Identification of Hazard Sources in Prefabricated Building Construction by Entropy Weight Method

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Abstract. Prefabricated building is the new construction method of technical reform and upgrading in China's construction industry. The construction of prefabricated buildings involves the production, transportation and hoisting of large prefabricated components. Due to the difficulty in handling large prefabricated components, lacking of prefabricated building construction experience of workers, insufficient management guidelines for prefabricated building, there are a large number of hazard sources in the new production environment. This paper is to identify hazard sources relating to prefabricated components which exist in four stages of production, transportation, on-site storage, and installation. Firstly, we used the method of literature study to initially identify the hazard sources of prefabricated buildings; then, expert investigation was applied and Entropy Weight Method was used to evaluate the severity of hazard sources; finally, significant hazard sources at each stage were identified and countermeasures were put forward for the prevention of accident. This study enriches the theoretical research on prefabricated building safety management and provides references for the prevention of prefabricated building safety risks.

1. Introduction

The source of hazard is possible causes of safety accident. It maybe the state of energy, materials or behavior. The words of risk or hazard sources, accident cause, hazards, hazardous factors, source of danger have the similar meaning [1]. Prefabricated building is a new type of construction technology in the domestic and foreign construction fields. It is different from traditional cast-in-place buildings. It mainly produces and processes prefabricated components in factories, transports them to construction sites by means of transportation, and then deploys and installs them on construction site. Compared with traditional cast-in-place buildings, prefabricated buildings improve the construction efficiency and reduce the harm to the environment. They are generally welcomed by the construction industry. However, prefabricated buildings have many hidden safety risk. The new construction environment and the handling and lifting of large components have some hazard sources that are not well recognized. For example, when a prefabricated component is transported, large components slips which cause a traffic accident; the prefabricated components stored on the site are not securely fixed, and slippage occurs. Once such an accident occurs, it will cause a huge loss of personnel and property. Therefore, it has important practical significance for the research on the hazard sources of prefabricated building construction.
Many scholars have conducted research in this area. According to accident cause theory and risk source identification theory, Yang Shuang [2] established the safety evaluation index based on existing literature, and applied it to safety evaluation of prefabricated building construction. Xiaowai Zou [3] made analysis of the hazard sources of prefabricated building construction by using the accident tree analysis method, and established a prefabricated building safety warning platform from the perspectives of the unsafe state, people's unsafe behaviors and unsafe environment. Xiaohang He [4] established a BIM-based building safety management framework model by comparing the differences between the safety management of traditional buildings and prefabricated buildings. In summary, most scholars choose indicators, component models or platforms from three aspects of human, resources and machines. At present, the research on the hazard sources of prefabricated building construction is still insufficient especially from the perspective of different stages of prefabricated building construction. This paper intends to take prefabricated components as the main research object, to examine the whole process of prefabricated building construction and determine the stages of hazard sources existence, to identify hazard sources relating to prefabricated components at each stage through literature and expert survey methods, to determine the significant hazard sources using the entropy weight method, and to put forward coping strategies with a view to providing a reference basis for preventing prefabricated building construction safety accidents.

2. Hazard source identification

2.1. Stage of existence of hazard sources

The prefabricated building construction is different from the traditional cast-in-place building, which requires the production of prefabricated components at the factory. In addition, it also includes another two stages: transportation and on-site assembly. Therefore, in this paper, according to the relevant process from production to installation of prefabricated components, the construction of prefabricated buildings is divided into four phases, namely the production stage, transportation stage, on-site storage stage, and hoisting and installation stage of prefabricated components. The hazard sources of prefabricated building construction are identified from the above four stages accordingly.

2.2. Hazard source identification list

This paper first establishes a list of hazard sources through the literature study. According to previous study [5-8], the 15 main hazard sources in 4 stages of the prefabricated building construction process are identified, as shown in Table 1.

| Process                      | Serial number | Hazard sources                                                                 |
|------------------------------|---------------|--------------------------------------------------------------------------------|
| Production stage (A)         | A1            | The company’s imperfect safety guarantee system, irregular use of electricity    |
|                              | A2            | No protective measures for vulnerable parts such as sharp angle or steel bar of prefabricated components |
|                              | A3            | Component size deviation                                                       |
|                              | A4            | Not firmly fixed mould and steel bar left all over the floor in the production process |
| Transportation stage (B)     | B1            | Unloading conditions are not checked before unloading prefabricated components   |
|                              | B2            | Transport vehicle overload                                                     |
|                              | B3            | Overspeed driving and observation oversight of transport vehicles entering construction sites |
| On-site storage stage (C)    | C1            | The component slides or collapses                                               |
### 3. Significant hazard sources

#### 3.1. Entropy weight method

The entropy weight method is a mathematical method that analyzes comprehensive indicators based on the amount of information provided by different factors after a comprehensive inspection. As a method of determining weights, the weights are mainly determined according to the amount of information provided to decision makers by different indicators. This article uses the entropy weight method to determine the significance of hazard sources.

#### 3.2. Identify important hazard sources at all stages

##### 3.2.1 Original data acquisition.

The hazard source identification list constructed above is scored according to the corresponding value, and the potential risk of the hazard source at each stage is scored according to the value of 1-5. See Table 2 for specific principles.

| Evaluation level | Score |
|------------------|-------|
| low risk         | 1     |
| Lower risk       | 2     |
| Medium risk      | 3     |
| Higher risk      | 4     |
| high risk        | 5     |

Between two adjacent levels  | Median of adjacent values
-------------------------------|-----------------------------

6 experts were consulted to score each hazard source on the 4 construction stages of prefabricated buildings. Thus, the evaluation value matrix is obtained. S1, S2, S3, and S4 are used to represent the evaluation value matrix of each stage. Among them, S1 represents the component production stage, S2 represents the component transportation stage, S3 represents the component on-site storage stage, and S4 represents the component lifting and installation stage. The following uses S4 as an example for evaluation.
3.2.2 Data standardization

The original data evaluation matrix is \( X = (a_{ij})_{mn} \), where \( a_{ij} \) is the evaluation value of the \( i \) activity under the \( j \) indicator. Normalized to get \( R = (r_{ij})_{mn} \), the normalized formula is:

\[
    r_{ij} = \frac{\max_j \{a_{ij}\} - a_{ij}}{\max_j \{a_{ij}\} - \min_j \{a_{ij}\}}
\]  

(1)

Use (1) to carry out matrix standardization on the evaluation value of the lifting and installation stage:

\[
    R4 = \begin{bmatrix}
        0.5 & 1 & 0 & 0.5 & 1 \\
        1 & 0.5 & 0 & 1 & 0 \\
        0.5 & 0 & 1 & 1 & 1 \\
        0.5 & 1 & 0 & 0.5 & 0 \\
        0 & 0.5 & 1 & 0.5 & 1 \\
        1 & 0.5 & 1 & 0 & 1 \\
    \end{bmatrix}
\]

3.2.3 Index entropy weight

The evaluation value weight of the indicator \( f_{ij} \) is:

\[
    f_{ij} = r_{ij} / \sum_{j=1}^{n} r_{ij}, \quad j = 1, 2, \cdots, n
\]

(2)

The entropy of the \( i \) evaluation index is:

\[
    h_i = -k \sum_{j=1}^{n} f_{ij} \ln f_{ij}
\]

(3)

However, \( k = 1 / \ln n \) when the evaluation value has a specific gravity \( f_{ij} = 0 \), \( f_{ij} \ln f_{ij} = 0 \). After the entropy of the \( i \) index is defined, the entropy weight of the \( i \) index can be obtained:

\[
    w_i = \frac{1 - h_i}{m - \sum_{j=1}^{m} h_j} (0 \leq w_i \leq 1, \sum_{i=1}^{m} w_i = 1)
\]

(4)
According to formula (2), the evaluation value weight matrix $F_4$ of the index during the hoisting and installation stage is:

$$
F_4 = \begin{bmatrix}
\frac{1}{7} & \frac{2}{7} & 0 & \frac{1}{7} & \frac{1}{4} \\
\frac{2}{7} & \frac{1}{7} & 0 & \frac{2}{7} & 0 \\
\frac{1}{7} & 0 & \frac{1}{3} & \frac{2}{7} & \frac{1}{4} \\
\frac{1}{7} & \frac{2}{7} & 0 & \frac{1}{7} & 0 \\
0 & \frac{1}{7} & \frac{1}{3} & \frac{1}{7} & \frac{1}{4} \\
\frac{2}{7} & \frac{1}{7} & \frac{1}{3} & 0 & \frac{1}{4}
\end{bmatrix}
$$

According to formulas (2) (3) (4), the entropy value and entropy weight are calculated. The results are shown in Table 3.

| Index | Entropy | Entropy weight |
|-------|---------|----------------|
| D1    | 0.865   | 0.133          |
| D2    | 0.865   | 0.133          |
| D3    | 0.613   | 0.380          |
| D4    | 0.865   | 0.133          |
| D5    | 0.774   | 0.222          |

### 3.3. Analysis results
According to the principle that the greater the entropy weight in the entropy weight method and the smaller the proportion, the important hazard sources at various stages of prefabricated building can be determined. In the lifting and installation stage, the entropy weights of $D_1$, $D_2$, and $D_4$ are the smallest, so three of them are important hazard sources in this stage. In the same way, important hazard sources at other stages can be determined, as shown in Table 4.

| Stage | The significant hazard sources |
|-------|--------------------------------|
| A Production stage | A2 No protective measures for vulnerable parts such as sharp angle or steel bar of prefabricated components, A4 Not firmly fixed mould and steel bar left all over the floor in the production process |
| B Transportation stage | B3 Overspeed driving and observation oversight of transport vehicles entering construction sites |
| C On-site storage stage | C3 No isolation measures in the stacking area of prefabricated components |
| D Lifting and installation stage | D1 Components collide with vertical steel bars or pole, D2 Lack of stability while lashing, lifting and installation, D4 Possible falling objects |

### 4. Risk prevention measures

#### 4.1. Production stage
As the important stage of prefabricated components construction, it is particularly important to effectively prevent accident in production stage. According to the above analysis results, the important
hazard sources in the production stage is A2 “No protective measures for vulnerable parts such as sharp angle or steel bar of prefabricated components” and A4 “Not firmly fixed mould and steel bar left all over the floor in the production process”. For the hazard source of A2, the construction company should check carefully during the acceptance to ensure the quality of the components. The production company must strictly abide by the relevant regulations in the production process to avoid consequences of loss and injuring. For the hazard source of A4, the production company should strengthen the management of factory, so as to ensure the personal safety of the production personnel.

4.2. Transport stage
The important hazard source in the transportation stage is B3 “Overspeed driving and observation oversight of transport vehicles entering construction sites”. The manager should pay attention whether the driver is in a fatigue state when daily starting work and regularly conduct safety training for the driver. At the construction site, a commissioner should be sent to accept the prefabricated components. Unrelated persons should be removed from the site in advance to avoid collision.

4.3. On-site storage stage
The important hazard source in the on-site storage stage is C3 “No isolation measures in the stacking area of prefabricated components”. After the prefabricated components are transported to the site, sleepers should be placed to prevent the components from slipping. It is best to use flexible materials as storage place, temporarily reinforce materials, make temporary fence, and set up warning signs outside the fence to warn persons passing by.

4.4. Lifting and installation stage
The important hazard sources during the lifting and installation stage are D1D2D4. For D1, “Components collide with vertical steel bars or pole”, the tower crane driver and the commander should communicate in a timely manner through the intercom, and pay close attention to the component descent process. For D2, “Lack of stability while lashing, lifting and installation”, the driver of the tower crane should be evaluated and certified to work; regular safety inspections should be carry out on the tower crane to ensure timely detection of potential safety risk. For D4, “Possible falling objects”, precautions should be made and confirmed in daily safety inspections before starting construction, and emergency plans for high-altitude falls should be prepared.

5. Conclusions
At present, with the widespread implementation of prefabricated technologies in China, higher requirements are put forward for the safety risk assessment and prevention of prefabricated building construction. During the entire life cycle of prefabricated building construction, there are many hazard sources, for example, prefabricated components fall from the height during the lifting process. This will not only threaten the lives of workers on the construction site, but also cause greater economic losses to the enterprise. Therefore, through literature reading and expert investigation, this article takes prefabricated components as the object and analyses hazard sources during the four stages of prefabricated building construction. According to identified seven significant hazard sources, the risk prevention measures are discussed to prevent accidents occurrence. It provides a reference for project manager in safety management of prefabricated building construction.

Acknowledgments
This study is partially supported by the basic research fund of NCUT.

References
[1] Li, H., Fu,G. (2019)Re-analysis on the meaning of danger source[J].Chinese Journal of Safety Science29(07):1-5.
[2] Zou, X.W., Zhang, D Ma, H. (2019) The establishment of a pre-warning platform for assembly building construction operations based on BIM and Internet of Things. Journal of Engineering Management.33(02):124-129.

[3] He, X.H. (2018) Research on PC Building Construction Safety Management Based on BIM. Zhengzhou University.

[4] Tian, R.F. (2018) Research on Dangerous Source Management and Safety Control of Assembled Concrete Structure Construction. XiAn Industrial University.

[5] Xie, L.L., Chen, Y.J. (2019) Research on the development of prefabricated buildings based on entropy weight method. Construction Economy.40(11):20-23.

[6] Sun, W. Li, H. (2018) Identification of risk factors for prefabricated buildings based on entropy weight method. Value Engineering.37(12):63-65.

[7] Li, H., R Li, Q., M Lu, Y. (2019) SEM-based analysis of key risk of assembly building construction safety. Chinese Journal of Safety Science. (04):171-176.

[8] Xiang, Z.Q. (2019) SEM-based analysis of key risk of assembly building safety. Chinese Journal of Safety Science29(04):171-176.

[9] Cai, Z.R. (2018) Application of fuzzy comprehensive evaluation method based on entropy weight in learning quality evaluation. Computer Times.(12):75-77.

[10] Huang, G.L., Hu, M.L. (2017) Research on safety risk assessment of construction process of prefabricated houses based on extension theory. Industrial Safety and Environmental Protection.43(02):33-38.

[11] Zhao, W.H. (2017) Analysis of construction safety risk management of prefabricated houses. Construction Safety.32(05):13-15.

[12] Sang, P.D., Li, J.X. (2017) Risk assessment of development and construction of prefabricated construction projects based on structural equations. Journal of Civil Engineering and Management. 34(04):89-95.