Journal of Applied Science and Engineering Innovation, Vol.11, No.1, 2024, pp.31-38
ISSN (Print): 2331-9062
ISSN (Online): 2331-9070

Transportation Risk Assessment of Prefabricated Building Pre-Components Based On AHP and TOPSIS

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Abstract: This study aims to evaluate the transportation risk of prefabricated building preset parts using the AHP-TOPSIS method, and select the appropriate transportation scheme for case projects based on these indicators. Identify the factors in the transportation plan by investigation and communicating with experts. Firstly, the weight of each influencing factor was determined by hierarchical analysis (AHP), and then the different pre-purchased parts transportation schemes were evaluated and ranked by TOPSIS method. In addition, the research limitations and the direction of future work are discussed, providing a useful reference for transportation management in the field of prefabricated buildings.

Keywords Prefabricated building, AHP, TOPSIS, Multi-objective decision making, Comprehensive evaluation

INTRODUCTION

As an innovative building method, prefabricated building has developed rapidly around the world in recent years. Construction, industry and transportation are the three major energy consumption sectors and the main sources of carbon emissions. In 2009, the United Nations Environment Programme (UNEP) released the report "Building and Climate Change", which pointed out that energy consumption in construction accounts for 30-40% of the global energy consumption, and carbon emission accounts for about 1 / 3 of the total global carbon emissions, which is one of the key areas of energy conservation and emission reduction [Wang, 2017]. Prefabricated buildings in achieving carbon neutrality can help reduce carbon emissions, improve energy efficiency and promote sustainable development. The carbon emissions of prefabricated buildings are reduced by 472.23kg/m² compared to traditional cast-in-place buildings [Qi, et. al., 2016].With the release of the Guiding Opinions of The General Office of the State Council on Vigorously Developing Prefabricated Buildings, prefabricated buildings have been vigorously developed and applied in China. So through Optimize the transportation mode and other ways to improve the transportation efficiency. It is more meaningful to optimize the transportation of pre-purchased parts of prefabricated buildings to promote the application of prefabricated buildings. This paper establishes an evaluation model based on ahp and topsis to evaluate the influencing factors of the transportation risk of prefabricated buildings, so as to help the transportation personnel to choose a safe and suitable transportation scheme, which plays a certain role in improving the suitability and safety of the transportation scheme of prefabricated buildings.

Most of the risk elements identified by the existing studies are based on the full life cycle. In addition, the research focus of scholars is mostly on the application and improvement of evaluation methods, and most of them ignore the influence degree and mechanism of action of risk factors, and do not effectively measure and analyze various risks. For example, Chen Weigang and others take the perspective of the whole life cycle and the vulnerability as the entry point, and use the vector cosine Angle to evaluate the safety of prefabricated buildings [Chen, et. al., 2020]. Ding Yan et al. used hierarchical analysis and ABC classification to assess various risk factors and identify key risks. Duan Yonghui et al. analyzed the safety risks of installation and construction based on SEM. Dong Xiang et al. used ternary interval number theory and sequence entropy method to evaluate super high-rise prefabricated buildings. Some people have studied the specific construction stage of prefabricated buildings. For example, Zhang Lixin et al. proposed a construction risk evaluation method of prefabricated building projects based on the entropy right DEMATEL and TOPSIS models.Li Tianshun introduced the cost management in the construction stage of the prefabricated project into BIM technology, and studied the application of the technology in the refined cost control in the construction stage combined with specific projects[8].

Si Jinzhong combined the interval level analysis method and the gray clustering method to construct the comprehensive evaluation model of the sustainable level of prefabricated building construction based on the gray interval level analysis method [Chen, et. al., 2020]. As a new construction technology, the transportation of pre-purchased parts is unprecedented in traditional cast-in-place buildings, so the risk analysis of this link is conducted. It not only helps to effectively control cost, maintain project progress, improve environmental friendliness, ensure quality and supply chain reliability, but also helps to follow regulatory compliance requirements and improve customer satisfaction. Through in-depth study and analysis of potential risks in the transportation phase, corresponding management strategies and countermeasures can be developed to ensure that prefabricated buildings achieve higher efficiency, reliability and sustainability in the transportation process, thus achieving the project objectives.

CONSTRUCT THE AHP-TOPSIS EVALUATION MODEL

Screen the risk influencing factors

This paper mainly combs and refers to the safety and quality of prefabricated buildings, design, supply chain and full life cycle risks [Wang Yu, 2017]. The literature is analyzed to identify and summarize the key risk factors in the transportation stage. Based on the characteristics of prefabricated buildings and the existing research results of prefabricated buildings, this paper takes 4M1E (Man, Machine, Material, Method and Environments) as the guidance, and consul relevant scholars and enterprise staff, and the risk factors are divided into five aspects: personnel risk, material risk, machine risk, path risk and environmental risk.

Personnel risk. The operation and decision-making of personnel in the transportation process directly affect the safety of transportation. Qualified personnel have safety awareness, technical ability, coordination and communication ability, etc., which can effectively deal with various transportation risks and ensure the safety and smooth progress of transportation. The main risk factors of this item are subdivided: ①HR reliability: consider whether the required personnel are familiar with the task, experience level and professional skills. ② Risk knowledge and training: to evaluate the team's awareness of the risk and related training. ③ Communication and coordination ability: to measure the level of information communication and collaboration among team members. ④ Safety awareness and operation: consider the safety awareness and operation standardization of personnel in the loading and unloading operation.

Material risk. Material risk directly affects the integrity and quality of prefabricated components during transportation. Suitable material selection and packaging design can reduce material loss and waste during transportation, and improve the utilization rate of materials. Therefore, the main risk factors of this item can be subdivided into: ①component integrity: to assess the extent to which the prefabricated components may be damaged during transportation. ②Goods packaging quality: consider the durability and suitability of goods packaging to prevent damage.

Pathway risk. By choosing the appropriate transportation path, the transportation efficiency can be improved, the risk of time delay can be reduced, and the transportation cost can be reduced, so as to ensure the smooth arrival of the components at the construction site and contribute to the smooth progress of the project. The main risk factors of this item are subdivided into: ① Flexibility of route selection: Consider choosing the best transportation route to adapt to different traffic and road conditions. ②Permit requirements: the time and process required to obtain the permit.③ Risk of transportation time delay: bad weather or traffic jams may lead to transportation time delay. ④ Assembly progress impact degree: the delay may affect the building assembly progress.

Appliance risk. Appliances play an important role in the whole transportation process, affecting the safety, efficiency and smooth progress of transportation. Suitable transportation equipment is the premise to ensure the safe transportation of prefabricated components. The tool factor can be subdivided into ① Transportation equipment availability: to ensure that the required transport tools, such as flat truck, crane, etc., are reliable and available.②Cost of lifting equipment: the cost of leasing and operating lifting equipment must be taken into account.

Environmental risks. Environmental risks exist to ensure the environmental sustainability and compliance of the prefabricated building transportation process. By fully considering environmental factors, the negative impact on the surrounding environment can be reduced, carbon emissions can be reduced, and sustainable development can be promoted. Environmental factors include：①Impact degree of weather conditions: bad weather may affect transportation and assembly progress, and preventive measures are required② Environmental impact management: to reduce the negative impact on the surrounding environment, such as noise and emissions.

Determine the weight of risk factors

The weight of the risk factors can be determined using the AHP method. AHP (Analytic Hierarchy Process) is a hierarchical analysis method for multi-criterion decision-making, initiated by the American operations radiologist Thomas L. Saaty in the 1970s. AHP is applicable to complex decision-making problems involving multiple guidelines and multiple alternatives, and it can help

decision-makers make comparisons and trade-offs between factors at different levels to ultimately make rational decisions. The basic idea of AHP is to decompose the decision problem into a hierarchy of goals, criteria, sub-criteria and alternatives. Then, the relative weights between the factors were obtained by performing pairwise comparisons of the factors at different levels. These comparisons form a weight matrix, which is then calculated mathematically to derive the final weights.

Table1. Risk factors for pre-purchased parts transportation of prefabricated buildings

First-level factors	Secondary factors
Personnel risk X_1	Human resources professional score X_{11}
	Personnel risk knowledge and training level score X_{12}
	Personnel communication and coordination ability score X_{13}
	Personnel safety awareness and operation score X_{14}
Material Risk X_2	The component integrity score is X_{21}
	Cargo packaging quality score X_{22}
Appliance risk X_3	Transportation equipment availability score X_{31}
	Lifting equipment cost and risk score X_{32}
Path Risk X_4	Route selection suitability score X_{41}
	Permission access difficulty score X_{42}
	Transportation time Delay risk score X_{43}
	Assembly progress impact degree score X_{44}
Environmental risk X_5	The influence degree of weather conditions is scored as X_{51}
	Environmental impact management measures score X_{52}

The specific steps are described as follows:

In order to determine the weight of the first level factors, this paper adopts the way of interview and investigation, to communicate with several prefabricated building construction personnel. Based on their own construction experience, these builders made pairwise comparisons of the primary factors listed in Table 1 by the 1~5 scale method to understand the relative importance of the different factors. In this process, the interviewees assessed each pair of factors and judged which factors were more important based on previous construction experience. The survey yielded the primary index weight values (Table 2)

Table.2 First-level index weights

	human factor	**material factor**	**Tools factors**	**Transportation method factors**	**environmental factor**
Personnel risk X_1	1	2	4/3	2/3	4
Material Risk X_2	1/2	1	3/2	1/3	2
Appliance risk X_3	3/4	2/3	1	1/2	3
Path Risk X_4	3/2	3	2	1	4
Environmental risk X_5	1/4	1/2	1/3	1/4	1

From the above table, 5 personnel factors, material factors, tool factors, transportation method factors and environmental factors were constructed for AHP hierarchy, and the eigenvector is

(1.273,0.772,0.839,1.767,0.349), and the corresponding 5 weights are W= (0.2547,0.1544,0.1678,0.3535%, 0.0697%). In addition, combining the feature vectors can calculate the maximum feature root λ max=5.101, ICR = 0.022 <0.1, and the consistency test is passed. Similarly, the vector matrix of the secondary index and its index weight value can be obtained. As shown in Table 3, the risk of transportation time delay has the biggest impact on the transportation risk of prefabricated building components, while environmental impact management measures are the least affected factors.

Table.3 Weight of secondary factor indicators

First-level factors	Secondary factors	Judgment matrix				weight	Relative weight
Personnel risk X_1	Human Resource Professional Score X 11	1	1.25	2	2	0.3628	0.0924
	Personnel risk knowledge and training level score X 12	0.8	1	1	1	0.2303	0.0586
	Personnel communication and coordination ability score X 13	0.5	1	1	1	0.2035	0.0518
	Personnel safety awareness and operation score X 14	0.5	1	1	1	0.2035	0.0518
Material Risk X_2	The component integrity score is X 21	1	0.5	×	×	0.3333	0.0515
	Goods packaging quality score X 22	2	1	×	×	0.6667	0.1029
Appliance risk X_3	Transportation equipment availability score X 31	2	1	×	×	0.6667	0.1118
	Lifting equipment cost and risk score X 32	1	0.5	×	×	0.3333	0.0559
Path Risk X_4	Route selection suitability score X 41	1	2	0.5	0.667	0.2000	0.0707
	Permission access accessibility score X 42	0.5	1	0.25	0.333	0.1000	0.0353
	Transportation Time Delay risk score X 43	2	4	1	1.333	0.4000	0.1414
	Assembly progress impact degree scoreX 44	1.5	3	0.75	1	0.3000	0.1060
Environmental risk X_5	Impact degree score of weather conditions X 51	1	3	×	×	0.7500	0.0523
	Environmental Impact Management Measures score X 52	1/3	1	×	×	0.2500	0.0174

Construct the evaluation model

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is a multi-attribute decision analysis method used to find the best choice in a set of candidates. It helps decision makers to identify the most suitable scheme based on the similarity principle under multiple evaluation criteria. We can evaluate the transportation risk of pre-ordered parts in prefabricated buildings based on the topsis.

First, experts can be invited to score the n indicators of the m schemes, from which the initial evaluation matrix X ij can be obtained

$$\left(X_{ij}\right)_{m\times n} = \begin{matrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{matrix}, n、m \in N^* \quad (1)$$

Standardized the scores for each candidate scheme under each evaluation indicator. The standardized method can be:

For the forward indicators:

$$b_{ij} = \frac{X_{ij} - \min_j\left(X_{ij}\right)}{\max_j\left(X_{ij}\right) - \min_j\left(X_{ij}\right)} \quad (2)$$

For reverse indicators:

$$b_{ij} = \frac{\max_j\left(X_{ij}\right) - X_{ij}}{\max_j\left(X_{ij}\right) - \min_j\left(X_{ij}\right)} \quad (3)$$

Where X ij is the original score of the i-th scheme under the j-th evaluation index, and b ij is the normalized score.

Construct a weighted standardization matrix: assign weights to each evaluation index, usually determined using subjective judgment, expert opinion or mathematical methods. The weighted standardization matrix C was constructed according to the index weights obtained by the previous hierarchical analysis method:

$$C_{ij} = \omega_{\mathrm{j}} \bullet \mathrm{b}_{\mathrm{ij}} \quad (4)$$

Among, ω j is the weight of the j th evaluation index.

Determine the ideal solution and the negative ideal solution: determine the best ideal solution C + and the worst negative ideal solution C-under each evaluation index

Calculate the distance between the solution and the ideal solution: Calculate the distance between each solution and the ideal solution C + and the negative ideal solution C-:

$$d_i^+ = \sqrt{\sum_{j=1}^{n}\left(C_{\mathrm{ij}} - C_{\mathrm{j}}^+\right)^2} \quad (5)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}\left(C_{\mathrm{ij}} - C_{\mathrm{j}}^-\right)^2} \quad (6)$$

$$E_i^+ = \frac{d_i^-}{d_i^+ + d_i^-} \quad (7)$$

$\mathrm{E}_{\mathrm{i}}^+$ Specifically, it reflects the proximity of the scheme to the positive ideal solution.

$\mathrm{E}_{\mathrm{i}}^+$ The scheme is ranked from high to low, and the transportation scheme with the best evaluation result is selected.

Based on the above steps, through the AHP-topsis method of construction and expert scoring, we can obtain the evaluation system model.

EXAMPLE ANALYSIS

Project overview

This paper takes a pre-purchase transportation project of a proposed prefabricated building in Xiongan New Area of Baoding city as an example, with a total of ten residential buildings, and each building has five floors. The project is planned to adopt prefabricated building technology to improve the efficiency and quality of the construction. In this project, the prefabricated building components will be produced in the manufacturing plant and then transported from the manufacturing plant to the construction site for assembly.

When choosing an appropriate transportation scheme, the project team needs to consider multiple risk factors, including personnel factors, material factors, appliance factors, path factors, and environmental factors. Based on the actual situation, the project team has developed three transportation plans:

(1) Scheme 1: multimodal transport

This scheme combines land transport, water transport and road transport to optimize transport efficiency and reduce risk.

Land transport: prefabricated components are transported from the manufacturing plant to the nearest railway station, using flatbed trucks. Pay attention to the package and fix of the goods in the transportation to ensure the safety.

Water transport: From the railway station, the components are transported by rail to a nearby water port, then loaded onto a barge, and transported by water to the nearest seaport.

Road transport: From the harbor, use environmentally friendly electric trucks to transport components to the construction site. Special attention should be paid to road traffic permits and traffic conditions at this stage.

(2) Scheme 2: Pre-assembly and transportation

The scheme emphasizes reducing the field assembly time and improving the assembly efficiency during transportation.

Assembly pre-assembly: pre component assembly to the greatest extent possible to reduce site construction time.

Water transport: transport the pre-assembled components from the manufacturing plant to the nearby water port, and then use a barge to the river port where the construction site is located.

Site assembly: At the river port, the crane and assembly workers will remove the components from the barge, and then the final assembly work will be performed at the building site.

(3) Scheme 3: Intelligent transportation

This scheme combines intelligent transport technology to monitor and adjust the risks in the transport process in real-time.

Intelligent water transportation: Use autonomous navigation ships equipped with sensors and GPS to monitor the position, status and transportation conditions of components in real time to ensure safe and punctual transportation.

Intelligent field assembly: In the construction site, using intelligent lifting equipment can monitor the weight and stability of components in real time to ensure safe assembly.

Real-time risk adjustment: Based on real-time weather, transportation and environmental information, timely adjustments can be made during transportation to avoid potential risks.

Transportation safety risk assessment

Several relevant experts are invited to score the transportation project. When it comes to the negative index, we can reverse score it, that is, the lower the score, the better the index. The scoring table for each scheme, namely the initial matrix, is shown in Table 4.

Table 4 Expert scoring results of the evaluation indicators of each program

factor	**weight**	**multimodal transportation**	**Pre-assembly transportation**	**Intelligent transport ation**	**Indicator type**
HR professional score	0.09	9	8.5	8	forward pointer
Personnel risk knowledge and training level score	0.06	8.5	8.5	7.5	forward pointer
Personnel communication and coordination ability score	0.05	8.8	7.8	9	forward pointer
Personnel safety awareness and operational score	0.05	8.2	8.2	9	forward pointer
The component integrity score	0.05	8.5	9	8.5	forward pointer
Cargo packing quality score	0.1	8.7	9	8	forward pointer
Transport equipment availability score	0.11	9.2	7.5	8.5	forward pointer
Lifting equipment cost and risk score	0.06	6.5	8.5	9	forward pointer
Route selection is appropriate to score	0.07	8.5	7.5	9.5	forward pointer
Easy score of access permit	0.04	9	8	8.5	forward pointer
Transport time delay risk score	0.14	3.2	1.5	1.5	Negative indicators
Impact degree score of assembly progress	0.11	3.2	1.5	1	Negative indicators
Impact degree score of weather conditions	0.05	4	3	2	Negative indicators
Environmental impact management measures	0.02	6	7.5	9	forward pointer

score	

Next, forward and standardize Table 4.Equations 4-7 can get the distance of each solution from the positive and negative ideal solutions, and multiply with the weight to obtain the comprehensive evaluation index of each scheme, so as to give the ranking of each scheme.

Table.5 Comprehensive score index and ranking of each scheme

scheme	d+	d-	Comprehensive score index	ranking
multimodal transportation	0.098301877	0.056203434	0.363763766	3
Pre-assembly transportation	0.065923717	0.080303867	0.549170442	2
Intelligent transportation	0.038995134	0.106810087	0.732553239	1

According to the analysis results, the intelligent transportation scheme performs the best in the comprehensive score and ranking, and the gap between the best scheme is the smallest. The pre-assembled transport scheme is ranked 2nd, with a moderate gap from the best scheme. The multimodal transport scheme ranked lowest and had relatively large distances from both the best and the worst scheme.

Results analysis

Multimodal transport performed the worst in the composite score. This may be because in practice, multimodal transport needs to coordinate multiple different transport modes with high management complexity, which may lead to low inefficiency and additional costs. The advantage of multimodal transport is that it can take full advantage of the advantages of various transportation modes, such as the combination of railway, water and road transportation, but it requires efficient coordination and management to achieve. Pre-assembled transport had a median performance in the composite score. This may be because pre-assembly transportation can reduce field assembly time and improve construction efficiency, but still transportation issues and design limitations need to be addressed. In practical applications, the pre-assembly transportation is suitable for those prefabricated components that can be partially prefabricated and transported, and the applicability has certain limitations. Intelligent transportation performed the best in the overall score. It is possible that intelligent transportation uses the Internet of Things technology to monitor and optimize the transportation process, which can realize real-time risk management and adjustment, thus improving the controllability and efficiency of transportation. In reality, intelligent transportation may require more technical support and investment, but it has a clear competitive advantage in reducing transportation risk, reducing delays and improving transportation quality.

CONCLUSION

In this study, we applied the AHP-TOPSIS method to establish the transportation safety risk evaluation model of prefabricated buildings and evaluate the transportation risk of pre-purchased parts of prefabricated buildings. This method takes into account the weights and scores of multiple risk factors, and provides a scientific and comprehensive evaluation tool for decision makers, so as to evaluate the risks of transportation scheme and choose the appropriate and safe transportation method, which is of great significance to the selection of transportation scheme of prefabricated building components. In our analysis, the intelligent transportation scheme ranked the highest in the comprehensive risk assessment with the best comprehensive score. This indicates that using the Internet of Things technology for real-time monitoring and optimizing the transportation process can significantly reduce the risk in the current transportation of pre-ordered parts in prefabricated buildings. However, due to the limitation of the data and the abstraction of the model. Our study still relies on the quality and accuracy of the available data and the evaluation model may not fail to cover all possible factors. Future studies could select more practical cases for a detailed case analysis of the transportation risks of different prefabricated building projects to verify the validity and utility of the model.

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