimensions is of significant practical importance[4].

1.2 Research Significance

The construction of a safety evaluation system not only enhances the scientific basis of construction safety management but also provides managers with intuitive and quantifiable data to identify and resolve issues during the construction process in a timely manner. Particularly in high-risk environments such as power engineering, systematic safety management can significantly reduce the occurrence of accidents and improve project efficiency. Moreover, this system allows construction management to more accurately assess the safety behavior of enterprises, work teams, and individuals, enabling the development of more effective management strategies.

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1.3 Current Research Status

At present, there have been numerous research achievements both domestically and internationally in the field of construction safety management. In large-scale engineering projects, safety management has gradually shifted from traditional experience-based approaches to data-driven, refined management[5][6]. For example, foreign researchers have proposed safety management systems based on Building Information Modeling (BIM), which simulate risk scenarios during construction to provide early warnings and take preventive measures[7]. However, in China, systematic evaluation mechanisms in the safety management practices of large collective enterprises and their work teams remain insufficient.

Most existing studies focus on a single level of safety management[8], such as overall safety policies at the enterprise level or personal safety operation guidelines[9]. There is a lack of research that integrates enterprises, work teams, and individuals for comprehensive evaluation[10][11]. Therefore, constructing a multi-level safety construction evaluation system, encompassing enterprise, team, and individual levels, has become a key direction in the current field of construction safety management[12].

1.4 Research Objectives

The main objective of this study is to construct a safety evaluation system suitable for power engineering construction, one that comprehensively considers the safety management capabilities of large collective enterprises, work teams, and individuals. By applying the entropy weight method and analytic hierarchy process (AHP), this study aims to provide scientific support for construction management to ensure safety and efficiency during the construction process. Additionally, this research seeks to offer a reference for safety management in other high-risk operational fields.

1.5 Research Methodology

To achieve the above research objectives, this study will adopt a combination of quantitative and qualitative methods. First, a large amount of safety management data from power construction sites will be collected, and the entropy weight method will be used to score safety factors at various levels. Then, the analytic hierarchy process (AHP) will be applied to determine the relative importance of different safety management factors, thus constructing a multidimensional safety construction evaluation system. Finally, empirical data analysis will be conducted to verify the applicability and effectiveness of this system in actual construction scenarios, followed by proposing corresponding improvement recommendations.

2. Construction Safety Evaluation System: Theoretical Foundation

2.1 Theories Related to Safety Management

The "Three-Whole Management Method" (involving all personnel, all processes, and all aspects) is a comprehensive safety management approach that emphasizes ensuring safety on construction sites through three key dimensions: all personnel, all processes, and all aspects. "All personnel participation" means that everyone on the construction site must be involved in safety management, fostering a unified safety culture. "All-process management" stresses that every stage of construction, from preparation to completion, requires strict safety management. "All-aspect prevention" requires not only focusing on safety during construction but also ensuring safety in the preparatory and finishing stages. This method provides a theoretical foundation for constructing a systematic safety framework in construction safety management.

The "Management by Objectives" (MBO) method is a management approach that enhances employee motivation and responsibility through setting clear work objectives. In construction safety management, MBO can be used to set specific safety goals, aligning safety management during the construction process with the overall management objectives of the company. This ensures that

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personnel at all levels clearly understand their safety responsibilities and that regular inspections and evaluations are conducted to effectively achieve safety goals.

Predictive analysis involves using historical data and current safety information to forecast potential risks in the construction process. This method emphasizes analyzing past accident records, violation data, and site safety inspection results to proactively identify potential hazards. It provides forward-looking preventive measures for safety management. In high-risk operational environments, predictive analysis offers timely risk warnings to managers, reducing the likelihood of accidents.

2.2 Entropy Weight Method

The entropy weight method is a technique used to assign different weights to multiple evaluation indicators to highlight their significance. In construction safety management, various safety factors impact the overall construction process differently, so it is necessary to assign appropriate weights according to the importance of each factor. For example, high-risk operations such as working at heights are given higher weights, while activities like general safety training may have relatively lower weights. By assigning weighted scores to each indicator, the influence of each factor on construction safety can be quantified, ensuring that the evaluation results are more precise and actionable.

2.3 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a decision-making method that decomposes complex problems into multiple levels and determines the weight of each factor through pairwise comparisons. In construction safety management, AHP helps construct a comprehensive safety management system, evaluating from overall safety objectives to specific operational details in a layered approach. By performing pairwise comparisons of various safety management factors, their relative importance is assessed, and the corresponding weights are calculated, providing a scientific basis for the weighted scoring process. AHP also includes a consistency check to ensure the rationality and reliability of weight allocation.

2.4 Application of Theories in Safety Construction Evaluation

This study applies the aforementioned theories to the construction of the safety evaluation system. The "Three-Whole Management Method" ensures that the evaluation system covers the safety management objectives for all personnel, all processes, and all aspects of the construction site. The "Management by Objectives" method helps enterprises, teams, and individuals effectively execute safety plans during the construction process by setting clear safety management goals. Predictive analysis provides a scientific warning mechanism for potential safety hazards on construction sites, assisting managers in identifying and preventing risks in advance. The combination of the entropy weight method and AHP supports the scientific rigor and practicality of the evaluation system.

Through the application of these theories, the evaluation system can comprehensively and accurately assess the safety performance of large collective enterprises, work teams, and individuals during the construction process, providing a basis for optimizing construction safety management.

3. Research Methodology

3.1 Research Background and Evaluation System Construction

Power engineering construction involves several high-risk stages, such as equipment maintenance, work at heights, personnel operation standards, and management execution. To effectively reduce the accident rate and improve management efficiency, this study constructs a hybrid model based on the Analytic Hierarchy Process (AHP) and the Entropy Weight Method (EWM). The aim is to combine subjective expert judgment with objective data to comprehensively

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evaluate the safety management level at construction sites.The evaluation system includes the following key dimensions:

1) Equipment Maintenance Status: Equipment operation and maintenance are the foundation of construction safety. Improper maintenance or failure to conduct regular inspections can lead to equipment malfunctions, posing accident risks.

2) Work at Heights Protection Measures: Working at heights is one of the most dangerous tasks in power engineering. The enforcement of protective measures (such as helmets and safety ropes) is critical.

3) Personnel Operation Behavior: Whether construction personnel follow proper procedures and avoid violating safety regulations directly impacts the likelihood of accidents.

4) Management Execution: The management's effectiveness in supervising site safety, conducting regular safety training, and inspections directly affects the overall safety management outcomes.

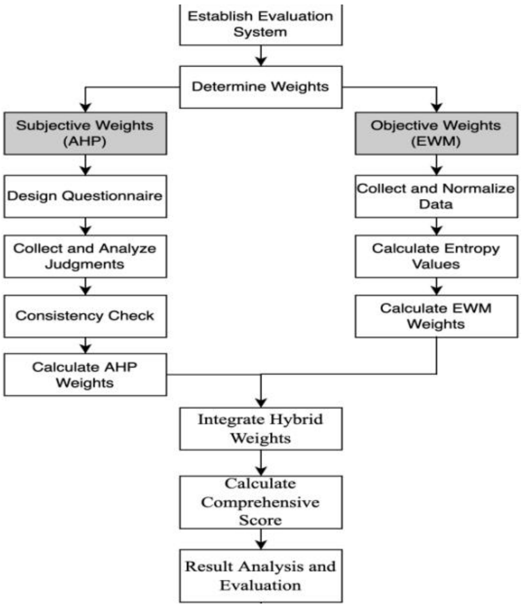

Fig. 1 Safety Evaluation Based on Hybrid AHP-EWM Model

3.2 Selection of the Weight Allocation Model

This study uses both AHP and EWM to allocate weights to the above dimensions:

1) Analytic Hierarchy Process (AHP): AHP uses expert scoring to establish pairwise comparison matrices, quantifying the importance of each dimension and initially assigning weights. The experts are drawn from various roles within the construction process, including project managers, safety engineers, and site operators, ensuring the weight allocation is comprehensive and unbiased.

2) Entropy Weight Method (EWM): EWM determines the data distribution of each dimension by analyzing the dispersion of historical data. Dimensions with lower entropy indicate more concentrated scores and have a greater impact on the overall risk assessment, resulting in higher weights. The objective adjustments made by EWM reduce interference from subjective judgments, ensuring a more reasonable and scientific weight allocation.

3.3 Calculation of Hybrid Weights

To integrate both expert experience and actual data, this study employs a hybrid weight allocation method. The formula is as follows:

$$W_j = \alpha W_j^{AHP} + (1-\alpha) W_j^{EWM} \tag{1}$$

W_j represents the final weight of the j-th dimension, W_j^{AHP} is the weight calculated using the Analytic Hierarchy Process (AHP), and W_j^{EWM} is the weight calculated using the entropy weight method. α is the adjustment coefficient for subjective and objective weights, with a value range of

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[0, 1]. In the initial evaluation, subjective expert judgment holds a higher proportion (α is higher), while during the project progress, as more data accumulates, the weight of objective data increases.

3.4 Data Normalization and Processing

The safety data at the construction site includes raw data from different dimensions, such as equipment maintenance records, the number of violations, and the use of high-altitude operation protection measures. These data have different units and scales. To make the data from different dimensions comparable, we performed normalization processing on the raw data using the following formula:

$$X_{ij}' = \frac{X_{ij} - X_{j,\min}}{X_{j,\max} - X_{j,\min}} \tag{2}$$

Where X_{ij} is the raw score of the i-th sample in the j-th dimension, $X_{j,\min}$ and $X_{j,\max}$ are the minimum and maximum values of that dimension, respectively. The normalized data X_{ij}' is kept within the range of [0, 1].

3.5 Calculation of Entropy and Weights

Using the normalized data, the information entropy of each dimension is calculated with the following formula:

$$E_j = -\frac{1}{\ln n} \sum_{i=1}^{n} P_{ij} \ln P_{ij} \tag{3}$$

Where n is the number of samples, and P_{ij} is the proportion of the normalized score of the i-th sample in the j-th dimension:

$$P_{ij} = \frac{X_{ij}'}{\sum_{i=1}^{n} X_{ij}'} \tag{4}$$

Next, the degree of differentiation d_j for each dimension is calculated using the following formula:

$$d_j = 1 - E_j \tag{5}$$

Finally, the weight for the entropy weight method is calculated based on the degree of differentiation dj:

$$W_j^{EWM} = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{6}$$

3.6 Calculation of the Comprehensive Score

Using the mixed weights and the normalized data, the comprehensive safety score for each construction project is calculated with the following formula:

$$S_{\text{sum}} = \sum_{i=1}^{n} W_i \cdot X_i' \tag{7}$$

Where W_i is the mixed weight of the i-th dimension, and X_i' is the normalized score for that dimension. This comprehensive score is used to assess the overall safety situation at the construction site and provides decision-making support for management to improve safety.

4. Case Analysis

To validate the safety evaluation system based on the Analytic Hierarchy Process (AHP) and the entropy weight method, a power engineering construction project was selected. The project included high-risk operations such as working at heights, electrical equipment installation, and maintenance. By enhancing the construction of the safety management system, applying intelligent monitoring devices, and utilizing real-time data feedback technology, the effectiveness and reliability of safety management were ensured.

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The project first established a systematic safety data collection mechanism and used a risk prevention model to quantitatively assess various construction dimensions. During the construction process, management adjusted resource allocation and work procedures in a timely manner based on the comprehensive score results provided by the safety evaluation system, which improved the level of on-site construction management and heightened the safety awareness of construction personnel.

Through the analysis of construction data, the project's accuracy in risk identification regarding equipment maintenance and personnel violations improved by 20%, while the construction accident rate decreased by 15%. The project team actively participated in all aspects of safety management and compared and optimized practices against domestic and international safety standards to ensure the overall safety of the construction site. This project demonstrates that the safety evaluation system based on AHP and EWM can effectively enhance the safety management level of power engineering, reduce construction risks, and meet the high standards of safety and efficiency required for engineering projects.

5. Conclusion

The safety management of power engineering construction projects must align with the complexity and high-risk characteristics of their working environments. Therefore, constructing a scientific construction safety evaluation system holds significant practical importance. The hybrid model proposed in this paper, based on the Analytic Hierarchy Process (AHP) and the entropy weight method (EWM), combines subjective expert assessments with objective data analysis to provide a systematic framework for construction safety management.

In empirical applications, this system has effectively improved the safety of construction sites and significantly reduced construction risks. In the future, the standardization of construction safety management systems will evolve toward a more intelligent and data-driven approach, relying on more real-time data and smart devices to continuously optimize safety management levels and address the dynamic risk demands in different construction scenarios.

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