Evaluation of risk for construction safety of fabricated buildings based on analytic hierarchy process

Cheng Feiyu¹⁺, Liu Yisheng¹

¹School of economics and management, Beijing Jiaotong University, Beijing, 100044, China

*Corresponding author’s e-mail: 19120633@bjtu.edu.cn

Abstract: In order to assist the construction safety risk control of fabricated building, 17 safety risk factors were identified from the five dimensions of man, machine, material, management, and environment. The safety risk evaluation index system of the fabricated building construction stage is constructed based on the AHP (Analytic Hierarchy Process). The risk level is divided according to weight. The results show that the focus should be on the on-site safety staffing, the professional ability of the operators, the quality of additional tools, and the overhaul and maintenance of mechanical equipment. Enough attention should be paid to material storage and maintenance, operator safety awareness, deployment of safety protection measures, transportation protection measures, operator protection work, mechanical equipment selection, natural environment, safety inspection work plan, prefabricated component production quality, mechanical equipment installation, and removal. General attention should be paid to the surrounding environment, the safety production responsibility system, and the construction site environment.

1. Introduction
The fabricated building is assembled by transporting the prefabricated parts to the construction site. It has many advantages such as saving resources and energy, reducing construction pollution, improving labor production efficiency and quality and safety. As the Chinese construction industry seeks industrialization, informatization, and intelligent transformation, fabricated buildings are developing rapidly. Statistics from the Ministry of Housing and Urban-Rural Development show that the newly constructed fabricated buildings nationwide in 2020 have reached 630 million square meters, an increase of 50% over 2019, accounting for approximately 20.5% of the newly built building area[1].

In the process of advancing this new construction method, it is of great practical significance to study how to avoid safety risks in the construction phase and thereby reduce safety production accidents and casualties.

Many scholars have also carried out research on this. By consulting the relevant literature, it can be found that the safety risk assessment research in the prefabricated building construction stage is mainly carried out from the perspectives of safety investment, dynamic early warning, financial risk, and construction period cost. The research methods, which contain qualitative evaluation, mathematical algorithms, have a certain reference value for risk avoidance.

However, in the new development situation, the construction safety risks of fabricated buildings are also dynamically changing, and it is necessary to identify new risks and eliminated risks. This research combines the development status of fabricated buildings and analysis safety risk factors from the five aspects of man, machine, material, management, and environment in the fabricated building
construction stage based on AHP. The safety risks that need to be guarded are put forward to provide a reference for better control of the construction safety of fabricated buildings under the new situation and avoid the construction safety problems of fabricated buildings.

2. Research methods
AHP is an evaluation method that combines quantitative and qualitative. It can express and process people’s subjective judgments in quantitative form, thereby providing a basis for decision-making[2].

2.1. Establish a hierarchical structure model
In order to reflect the relationship between the various factors, according to the complexity of the problem and analysis needs, the research problem is divided into the target layer, the criterion layer (or indicator layer), and the program layer.

2.2. Construct judgment matrices
The judgment matrix can reflect the relative importance of the factors of a certain level relative to a factor of the previous level. Assuming that the factor \( a_k \) of the A layer is related to the factors \( B_1, B_2, \ldots, B_n \) in the next layer B, the following judgment matrix can be constructed.

| Table 1. Judgment matrix |
|--------------------------|
| \( a_k \)  | \( B_1 \)  | \( B_2 \)  | \( B_3 \)  | \( B_n \)  |
| \( B_1 \)  | /       | \( b_{12} \) | \( b_{13} \) | \( b_{1n} \) |
| \( B_2 \)  | \( b_{21} \) | /       | \( b_{23} \) | \( b_{2n} \) |
| \( B_3 \)  | \( b_{31} \) | \( b_{32} \) | /       | \( b_{3n} \) |
| \( B_n \)  | \( b_{n1} \) | \( b_{n2} \) | \( b_{n3} \) | /       |

Among them, \( b_{ij} \) represents the relative importance of factor \( B_i \) to \( B_j \) relative to the previous level factor \( a_k \), and its value is represented by numbers 1-9 and its reciprocal. The larger the value, the more important \( B_i \) is relative to \( B_j \).

2.3. Hierarchical order and consistency check
The consistency ratio CR is used to test the consistency of the judgment matrix. When CR<0.1, the consistency of the judgment matrix is acceptable; the larger the CI, the worse the consistency of the judgment matrix, which also needs to pass the consistency test.

\[
CR = \frac{CI}{RI}
\]  

Among them, \( CI = (\lambda_{\text{max}} - n)/(n - 1) \), \( \lambda_{\text{max}} \) is the largest characteristic root of the judgment matrix, and RI is the average random consistency index.

2.4. Hierarchical total ranking and consistency check
The weights under the single criterion are synthesized from top to bottom, and the ranking weight of each factor for the decision objective is obtained. The total ranking random consistency ratio CR is used to test the consistency of the judgment matrix, and the test criterion is the same as above.

\[
CR = \frac{\sum_{j=1}^{N} a_{ij} CI_j}{a_{ij} RI_j}
\]

Among them, \( CI_j \) is the single-rank consistency index, and \( RI_j \) is the corresponding average random consistency index.

3. Model and Analysis
3.1. Establish a risk evaluation index system
First, based on a large number of documents and extensive visits and investigations, the safety risk
factors of the fabricated building construction stage are summarized from five aspects.

(1) Man
Through analysis of accident cases in fabricated building construction, the cause of the accident was found and summarized as follows. Due to the low level of professional skills of operators, irregular or even illegal operations in specific operations have increased potential safety hazards. Due to poor safety awareness of operators, they do not pay attention to wearing protective equipment during operation, which increases the probability of personal injury[3]. Due to operator lack of emergency escape and self-rescue ability, lack of professional safety personnel deployment, often passively suffer injuries when accidents occur, lack of self-rescue ability and other rescue conditions, aggravates the degree of personal injury.

(2) Material
Problems in the production, transportation, storage, and installation of materials may be sources of safety risks. Specifically, the accuracy and strength of fabricated parts and components that do not meet the design requirements can easily lead to safety accidents such as falling during hoisting operations. Inadequate protective measures during transportation can easily cause cracks, deformation, and damage to components. Unreasonable stacking, unscheduled inspection, and maintenance, etc. will damage the quality of the parts. In addition, temporary support systems, professional construction tools, etc., also require strict quality control to prevent safety accidents[4-5].

(3) Machine
The component installation and hoisting operations of fabricated buildings place higher requirements on the equipment. The selection of mechanical equipment should meet the requirements of the hoisting plan to avoid overloading. The inspection and maintenance of the mechanical equipment should be done when it is idle to avoid the aging and damage of the mechanical equipment[6]. The installation and dismantling of the mechanical equipment should be carried out in strict accordance with the special construction plan to avoid accidents.

(4) Management
In terms of organization and management, the inadequate implementation of quality and safety production responsibilities, the lax implementation of quality and safety inspections, and the lack of deployment of safety protection measures are the main causes of accidents.

(5) Environment
The safe construction of fabricated buildings requires good environmental protection, which can be subdivided into three aspects: the construction site environment, the natural environment, and the surrounding environment. The construction site must have a good civilized construction situation to form a safe production atmosphere[7-9]. There must also be a plan to deal with the harsh natural environment and proper suspension of work and production. The surrounding environment mainly considers whether public security factors, water and electricity supply, etc. are normal.

Then, following the principles of scientificity, comprehensiveness, maneuverability, dynamicity, and systematicity, the following evaluation index system was constructed by gathering expert opinions.

| Table 2. Safety risk evaluation index system |
|--------------------------------------------|
| **Target layer** | **Criterion layer** | **Index layer** |
| Construction safety risks of fabricated buildings U | Man U₁ | Operator safety awareness ň₁₁ |
| | | Professional competence of operators ň₁₂ |
| | | Protective work of workers ň₁₃ |
| | | On-site security personnel ň₁₄ |
| | | Production quality of fabricated parts ň₂₁ |
| | Materials U₂ | Transport protection measures ň₂₂ |
| | | Material storage and maintenance ň₂₃ |
| | | Quality of auxiliary tools ň₂₄ |
| | | Selection of mechanical equipment ň₃₁ |
| | Machine U₃ | Overhaul and maintenance of mechanical equipment ň₃₂ |
3.2. Judgment matrices

The group decision-making method is used to synthesize the opinions of five experts to construct judgment matrices. First, each expert analyzes and compares the risk factors separately and uses the 9-scale method to construct a judgment matrix that can pass the consistency test. Then, use the arithmetic average method to integrate expert opinions and adjust, obtain the judgment matrix and weights that pass the consistency test, reflect the experts' opinions, and express the importance of each risk factor, as shown in the table below.

| Total criterion weight | Total ranking weight |
|------------------------|----------------------|
| U11 0.1097             | 0.0546               |
| U12 0.3483             | 0.1732               |
| U13 0.0671             | 0.0334               |
| U14 0.4749             | 0.2362               |
| U21 0.0610             | 0.0152               |
| U22 0.1435             | 0.0358               |
| U23 0.2499             | 0.0623               |
| U24 0.5457             | 0.1361               |
| U31 0.2176             | 0.0320               |
| U32 0.6910             | 0.1017               |
| U33 0.0914             | 0.0135               |
| U41 0.1000             | 0.0064               |
| U42 0.3000             | 0.0193               |
| U43 0.6000             | 0.0385               |
| U51 0.1061             | 0.0044               |
| U52 0.7010             | 0.0293               |
| U53 0.1929             | 0.0081               |

According to the weight, the first-level indicators can be sorted as: U1, U2, U3, U4, U5, and the second-level indicators can be sorted as: U14, U12, U24, U32, U23, U11, U43, U22 according to the total ranking weight, U13, U31, U52, U42, U21, U33, U53, U41, U51.

3.3. Classify risk

Based on the comprehensively calculated weights of the secondary indicators, risk factors can be divided into three levels: serious, normal, and minor, which are represented by I, II, and III, respectively. The classification standards and results of risk factors are shown in the table below.

| Risk level | Weight range | Attention | Risk factors |
|------------|--------------|-----------|--------------|
| I          | 0.1-1        | Focus on prevention | U14, U12, U24, U32, U23, U11, U43, U22 |
| II         | 0.01-0.1     | Enough attention   | U13, U31, U52, U42, U21, U33 |
| III        | 0.0-0.01     | General concern    | U53, U41, U51 |
4. Conclusions
This research combines the development status of fabricated buildings and regards the fabricated building construction process as a complex system. It analyzes and identifies 17 safety risk factors from the five dimensions of personnel, equipment, materials, management, and environment, and uses the analytic hierarchy process to construct Safety risk evaluation index system and evaluation, divided the safety risk grades, and obtained the risk factors that should be focused on prevention, sufficient attention, and general attention, which provided a basis for the safety risk control of fabricated building construction, and also used to evaluate the safety of construction plans. Risk in turn, provides a reference to assist decision-making.

References
[1] Xinhua News Agency, 2021. In 2020, new fabricated buildings nationwide will exceed 600 million square meters. http://www.gov.cn/xinwen/2021-03/19/content_5593982.htm.
[2] Liu Y.S. (2019) Management scientific research methods and thesis writing. China Architecture & Building Press, Beijing.
[3] Li H.R., Li M.Q., Lu Y. (2019) Analysis of key safety risks in fabricated building construction based on structural equation model. China Safety Science Journal, 29: 171-176.
[4] Chen W., Fu J., Xiong F.G., Yang J. (2016) Grey clustering evaluation model for construction safety of fabricated building project. China Safety Science Journal, 26: 70-75.
[5] Ding Y., Tian Y.F. (2019) Research on Quality and Safety Risk Evaluation of Fabricated Building Assessment. Construction Economy, 40: 80-84.
[6] Feng Y.J., Du S.Z., Zhang J.Y. (2019) Safety evaluation and prediction of fabricated building construction based on EW-SPA. China Safety Science Journal, 29: 85-90.
[7] Zou X.W., Zhang D., Ma H. (2019) The Establishment of Precautionary Platform for Safety of Assembly Building Construction Based on BIM and Internet of Things. Journal of Engineering Management, 33: 124-129.
[8] Liu J., Yuan J.L., Chang C.G. (2017) Safety risk assessment of fabricated building construction based on unascertained measurement. Journal of Shenyang Jianzhu University (Social Science), 19: 387-393.
[9] Li W.L., Li H.M. (2019) Evaluation of construction safety risk for fabricated building based on entropy-uncertainty measure theory. Journal of Xi’an University of Architecture & Technology (Natural Science Edition), 51: 369-374.