Safety Risk Assessment of Prefabricated Building Construction Based on Bayesian Network

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Abstract. A safety risk assessment index system including four types of risk conditions: foundation pit construction risk status, construction and shipment risk status, hoisting operation risk status and prefabricated component installation risk status is established. Based on Bayesian network, fabricated by Netica software to evaluate the construction safety risk probability, through the function of Sensitivity to Findings conduct sensitivity analysis on the probability of risk occurrence. Based on the risk calculation, get the more prominent risk factors in each type of risk situation. According to the result of risk assessment, the countermeasures of construction safety risk of prefabricated building are put forward.

1. Introduction
In recent years, China's construction industry has developed rapidly. Under the guidance of national policies, assembled buildings have achieved many positive results under the joint efforts of the industry [1, 2], but the safety problem in the construction stage of prefabricated building is always an obstacle in the process of building industrialization. The risk of prefabricated building construction is the main aspect of the various risk factors that constrain the quality of the project and the main source of risk. By studying the safety risks of prefabricated building construction, the construction risk of the assembled project can be effectively and accurately evaluated, and the risk loss can be reasonably controlled. It is of great significance to improve the efficiency of the project.

Bayesian network method has been applied in many fields such as economic risk, safety atmosphere and safety behaviour research, ecology, product life cycle analysis and environmental impact assessment, mining and address data research, because of its great advantages in solving uncertain and incomplete problems[3]. Uncertainty is the main problem faced by construction engineering safety risk management, and Bayesian network model has unique advantages in dealing with uncertainty factors. Therefore, applying Bayesian theory to the research of assembly building construction safety risk, construction safety risk management can be made more scientific and agile [4].

2. Bayesian network system calculation formula
For a Bayesian network with n nodes, the set of variable nodes is Ω= (E₁, E₂, ……Eₙ) . Let m be one of the state values of Eᵢ, and the probability interval of a parameter obtained by Eᵢ in the m state through the questionnaire is [x, y], then
\[ P(E_i = m) = \phi^{x+y} z \]  

(1.1)

Where \( \Phi \) represents the set of all parameters in the state of the node that need to be determined. Then \( E_i \) can be set \((1 \leq i \leq n)\) is the top node of the entire network, then

\[
P(E_i = m) = \sum_{E_1, E_2, \ldots, E_i = m} P(E_1, E_2, \ldots, E_n) = \sum_{E_1, E_2, \ldots, E_i = m} P \left( E_i = m \right) \prod E_{-i}
\]

(1.2)

According to the chain rule:

\[
P(E_j = m \prod e_{-j}) = P(E_j = m | E_1, E_2, \ldots, E_{j-1}, E_{j+1}, \ldots E_n) \\
P(E_j = m) = \sum_{E_{j-1}, E_{j+1}, \ldots E_n} P(E_{j-1}, E_{j+1}, \ldots E_n | E_j = m) \cdot P(E_j = m)
\]

(1.3)

\[
P(E_j) = \prod_{k=1,2,\ldots,j-1,j+1,n} P(E_j = m | E_k) \cdot P(E_j = m)
\]

(1.4)

3. Bayesian-based safety evaluation index system for prefabricated building construction

3.1. Component-assembled building construction safety risk assessment system

The construction process of the prefabricated building is different from the traditional building. Compared with the traditional cast-in-place construction, the construction process is very different. For the prefabricated building, the risk factors are fully identified. From the actual construction situation, various risk factors are applied to the construction. The degree of influence of safety is not the same. In order to simplify the structure level, avoid unnecessary calculations, screen out more important risk factors for risk assessment, consider the independence between indicators, and divide risk factors into foundation pit construction and construction. Shipment, lifting operations, prefabricated components are installed in four categories as shown in Table 1.

Table 1. Construction safety risk evaluation index system for prefabricated building.
| Risk status                     | Risk factor                                                                 |
|-------------------------------|-----------------------------------------------------------------------------|
| Foundation pit construction  | Improper design of the pit wall U1                                           |
| risk status U                 | Pay no attention to the treatment of surface water U2                        |
|                               | Component stacking and protection is inadequate V1                           |
|                               | Unreasonable transportation route planning V2                                |
| Construction shipment risk    | Prefabricated component fixing measures are not in place V3                   |
| status V                      | Limited crane site area V4                                                   |
|                               | The materials and accessories used for component installation have not been tested W1 |
|                               | The tower crane is raised and the wall is not in accordance with the requirements. W2 |
| Hoisting operation risk status | The attachment is not reasonable W3                                           |
| W                             | Hanging point position setting is unreasonable W4                             |
|                               | Overload lifting W5                                                          |
|                               | Lack of construction workers with hoisting experience W6                     |
|                               | Mechanical connection or welded joint does not meet the requirements P1      |
|                               | Prefabricated components are not up to standard P2                           |
|                               | Prefabricated components are not up to standard P3                           |
|                               | Temporary support is not strong, unstable P4                                 |
|                               | Safety ropes are nowhere to be hung or tied P5                               |
| Prefabricated component       | Grout performance does not meet the requirements P6                           |
| installation risk status P    | Grouting is not full P7                                                      |
|                               | Holes and frontier protection are not in place P8                            |
|                               | Poor civilized construction in the work area P9                              |
|                               | Time-varying structure safety monitoring technology is not in place P10      |
|                               | Operator's inoperable work platform P11                                      |

3.2. Building a Bayesian network model
The above risk evaluation index system is transformed into the Bayesian network model as shown in Fig. 1. Since the risk evaluation index system is established on the basis of considering the independence of the indicator, the independence between the nodes of the Bayesian network can be guaranteed after the conversion. The relationship between the risk factors of each layer in the original evaluation index system is reflected by the Bayesian network model, and the degree of influence of the mutual relationship between the indicators is reflected and transmitted upward by the probability relationship between the nodes.
4. Probabilistic assessment and sensitivity analysis of safety risk factors for prefabricated building construction

4.1. Risk probability calculation

4.1.1. Prior probability calculation. Through the questionnaire survey of the safety risk person in charge of each assembly project and the experts in the assembly industry, the data collected by the literature research is integrated, and the CPT of each node in the Bayesian network is obtained, and the prior probability of each node at the bottom layer is obtained, as shown in Table 2. As shown, where the risk occurrence state is represented by Y and the risk non-occurrence state is represented by N.

| Risk factor | Y  | N  | Risk factor | Y  | N  |
|-------------|----|----|-------------|----|----|
| U1          | 0.16 | 0.84 | P1          | 0.49 | 0.51 |
| U2          | 0.35 | 0.65 | P2          | 0.27 | 0.73 |
| V1          | 0.45 | 0.55 | P3          | 0.22 | 0.78 |
| V2          | 0.17 | 0.83 | P4          | 0.70 | 0.30 |
| V3          | 0.41 | 0.59 | P5          | 0.52 | 0.48 |
| V4          | 0.15 | 0.85 | P6          | 0.39 | 0.61 |
| W1          | 0.34 | 0.66 | P7          | 0.47 | 0.53 |
| W2          | 0.61 | 0.39 | P8          | 0.79 | 0.21 |
| W3          | 0.57 | 0.43 | P9          | 0.47 | 0.53 |
| W4          | 0.14 | 0.86 | P10         | 0.81 | 0.19 |
| W5          | 0.19 | 0.81 | P11         | 0.49 | 0.51 |
| W6          | 0.33 | 0.67 |             |     |    |
4.1.2. Posterior test result. According to the Bayesian network system calculation formula, Netica software is used to calculate the probability of occurrence of the four types of risk conditions, as shown in Table 3.

|   | Posteriori | U   | V   | W   | P   |
|---|------------|-----|-----|-----|-----|
| Y | 0.410      | 0.610| 0.733| 0.743|
| N | 0.590      | 0.390| 0.267| 0.257|

4.2. Sensitivity analysis

In order to evaluate the safety risks of prefabricated building construction as accurately as possible, it is necessary to establish a vague connection between the probability of occurrence of risks and the probability of occurrence of risks. After Bayesian estimation, the probability values of various risk factors and various risk situations can be obtained. According to the probability calculation result and the actual construction safety risk situation, the probability corresponding to different risk occurrence probability levels as shown in Table 4 can be determined. Divide the interval. Table 4 shows the level of possibility of construction safety risks.

| Probability level | I     | II    | III   | IV    | V     |
|-------------------|-------|-------|-------|-------|-------|
| Incidence probability | ≥0.75 | 0.65 - 0.75 | 0.50 - 0.65 | 0.30 - 0.50 | ≤0.30 |

The impact of each risk factor on the construction shipment risk status is different. The sensitivity analysis can be used to determine the relative impact of each risk factor on the corresponding risk situation. In order to understand the impact of various risk factors on the construction risk status in each risk status category, Netica's Sensitivity to findings function is used to conduct sensitivity analysis for each type of risk situation. The results of the sensitivity analysis are shown in Table 5.

| Risk category | Risk probability | Risk probability level | Risk factor sensitivity ranking |
|---------------|------------------|------------------------|--------------------------------|
| U             | 0.410            | IV level               | U2 > U1                        |
| V             | 0.610            | III level              | V3 > V1 > V4 > V2              |
| W             | 0.733            | II level               | W6 > W5 > W2 > W3 > W4 > W1    |
| P             | 0.743            | II level               | P11 > P10 > P2 > P8 > P3 > P4 > P5 > P1 > P9 > P6 > P7 |

In summary, the Bayesian network calculates and analyses the safety risk probability of prefabricated building construction, according to the risk occurrence probability classification standard, the order of occurrence probability of each risk situation is: P > W > V > U. Hoisting operations risk and component installation risk are the most probable risk categories and are more likely to occur. For each specific risk factor included under each risk category, the most sensitive, is relatively most likely, risk factors under the four categories of risk categories U, V, W, and P are that U2 is not treated for surface water treatment, and prefabricated components are fixed. The measures are not in place V3, there is no construction worker W6 with hoisting experience, and the operator has no operational platform P11.

5. Risk prevention and control measures during the construction phase of prefabricated buildings

At present, China's construction industry is facing serious problems such as low level of information in the construction process, lack of means and concepts of full life cycle, low production efficiency and weak risk control ability. With the rapid development of computer technology, in addition to the comprehensive and flexible use of common risk management principles and methods, we must also pay attention to the combination of common risk management measures and information systems.

5.1. Foundation pit construction risk control

Prefabricated buildings have little difference in the risk of foundation pit construction from traditional cast-in-place concrete buildings. Once a safety accident occurs, it will cause huge losses [7]. The
following points should be noted in the control of foundation pit construction risk: 1) Do the preliminary investigation and design work of the foundation pit. 2) Risk supervision should be strengthened during the construction process, and the supervision and management system should be improved. 3) Improve the professional level and quality of the staff.

5.2. Construction shipment safety risk control

Compared with the traditional cast-in-place concrete building assembly construction, the assembly and transportation process has brought additional safety risk factors [6]. 1) According to the sensitivity analysis of various risk factors mentioned above, it can be known that the prefabricated fixed measures are not the most risk factor for the construction shipment risk status. There are many types of prefabricated components, and there are many models, and the force forms are different during transportation. In order to ensure that there is no collapse and overturning accident during transportation, the transportation plan should be formulated according to the different shapes and force requirements of the components. 2) The effect of component stacking and protection failure on the construction shipment risk status is second only to the prefabricated component fixing measures. The phenomenon of random placement of components occurs frequently at the construction site. Information management measures should be adopted. The combination of the Internet of Things and the information platform should be used to reasonably plan the location of the components before the components enter the site, and set corresponding protective measures to make each component "having a trace" and "having a place to go."

5.3. Hoisting operation risk control

Different from the traditional cast-in-place construction technology, during the construction process of the assembly-type building, a large number of component assembly work is added, which accounts for nearly 80% of the construction time in the running rhythm of the running water, and the component quality is large, and the lifting frequency is high. Therefore, the work of tower crane operation, command and dispatch and safe lifting is especially important [7]. Based on the results of the risk assessment, it is known that the risk of hoisting operations is the most likely risk category in the construction of a prefabricated building, which is second only to the risk of component installation. Although the risk occurrence probability is slightly less than the risk of prefabricated component installation, in terms of risk loss, the risk of lifting operation is the most serious. According to Netica sensitivity analysis, there is a lack of construction personnel who have experience in hoisting, overload hoisting, tower crane lifting, and the wall is not in accordance with the requirements of the top three risk factors in the risk of hoisting operations. The control of the risk of lifting operations should be carried out in the following three aspects: 1) Strengthen the management and training of the lifting workers. 2) Carefully choose the attachment measures. 3) Information technology (BIM, RFID, etc. [8]) can be applied in many aspects to help control the risk of lifting operations.

5.4. Prefabricated component installation risk control

According to the results of the risk assessment, the prefabricated component installation risk status is the safety risk category with the highest probability of occurrence during the construction of the prefabricated house. The operator has no operational platform, the safety monitoring technology of the time-varying structure is not in place, and the strength of the prefabricated component is not to reach the standard, the hole and the protection of the edge are the top four risk factors that have the greatest impact on the risk category. In order to facilitate the installation of the prefabricated components and further reduce the impact of the installation risk of the prefabricated components, measures can be taken from the following aspects. control. 1) Set the external scaffolding to ensure that the prefabricated component installation workers have sufficient operable platforms. 2) Do a good job of safety monitoring of time-varying structures. 3) Improve the quality of prefabricated components. 4) Strengthen the safety protection of aerial work. 5) Reasonably choose the temporary support system. 6)
The connection node is the key part of the fabricated structure and the complicated part of the process. The research of connection technology is a hot spot for assembled R&D personnel. However, the current connection nodes still cannot meet the requirements of prefabricated buildings, and the investment in connection nodes should be increased. 7) Ensure the investment of safe and civilized construction fees, and strive to create a safe and civilized standard chemical land [9]. 8) Application of information technology to assist management.

In general, managers should have a strategic vision. In the construction safety risk management, develop safety systems and management manuals for the characteristics of prefabricated buildings, formulate construction specifications, and apply information technology to the entire life cycle of fabricated buildings, reduce security risks.

6. Conclusion
With the help of Netica Bayesian simulation software and bayesian network method, the construction safety risk of prefabricated housing is assessed, so as to help engineering managers find the risk factors most likely to cause safety accidents, and help engineering project management team to establish a more clear and correct understanding of engineering construction safety risk. In order to better prevent construction safety risks, strengthen the safety management, ensure the smooth progress of the project. According to the characteristics of the prefabricated building construction safety risk, and puts forward some specific prefabricated construction phase control measures to prevent risks, for construction industrialization under the background of prefabricated construction safety management to provide the referenc.

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