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Analysis of quality risk factors in prefabricated construction based on association rule mining algorithm

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***Abstract*—Prefabricated construction has gained significant popularity in the modern building industry due to its advantages in efficiency and quality control. However, various quality risk factors exist during the prefabricated construction process, which may lead to potential negative impacts on project outcomes. In this research, the data related to quality risk factors in prefabricated construction are first collected. After that, data mining is performed with the application of the analytic hierarchy process (AHP) to analyze the risk data. Subsequently, the triangular fuzzy number method is employed to calculate the weight of each level of risk source within prefabricated construction. It then mines association rules based on support degree and confidence degree, extracting quality risk factors in prefabricated construction. Secondly, the fuzzy comprehensive evaluation method is utilized to ascertain the risk level in prefabricated construction. Ultimately achieving a quantitative risk assessment and analysis of the key stages of the prefabricated concrete building structure. This method not only avoids the subjectivity of assessment experts but also solves the objective problem of purely theoretical calculation. Thus, according to the results of risk analysis, targeted construction risk control measures are proposed, providing an innovative approach for the safety assessment of prefabricated construction.**

Keywords*—prefabricated construction, quality risk factors, association rule mining algorithm

I. Introduction

Prefabricated construction has emerged as a significant trend in the modern building industry, offering enhanced efficiency and better quality control. However, the construction process of prefabricated buildings is characterized by its complexity, which encompasses multiple sequential stages such as the production of prefabricated components, transportation thereof, lifting operations, and on-site assembly. The conduction of precise construction risk evaluations constitutes a pivotal factor in ensuring the triumphant execution and delivery of projects, as well as in attaining the requisite building quality benchmarks. With regard to evaluating the construction risks of prefabricated concrete edifices, a multitude of academics have initiated corresponding investigations. Tian and Li identify and classify risk sources in light of the characteristics of prefabricated buildings and uses a fault tree to model the causal relationships of risk factors, thereby constructing a prefabricated building quality risk analysis model based on the fault tree - fuzzy Bayesian network[1]. Wang and Zhang explored the correlation among the quality risk factors of prefabricated buildings. They calculated the objective weights by considering the variable weight theory of the local punishment-incentive mechanism and proposed the weighted Apriori algorithm to conduct association rule mining and analysis on the risks in various workspaces of prefabricated buildings[2].

Traditional statistical models, exemplified by regression analysis and discriminant analysis, have been extensively employed within the realm of risk assessment. Neural network models, particularly those of the deep learning variety, conduct intricate mappings of data through the construction of multi-layer neural networks and exhibit superiority in handling high-dimensional and nonlinear data[3]-[8]. Nevertheless, these models hinge upon a substantial amount of precise data and are required to fulfill specific distributional assumptions[9]-[16]. Moreover, they are beset with limitations when it comes to grappling with complex nonlinear relationships and multi-factor interactions[17]-[18]. Given this situation, this research applies the analytic hierarchy process, triangular fuzzy number method, and fuzzy evaluation theory to the construction risk assessment process of prefabricated buildings. It also utilizes the support degree and confidence degree to mine association rules and extract the factors that affect the quality of prefabricated concrete buildings, thereby achieving a quantitative risk assessment and analysis of the key stages of prefabricated concrete building main structure quality control.

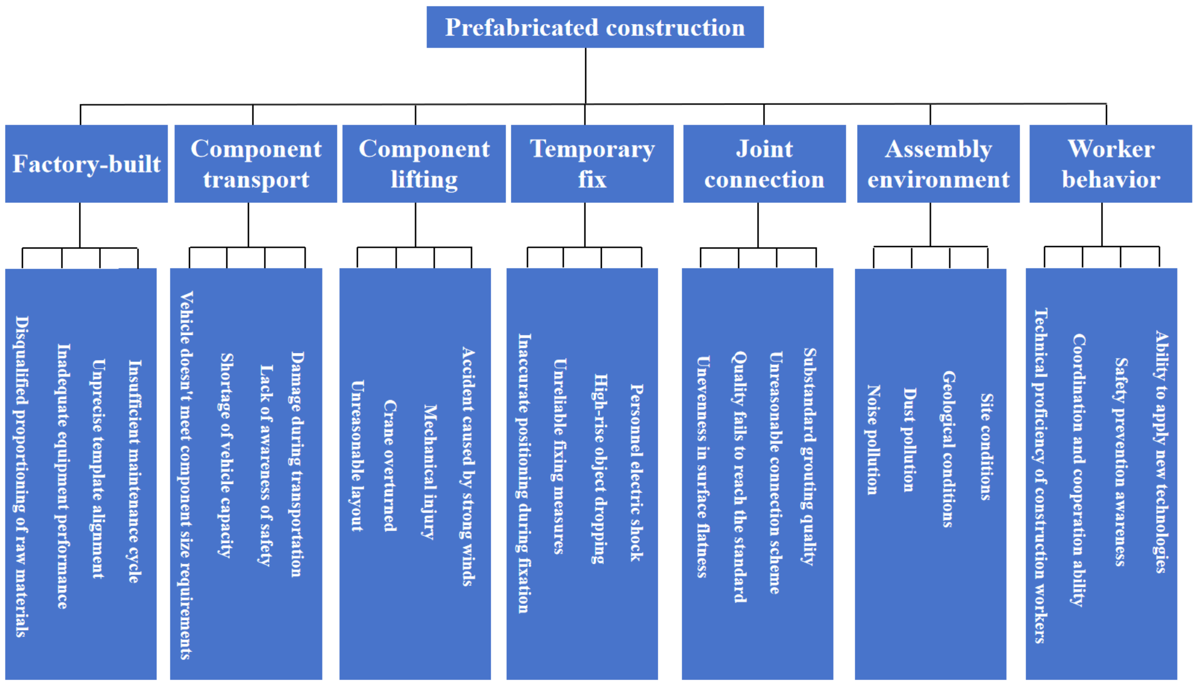

Fig. 1.Pre-cast concrete construction hierarchical analysis model.

II. CONSTRUCTION RISK ANALYSIS MODEL ESTABLISHMENT

A. *Model Establishment*

In prefabricated concrete construction, the assembly method is adopted. Prefabrication factories manufacture components in line with standardized design specifications. Subsequently, these components are delivered to the construction site, where they are mechanically hoisted and assembled to form a complete building structure. Given the intricacy of these procedures, managing risks in prefabricated concrete construction has become considerably more challenging.

This research establishes a risk source model for precast concrete construction at various levels using the analytic hierarchy process (AHP). It determines the key construction processes of assembling components, including factory prefabrication, transportation of assembled components, lifting of assembled components, temporary fixing of assembled components, and joint connection, as the first-level risk source indicators. The model was utilized to carry out an evaluation on the quality risk sources during the construction of prefabricated buildings, just as illustrated in Figure 1.

B. *Comparative Analysis*

1) *Data Requirements*

The research method adopted in this study combines the Analytic Hierarchy Process (AHP) with expert surveys, which allows the determination of risk factors and their importance using limited data. In contrast, traditional methods such as regression analysis and discriminant analysis require a large amount of specific data to ensure accuracy, and neural network models rely on extensive labeled data.

2) *Ability to Handle Complex Relationships*

This study employs triangular fuzzy numbers and fuzzy evaluation methods to deal with the fuzziness and complexity of risk factors, taking various factors in construction into account. Meanwhile, traditional methods have their limitations. Regression analysis works well for straightforward linear connections yet falls short when it comes to complex interplays. Discriminant analysis centers on classification and struggles to cope with intricate interactions. Although neural network models are capable of managing complex relationships, they do a poor job of explicating them.

3) *Impact of Subjective Factors*

This study takes expert experience into account and utilizes scientific methods to reduce subjective bias, making the evaluation more objective. Traditional methods such as regression analysis and discriminant analysis may lead to deviations due to subjective choices, and neural network models also have subjectivity in terms of design and interpretation.

4) *Application Convenience*

The method proposed here is easy to use, requiring no complex adjustments or profound knowledge, and is suitable for engineers. Traditional methods, such as regression analysis and discriminant analysis, require statistical knowledge, and the training and tuning of neural network models are complex.

III. IDENTIFYING CONSTRUCTION RISKS BASED ON THE ASSOCIATION RULE MINING ALGORITHM

In order to accurately identify the risk sources in prefabricated concrete construction and quantitatively analyze the risks at various levels, we will collect risk data on prefabricated quality information and conduct data mining based on the AHP.

$$\{Low, Inferior, Med, High, Excellent\} = \{(0,0,0.3),(0.1,0.3,0.5),(0.3,0.5,0.7),(0.5,0.7,0.9),(0.7,1,1)\} \quad (1)$$

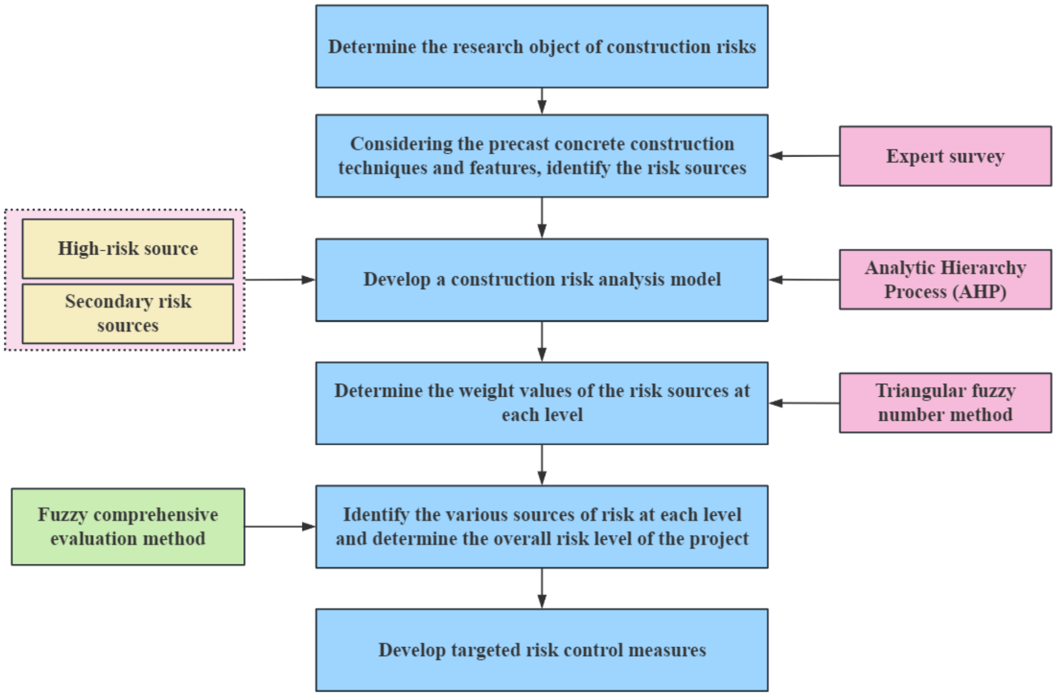

Fig. 2.Construction risk analysis process for prefabricated concrete construction

The weights of the risk sources at various levels will be calculated using the triangular fuzzy number method, a rule-determining model will be established based on association rules, and association rules will be mined based on support degree and confidence to extract the risk factors of prefabricated building quality. Minimize the influence of subjective factors as much as possible to form a set of safe risk assessment methods suitable for prefabricated concrete structures in construction, as shown in Figure 2.

A. Calculation and Ranking of Risk Source Weights

A hierarchical analytical model of prefabricated concrete construction was set up with the aim of assessing the safety risk level of such construction. And the weights and order of each construction risk source were obtained by using the triangle fuzzy number method.

In this research, with the aim of quantifying the results of risk assessment, the characteristics of prefabricated concrete construction techniques are incorporated and five variables based on the actual situation are established, Low, Inferior, Medium, High, and Excellent. For five-level linguistic variables, the corresponding triangular fuzzy numbers are related by the relationship (1).

Fuzzy sets M are triangular fuzzy numbers defined on $R \in (0,1)$, It is noted as $M(l, m, u)$, The corresponding membership function is represented as $\gamma(X)$:

$$\gamma_{M(X)} = \begin{cases} \dfrac{x-l}{m-l}, x \in [l,m] \\ \dfrac{x-u}{m-u}, x \in [m,u] \\ 0, other \end{cases} \quad (2)$$

Let C be a criterion. When dealing with n elements $u_1, u_2, \ldots, u_n$ for fuzzy sorting. Element u_i should be compared with element u_j initially. The relative importance of elements u_i and u_j to criterion C is denoted as γ_{ij} and γ_{ji}, $\gamma_{ij} = (l_{ij}, m_{ij}, u_{ij})$, $\gamma_{ji} = (l_{ji}, m_{ji}, u_{ji})$. One of the n-dimensional matrices formed by the relative attribute γ_{ij} is referred to as the attribute judgment value, and its calculation process is presented as follows:

1) *Total score calculation for risk assessment objects*

$$\sum_{i=1}^{n} f_i = \left[\sum_{i=1}^{n}\sum_{j=1}^{n} l_{ij}, \frac{n(n-1)}{2}, \sum_{i=1}^{n}\sum_{j=1}^{n} u_{ij}\right] \quad (3)$$

2) *Weight for different levels of risk objects*

$$w_{u_i} = \frac{f_i}{\sum_{i=1}^{n} f_i}\left[\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} l_{ij}}, \frac{\sum_{j=1}^{n} l_{ij}}{n(n-1)}, \frac{\sum_{i=1}^{n} u_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} u_{ij}}\right] \quad (4)$$

3) Clarification processing

$$M=(l,m,u)\rightarrow S(M)=\frac{l+2m+u}{4} \tag{5}$$

Finally, the weight matrix after clarification was normalized, and the risk sources at each level of prefabricated concrete construction were ranked in accordance with the risk order.

B. Risk Source Fuzzy Comprehensive Analysis and Risk Level Assessment

To overcome the limits of single risk factor judgment, a comprehensive fuzzy evaluation method is adopted to determine the risk level of prefabricated concrete construction both qualitatively and quantitatively. First, the set of fuzzy factors and evaluation set *V={v1, v2, v3, v4, v5}={Low, Inferior, Medium, High, Excellent}* are determined. Then, a single factor evaluation matrix is established. One of the sets of uncertain factors is composed of all primary risk sources or all secondary risk sources under the same primary risk source. A fuzzy evaluation model is established.

$$B=W\cdot R=(w_1,w_2,...,w_n)\cdot\begin{bmatrix} r_{11} & ... & r_{1n} \\ ... & ... & ... \\ r_{m1} & ... & r_{nm} \end{bmatrix}=(b_1,b_2,...,b_n) \tag{6}$$

In the equation: B is a fuzzy evaluation vector for level 1 risk factors, R is a fuzzy evaluation matrix for secondary risk factors, *W* is Fuzzy evaluation vector of secondary risk factors, $b_j(j=1, 2, \ldots, n)$ is Fuzzy Comprehensive Evaluation Indicators. The *j* element in the set of evaluation criteria for the risk evaluation object when only the risk impact of secondary objects is considered.

IV. ENGINEERING APPLICATIONS AND ANALYSIS

With the aim of quantitatively evaluating the construction risks associated with precast concrete, the construction safety risk analysis approach presented in this paper was implemented in actual project. Calculation and analysis are detailed as follows:

1)Calculate weight values

According to formulas (3) to (5), the weighting method for calculating the risk factors is calculated separately, as shown in Table 1.

TABLE I. WEIGHTED RISK FACTORS FOR PREFABRICATED CONCRETE CONSTRUCTION

Number	Weight values	Number	Weight values
C_1	0.101	C_{11}	0.103
		C_{12}	0.174
		C_{13}	0.246
		C_{14}	0.477
C_2	0.163	C_{21}	0.066
		C_{22}	0.436
		C_{23}	0.324
		C_{24}	0.174
C_3	0.155	C_{31}	0.215
		C_{32}	0.065
		C_{33}	0.245
		C_{34}	0.475
C_4	0.216	C_{41}	0.066
		C_{42}	0.136
		C_{43}	0.364
		C_{44}	0.434
C_5	0.164	C_{51}	0.300
		C_{52}	0.287
		C_{53}	0.140
		C_{54}	0.213
C_6	0.069	C_{61}	0.397
		C_{62}	0.325
		C_{63}	0.065
		C_{64}	0.213
C_7	0.132	C_{71}	0.177
		C_{72}	0.286
		C_{73}	0.250
		C_{74}	0.287

By using the triangular fuzzy number method, the risk weight values for each risk source at Level 1 are ranked in the following order according to the table: $C_4 > C_5 > C_2 > C_3 > C_7 > C_1 > C_6$. The risk weight regarding the temporary fixing of assembly components is the highest, specifically 0.216. On the other hand, the risk weight value for the assembly environment is the lowest, precisely 0.069.

2)Fuzzy comprehensive evaluation and risk level assessment

The risk levels of precast concrete construction are evaluated by employing the fuzzy comprehensive evaluation method. After determining the risk sources at each level and the set of risk evaluation criteria, an expert panel is invited to evaluate the risk sources at each level. Then, a fuzzy evaluation matrix *R* is constructed.

$$R_{c_4}=\begin{bmatrix} 0 & 0.1 & 0.2 & 0.4 & 0.3 \\ 0.2 & 0.3 & 0.4 & 0.1 & 0 \\ 0.1 & 0.4 & 0.3 & 0.2 & 0 \\ 0.2 & 0.6 & 0.1 & 0.1 & 0 \end{bmatrix}$$

Secondary risk sources in precast concrete construction is *W*.

$$W_{C_4}=\begin{bmatrix}0.066 & 0.136 & 0.364 & 0.434\end{bmatrix}$$

Based on the fuzzy evaluation matrix and the combination weight of risk sources, the second-level fuzzy comprehensive evaluation result of prefabricated concrete construction can be obtained using Equation (6).

$$B_{C_4}=\begin{bmatrix}0.150 & 0.453 & 0.220 & 0.156 & 0.020\end{bmatrix}$$

Similarly, following the above calculation process, the secondary risk fuzzy evaluation results for the other four risk sources can be obtained.

$$\begin{bmatrix} B_{C_1} \\ B_{C_2} \\ B_{C_3} \\ B_{C_5} \\ B_{C_6} \\ B_{C_7} \end{bmatrix} = \begin{bmatrix} 0.120 & 0.233 & 0.220 & 0.170 & 0.257 \\ 0.130 & 0.278 & 0.307 & 0.137 & 0.148 \\ 0.117 & 0.281 & 0.428 & 0.079 & 0.097 \\ 0.021 & 0.150 & 0.350 & 0.286 & 0.193 \\ 0.094 & 0.190 & 0.390 & 0.210 & 0.150 \\ 0.054 & 0.190 & 0.390 & 0.210 & 0.157 \end{bmatrix}$$

By applying the membership degree method, the results of the secondary fuzzy comprehensive evaluation can be further combined by means of the fuzzy comprehensive method.

$$B_{total} = W_{tatal} \cdot R_{C_i} = \begin{bmatrix} 0.101 & 0.163 & 0.155 & 0.216 & 0.164 & 0.069 & 0.132 \end{bmatrix} \begin{bmatrix} 0 & 0.1 & 0.3 & 0.3 & 0.3 \\ 0.1 & 0.2 & 0.4 & 0.3 & 0 \\ 0 & 0 & 0.2 & 0.4 & 0.4 \\ 0.1 & 0.3 & 0.5 & 0.1 & 0 \\ 0.1 & 0.2 & 0.4 & 0.3 & 0 \\ 0.1 & 0.3 & 0.5 & 0.1 & 0 \\ 0 & 0.1 & 0.3 & 0.3 & 0.3 \end{bmatrix}$$

$$= \begin{bmatrix} 0.061 & 0.174 & 0.374 & 0.259 & 0.132 \end{bmatrix}$$

V. Conclusion

Based on the in-depth analysis of the research results, during the construction process, it was found that the risk in the prefabricated component installation stage is relatively high, and inaccurate positioning and unreliable fixing measures are the main risk factors. It was found that the root causes lie in the insufficient technical proficiency of the construction personnel and the need for optimization of the construction process. Therefore, the following risk management suggestions are proposed: strengthening staff training, including technical training (for example, the positioning error rate in a certain project was reduced by 30%) and safety training (strengthening safety awareness); optimizing the construction process (for example, the component installation time in a certain project was shortened by 20% and the quality pass rate was increased by 15%) and introducing BIM technology for assistance, etc.

This study combines the association rule mining algorithm, analytic hierarchy process, triangular fuzzy number method and fuzzy comprehensive evaluation method to precisely quantify the construction risks of prefabricated concrete buildings. This method avoids the interference of subjective biases of evaluation personnel, can effectively promote the high-quality development of the prefabricated building industry and enhance its construction safety simultaneously. It doesn't require complex algorithm adjustments or a professional knowledge background, and is convenient for engineering personnel to apply.

Although this research has achieved certain results, there are still expandable directions in future research. For example, further exploration can be made in the integration with machine learning algorithms (such as deep learning, support vector machines, etc.), enabling them to automatically learn the patterns and regularities in the data, which is expected to further improve the accuracy and efficiency of risk prediction.

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