Journal of Nonlinear and Convex Analysis
Volume 26, Number 7, 2025, 2279–2290

Yokohama Publishers
ISSN 1880-5221 ONLINE JOURNAL

A COMBINED WEIGHT CALCULATION MODEL FOR EVALUATING THE TOUGHNESS OF ASSEMBLED BUILDING SUPPLY CHAIN

JINJIN LI, LAN LUO, ZHANGSHENG LIU*, AND HENGHENG SU

Abstract. To scientifically identify the key factors affecting the toughness of prefabricated building supply chain, this paper presents a combined weight calculation model for evaluating its toughness. After developing the index system for the supply chain toughness of prefabricated buildings, the Extension Analytic Hierarchy Process (EAPH) is used to assign the index subjective weights to the indices, while the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) is applied to determine the objective weights. In addition, to ensure the rationality of the weight result, game theory is employed to integrate and balance the subjective and objective weights. Finally, the Taohua Shantytown Project in Nanchang City is selected to assess the effectiveness of the model.

1. Introduction

As a new type of construction, prefabricated buildings have gained significant attention and development worldwide in recent years. In 2023, the newly started area of prefabricated buildings in China reached 1.016 billion square meters, accounting for more than 25% of the total newly started residual areas in the country. The market scale of prefabricated modular buildings in China grew from 29.8 billion RMB in 2015 to 134 billion RMB in 2022. Prefabricated building projects face significant risks due to their multi-stage process, high costs, and poor construction management, making their supply chains susceptible to disruptions.Supply chain resilience refers to the ability of a supply chain to quickly return to its ideal state after being disturbed or interrupted [10]. For prefab structures, a robust supply chain is key to minimizing disruption risks, keeping operations steady and boosting business competitiveness.

Research on the factors affecting the toughness of prefabricated building supply chain has become a prominent topic in academic circles. For example, Zhang et al. [13] examined the factors affecting the supply chain flexibility of prefabricated buildings across three key stages: design, production, transportation, and construction. Moreover, Zhang and Liu [14] constructed an evaluation index system for building supply chain toughness from four perspectives: prediction ability, absorption ability, adaptability, and resilience. In addition, Gao et al. [5] conducted a

2020 *Mathematics Subject Classification.* 94D005, 91-08.
Key words and phrases. EAHP, TOPSIS, prefabricated buildings, supply chain resilience, combination weight.
This study was supported by National Natural Science Project (71863020) and Jiangxi Province Culture, Art and Science Planning General Project (YG2022098).
*Corresponding author.

comprehensively analysis of the factors affecting the toughness of the prefabricated building supply chain under Engineering, Procurement, and Construction (EPC) model. Furthermore, Liu et al. [8] explored various factors affecting supply chain toughness from the perspective of dynamic capability, and identified and validated the relationships between these factors using Structural Equation Modeling. Added to that, Ekanayake et al. [4] established an evaluation index system for supply chain toughness in prefabricated buildings, focusing on supply chain fragility and capability. Added to that, Ingirige et al. [1] identified five key factors influencing the resilience of supply chain through a survey filled by 105 professionals. Finally, Wedawatta et al. [12] argued that extreme weather is a critical factors affecting the resilience of construction supply chain.

Currently, many quantitative models have been proposed for evaluating the toughness of the assembled building supply chain. For instance, Wang et al. [11] developed a calculation model of the toughness weight of the assembly building supply chain using the Analytic Network Process. In addition, Zhu et al. [15] employed a Back Propagation Neural Network (BPNN) to predict risks throughout the whole prefabricated building supply chain. Moreover, Liu [7] used the Analytic Hierarchy Process (AHP) to quantify the results of the toughness evaluation for the assembled building supply chain. As for Cai et al. [2], they combined AHP and the DEcision-MAking Trial and Evaluation Laboratory (DEMATEL) method to establish a set of calculation model for the combined weight of the assembly building supply chain and conducted a comprehensive and systematic analysis of the indicators. Furthermore, Lu [8] proposed an evaluation model for the flexibility of the assembled building supply chain based on DEMATEL and Interpretive Structural Modeling Method, analyzing the key factors affecting supply chain flexibility and their underlying mechanism.

In summary, research on quantifying key factors is scarce, and existing methods for calculating indicator weights are rather basic. Thus, this paper introduces an innovative research framework to address these limitations.Therefore, this paper proposes a new research framework. First, the Extension Analytic Hierarchy Process (EAHP) is used to determine the subjective weight influencing the toughness index of the prefabricated building supply chain. Second, TOPSIS is applied to calculate the objective weight of the indicators. Finally, based on game theory, a comprehensive method for calculating the weight of the toughness index of the assembled building supply chain is developed.

2. Methodology

2.1. **Weight calculation method based on EAHP.** EAHP is developed based on AHP. It constructs judgment matrix with interval number instead of point number, overcoming the ambiguity of AHP in solving expert experience judgment. Specific calculation steps are defined as follows [9]:

Step 1. Constructing an extension interval number judgment matrix

The subcontracting of construction projects involves the process in which a general contracting unit for a construction project delegates specific portions or multiple parts of the project to other contracting units. These units then sign subcontract agreements with the general contractor under the main contract.

After constructing the index system for building supply chain toughness, it is necessary to compare each index in pairwise. To more accurately describe the relative importance of these indicators, using extension intervals for quantitative description. This allow to construct an extension judgment matrix, as outlined below [9]:

$$C=\begin{pmatrix}\langle c_{11}^-,c_{11}^+\rangle & \langle c_{21}^-,c_{21}^+\rangle & \cdots & \langle c_{n1}^-,c_{n1}^+\rangle\\ \langle c_{12}^-,c_{12}^+\rangle & \langle c_{22}^-,c_{22}^+\rangle & \cdots & \langle c_{n2}^-,c_{n2}^+\rangle\\ \vdots & \vdots & \ddots & \vdots\\ \langle c_{1n}^-,c_{1n}^+\rangle & \langle c_{2n}^-,c_{2n}^+\rangle & \cdots & \langle c_{nn}^-,c_{nn}^+\rangle\end{pmatrix} \tag{2.1}$$

where$\langle c_{ij}^-,c_{ij}^+\rangle$ are extension interval numbers, c_{ij}^- represents the lower limit of extension interval,C^+ indicates a positive reciprocal matrix,and $r_{ij}^{(k)}=\langle r_{ij}^{(k)-},r_{ij}^{(k)+}\rangle=\langle\frac{1}{r_{ij}^{(k)+}},\frac{1}{r_{ij}^{(k)-}}\rangle$.

Through data collection process, every element data c_{ij}^- and C^+ in the judgment matrix of extension interval number is given an integer in the scale of 1-9 in the traditional analytic hierarchy process to ensure the accuracy of expert scoring.

Step 2. Calculating the interval weight vector of the extension judgment matrix.

(1) Construction of the extension judgment matrix$C=[C^-,C^+]$ according to Eq. (2.1). This leads to $C^-=(c_{ij}^-)_{n\times n}$, $C^+=(c_{ij}^+)_{n\times n}$.

(2) Calculation of m and k from C^- and C^+ using Eq. (2.2) [9]

$$m=\sqrt{\sum_{j=1}^{n}\left(\frac{1}{\sum_{i=1}^{n}c_{ij}^-}\right)}\,k=\sqrt{\sum_{j=1}^{n}\left(\frac{1}{\sum_{i=1}^{n}c_{ij}^+}\right)} \tag{2.2}$$

where m and k are two positive real numbers, satisfying $0\le k\le 1\le m$; the extension judgment matrix will be regenerated until the requirements are met [9].

(3) Finding the weight vector of the extension judgment matrix [9]:

$$W^d=(W_1^d,W_2^d,\ldots,W_n^d)=(k\omega^-,k\omega^+) \tag{2.3}$$

where W_n^d denotes the weight of the n^{th} element in the d^{th} layer relative to a certain element in the previous layer. It is expressed using the extensible interval number $W_n^d=\langle W_n^{d-},W_n^{d+}\rangle$. Moreover, W^d represents the extensible interval weight vector of the judgment matrix C, demonstrating that the weight vector derived from this equation is uncertain.

Step 3. Calculate the ranking weight of each indicator list.

The relative importance of indexes $C_1^d,C_2^d,\ldots,C_i^d,\ldots,C_n^d$ are computed using the extension judgment matrix weight vector W^d. It is defined as follows [9]:

$$V(W_i^d\ge W_j^d)=\frac{2(W_i^{d+}-W_j^{d-})}{(W_j^{d+}-W_j^{d-})+(W_i^{d+}-W_i^{d-})}. \tag{2.4}$$

For any $i=1,2,\ldots,n$, $V(W_i^d\ge W_j^d)\ge 0$, there is [9]:

$$\begin{cases}P_{jb}^d=1\\ P_{ib}^d=V(W_i^d\ge W_j^d)\end{cases} \tag{2.5}$$

where P_{jb}^d represents the weight of evaluation index C_i^d on the d layer to evaluation index C^{d-1} on the $d-1$ layer. Moreover, $P_b^d = (P_1^d, P_2^d, \ldots, P_n^d)$ is obtained after normalizing P_{ib}^d, representing the evaluation indexes $C_1^d, C_2^d, \ldots, C_n^d$ on the d layer.

2.2. **Weight calculation method based on TOPSIS.** The TOPSIS method is used to evaluate the quality of samples based on their proximity to the ideal solution. First, the initial data matrix is standardized, the best and worst alternatives within the group are identified. Then, the distances between the scheme to be evaluated and the two extreme schemes are measured. The quality of the alternative is judged to be evaluated based on these distances. Specifically, as follows [3]:

(1) Pre-treatment of impact indicators: For the forward processing of reverse indicators, the following expression is defined:

$$x_{ij} = \max(x_{ij}) - x_{ij} \tag{2.6}$$

where $\max(x_{ij})$ represents the maximum value of negative indicator set.

(2) Implement dimensionless data processing: The purpose is to normalize the index matrix to eliminate the dimensional influence between the different indexes:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_i x_{ij}^2}}. \tag{2.7}$$

The normalized index matrix is defined as follows:

$$Z = \begin{pmatrix} Z_{11} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots \\ Z_{m1} & \cdots & Z_{mn} \end{pmatrix}.$$

(3) Calculate the optimal solution set z^+ and the worst solution set z^-, identifying the best and worst performance of each impact indicator across all samples. Then, calculate the z^+ and z^- using the following equation [3]:

$$z^+ = \left(Z_1^+, Z_2^+, \ldots, Z_m^+\right), \tag{2.8}$$

$$z^- = \left(Z_1^-, Z_2^-, \ldots, Z_m^-\right). \tag{2.9}$$

(4) Calculate the distance H_i^+ between the influence index z_{ij} and the corresponding optimal value z_i^+ from the optimal solution set. Similarly, calculate the distance H_i^- between the influence index z_{ij} and the corresponding worst value z_i^- from the worst solution set.

$$H_i^+ = \sqrt{\sum_j \left(z_{ij} - z_i^+\right)^2}, \tag{2.10}$$

$$H_i^- = \sqrt{\sum_j \left(z_{ij} - z_i^-\right)^2} \tag{2.11}$$

where $i = 1, 2, \ldots, m$ is the number of characteristic indicators, $j = 1, 2, \ldots, n$ being the number of samples.

(5) Calculate the relative closeness between each evaluation index and the optimal value S_i as follows:

$$S_i = \frac{H_i^-}{H_i^+ + H_i^-}. \tag{2.12}$$

(6) Calculate the objective w eight of indicators, normalize the relative proximity S_i, and get the objective weight of each index β_i as follows:

$$\beta_i = \frac{s_i}{\sum_{j=1}^{m} s_i} \tag{2.13}$$

where $\beta = (\beta_1, \beta_2, \ldots, \beta_m)$ denotes the objective weight vector of the index.

2.3. **Game theory to calculate the combination weight.** This section adopts a combined weighting strategy to define the index weight. This approach aims to avoid the excessive subjectivity introduced by relying solely on expert experience, while also addressing the problem of weight allocation in the objective method. The goal is to ensure a more reasonable and effective allocation of index weights.

In this paper, a fundamental principle is applied to minimize the difference between subjective and objective weight distribution results: minimizing heterogeneity when combining weights. While the weighted average of subjective and objective weights can reduce this heterogeneity to some extent, it is not the optimal solution and cannot ensure its minimization. Therefore, this section innovatively introduces game theory and applies it to the integration of subjective and objective weights. This method allows for a comprehensive evaluation of the unique role of both subjective and objective weight within the system, and ensures an accurate balance of the differences between weights through carefully designed weight distribution coefficients.

Suppose that the weight vectors $W_l = (w_{1,l}, w_{2,l}, \ldots, w_{n,l})(l = 1, 2, \ldots, L)$ of n indicators are calculated using the L weighting method; thus, the basic weight set can be obtained as follows:

$$W_{\text{inte}} = \sum_{l=1}^{L} \alpha_l W_l \tag{2.14}$$

where α_l is the distribution coefficient of the L^{th} basic weight. There are several linear combinations of L basic weights. To find the optimal combination weight W_{inte}^*, this part uses the idea of game theory to optimize the basic weight distribution coefficient in Eq. (2.14). The optimization goal consists of minimizing the heterogeneity (deviation) of the optimal combination weight and all basic weights. This is expressed as follows:

$$\min \sum_{i=1}^{L} \left\| \left(\sum_{l=1}^{L} \alpha_l W_l \right) - W_i \right\|_2 \tag{2.15}$$

where $\|U\|_2$ represents the second norm of vector U, α_i is a variable to be decided, and $\sum \alpha_i = 1$.

The optimal value α_i^* of Eq. (2.15) can be calculated using the mature commercial solver of MATLAB. Moreover, the combination weight based on game theory can be expressed as follows [15]:

$$W^*_{\text{inte}} = \sum_{l=1}^{L} \alpha_l^* \times W_l \tag{2.16}$$

Specifically, in this paper, two basic weights are combined: W_1, the objective weight based on TOPSIS, and W_2, the subjective weight based on EAHP. The goal is to minimize the deviation between the combined weights and the subjective and objective weights, thereby balancing the index importance reflected by both. In other words, the combined weights should not only capture the inherent attributes of each index but also effectively incorporate the original data information of the index.

2.4. **Realization of the proposed model.** The model evaluation flow chart is displayed in Figure 1.

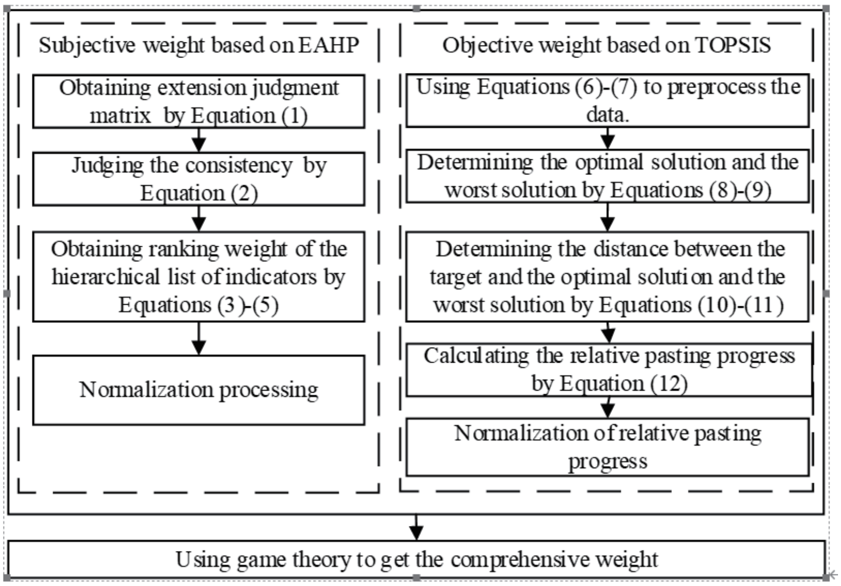

FIGURE 1. Ranking of all evaluation methods

Step 1. Calculate the subjective weight. The extension judgment matrix is established using Eq. (2.1), and the data in the matrix is obtained through expert scoring. The consistency of the matrix is then verified using the consistency test numbers k and m. Then, the weight vector of the extension judgment matrix is calculated using Eq. (2.3). Finally, the results from Eqs. (2.4) and (2.5) are normalized to obtain the subjective weight of the index.

Step 2. Calculate the objective weight. The actual value of the index is generated through expert scoring, and the original data matrix is constructed. Eqs. (2.6) and (2.7) are used to preprocess the data. Moreover, Eqs. (2.8) to (2.12) are employed to get the objective weight of the indicators.

Step 3. Combine the weight values obtained by both methods with the game theory to generate the final weight.

3. Case study

3.1. Project Overview. The case study selected in this paper is the Taohua shantytown project in Nanchang. The project consists of five high-rise residential buildings (1#, 2#... 5#), three commercial buildings with service rooms (6#, 7# and 8#), and a two-story underground garage. Among them, the residential buildings feature an assembled frame-shear wall structure, with 24 to 26 floors above ground. The highest building reaches a height of 80.10m, and the podium is a frame structure with 3 to 6 floors. The total construction area is about 137,000 m with 103,000 m above ground and 34,000 m underground. The proportion of assembled components in this project is 45%, primarily consisting of vertical components and stairs.

3.2. Building an index system. The operation of the prefabricated building supply chain involves a wide range of stakeholders, with diverse and complex sources of resilience influencing factors. To accurately identify these factors, a toughness index system of assembled building supply chain is constructed through literature research [5, 12–14] and expert interviews. This system consists of five first-level indicators and 15 second-level indicators. Details are found in Table 1.

Table 1. Index system of prefabricated building supply chain

Primary indicators	Refs	Secondary indicators	Refs
Design Stage A_1	[5, 12, 13, 14]	Technical Capability A_{11}	[5, 12, 13]
		Design ability A_{12}	[5, 13, 14]
		Information exchange ability A_{13}	[?, 12]
Component production stage A_2	[12, 13, 14]	Component redundancy A_{21}	[12, 13, 14]
		Component system A_{22}	[12, 13]
		Factory management A_{23}	[12, 13, 14]
		Logistics company reliability A_{31}	[12, 13, 14]
Transportation management ability A_3	[5, 12, 13]	Transport flexibility A_{32}	[12, 13]
		Transportation Distance and Cost A_{33}	[12, 13, 14]
Quality control A_4	[?, 12, 13, 14]	Professionals A_{41}	[13, 14]
		Construction Technology A_{42}	[5, 13, 14]
		Regulatory mechanism A_{43}	[5, 13, 14]
Human Resource Management A_5	[5, 12, 13, 14]	Education and Training A_{51}	[?, 12, 14]
		Cross-functional team A_{52}	[5, 12, 14]
		Crisis management A_{53}	[12, 13]

3.3. EAHP subjective weight assignment.

3.3.1. *Construction of extension interval number judgment matrix.* Following the calculation steps of EAHP, two experts in relevant fields are invited to score the importance of each pair of indicators at the same level using the 1-9 scale method. Both experts have more than 10 years of engineering experience and have participated in the supply chain management of the case project. Due to the limited number of supply chain management experts available for this case, Only two experts were selected in this paper. Then, the extension interval number judgment matrix C is constructed for the indicators at the same level, relative to the indicators at the previous level. Taking the first-level indicators A_1, A_2, A_3, A_4, A_5 as examples, the extension interval number judgment matrix C is displayed in Eq. (2.1), and the meaning of each scoring value is detailed in Table 1.

$$C = \begin{pmatrix} (1,1) & (\frac{1}{3},\frac{1}{2}) & (\frac{1}{4},\frac{1}{3}) & (\frac{1}{6},\frac{1}{5}) & (2,4) \\ (2,3) & (1,1) & (\frac{1}{6},\frac{1}{5}) & (\frac{1}{7},\frac{1}{6}) & (2,3) \\ (3,4) & (5,6) & (1,1) & (\frac{1}{3},\frac{1}{2}) & (3,5) \\ (5,6) & (6,7) & (2,3) & (1,1) & (3,6) \\ (\frac{1}{4},\frac{1}{2}) & (\frac{1}{3},\frac{1}{2}) & (\frac{1}{5},\frac{1}{3}) & (\frac{1}{6},\frac{1}{3}) & (1,1) \end{pmatrix}. \tag{3.1}$$

The matrix C is decomposed into a negative matrix C^- containing the lower limit of the extension interval number and a positive matrix C^+ regrouping the upper limit of the extension interval number. Both matrices are represented as follows:

$$C^- = \begin{pmatrix} 1 & \frac{1}{3} & \frac{1}{4} & \frac{1}{6} & 2 \\ 2 & 1 & \frac{1}{6} & \frac{1}{7} & 2 \\ 3 & 5 & 1 & \frac{1}{3} & 3 \\ 5 & 6 & 2 & 1 & 3 \\ \frac{1}{4} & \frac{1}{3} & \frac{1}{5} & \frac{1}{6} & 1 \end{pmatrix}, \quad C^+ = \begin{pmatrix} 1 & \frac{1}{2} & \frac{1}{3} & \frac{1}{5} & 4 \\ 3 & 1 & \frac{1}{5} & \frac{1}{6} & 3 \\ 4 & 6 & 1 & \frac{1}{2} & 5 \\ 6 & 7 & 3 & 1 & 6 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{3} & \frac{1}{3} & 1 \end{pmatrix}.$$

3.3.2. *Solve the eigenvector of the extension interval judgment matrix.* Solving the eigenvectors ω^+ and ω^- using the positive components of matrices C^+ and C^-, while employing the root method leads to the following:

$$\omega^+ = (0.0838, 0.0986, 0.2844, 0.4720, 0.0612),$$
$$\omega^- = (0.0815, 0.1043, 0.2869, 0.4716, 0.0558).$$

3.3.3. *Consistency of judgment matrix.* Using Eq. (2.2) to solve the values of k and m leads to:$m = 1.0313$, $k = 0.9210$

Based on these equations, we can get that $0 \leq k = 0.9210 \leq 1 \leq m = 1.0313$. Thus, the consistency of the extension interval judgment matrix is acceptable.

3.3.4. *Determine the relative importance of indicators.* The extension comprehensive weight vector obtained by Eq.(2.3) for comparing each first-level index is defined as follows:

$$W_1^1 = \langle 0.0751, 0.0864\rangle, \quad W_2^1 = \langle 0.0961, 0.1016\rangle, \quad W_3^1 = \langle 0.2642, 0.2933\rangle,$$
$$W_4^1 = \langle 0.4343, 0.4868\rangle, \quad W_5^1 = \langle 0.0514, 0.0632\rangle.$$

According to Eq. (2.4), the relative importance V of each level index can be obtained as follows:

$$V(W_2^1 \geq W_5^1) = \frac{2 \times (0.1016 - 0.0514)}{(0.1016 - 0.0961) + (0.0632 - 0.0514)} = 5.7884 = P_2$$
$$V(W_3^1 \geq W_5^1) = \frac{2 \times (0.2933 - 0.0514)}{(0.2933 - 0.2642) + (0.0632 - 0.0514)} = 11.8477 = P_3$$
$$V(W_4^1 \geq W_5^1) = \frac{2 \times (0.4868 - 0.0514)}{(0.4868 - 0.4343) + (0.0632 - 0.0514)} = 13.5507 = P_4$$

$$V(W_1^1 \geq W_5^1) = \frac{2 \times (0.0864 - 0.0514)}{(0.0864 - 0.0751) + (0.0632 - 0.0514)} = 3.0308 = P_1$$

By normalizing P_1, P_2, P_3, P_4, and P_5, the weight of five first-level indicators to the total target layer can be obtained. Thus, according to $P_i' = \frac{P_i}{\sum_{j=1}^{n_d} P_j}$, one can write:

$$P_A = \left(\frac{P_1}{\sum_{j=1}^{5} P_j}, \frac{P_2}{\sum_{j=1}^{5} P_j}, \frac{P_3}{\sum_{j=1}^{5} P_j}, \frac{P_4}{\sum_{j=1}^{5} P_j}, \frac{P_5}{\sum_{j=1}^{5} P_j} \right)^T$$
$$= (0.0861, 0.1644, 0.3364, 0.3848, 0.0284)^T$$

That is, the subjective weights of the first-level indicators relative to the toughness of prefabricated building supply chain are as follows: design stage 8.61%, component production stage 16.44%, transportation management ability 33.64%, construction assembly 38.48%, and quality control 2.84%.

By analogy, to facilitate the calculation, the extension interval number judgment matrix of each secondary index is imported into `MATLAB` for programming. This allows for the calculation of the subjective weight of each secondary index, with the results summarized in Table 2.

3.3.5. *TOPSIS method objective weight assignment.* Given that the index system is mostly qualitative, ten staff members involved in the supply chain of prefabricated buildings are invited to score it based on the established toughness index system and the actual conditions of the project. The scores are provided using a 100-point system. Taking transportation management capability A_3 as an example, the original data matrix S is constructed as follows:

$$S = \begin{pmatrix} 70 & 80 & 83 & 95 & 77 & 78 & 85 & 74 & 77 & 90 \\ 78 & 74 & 73 & 68 & 69 & 84 & 85 & 82 & 74 & 71 \\ 75 & 86 & 89 & 84 & 75 & 68 & 88 & 72 & 72 & 76 \end{pmatrix}$$

According to Eqs. (2.8) and (2.9), the optimal solution set z^+ and the worst solution set z^- in matrix S are described as follows:

$$z^+ = (78, 86, 89, 95, 77, 84, 88, 82, 77, 90), \quad z^- = (70, 74, 73, 68, 69, 68, 85, 72, 72, 71).$$

The distances of three indexes, namely, A_{31}, A_{32}, and A_{33}, are calculated relative to the optimal solution set z^+ and the worst solution set z^-. Therefore, one can get:$H_1^+ = 15.6525$, $H_1^- = 37.6696$, $H_2^+ = 39.6485$, $H_2^- = 20.5913$, $H_3^+ = 26.6646$, and $H_3^- = 27.4044$.

Using Eq. (2.12), the relative closeness degree S_i between each secondary index and the optimal value under transportation management capacity A_3 is determined as follows: $S_1 = 0.7065$, $S_2 = 0.3418$, $S_3 = 0.5068$.

Finally, the objective index weight β_i is obtained by normalizing S_1, S_2, and S_3. Thus, $\beta_1 = 0.4543$, $\beta_2 = 0.2198$, and $\beta_3 = 0.3259$.

Similarly, the objective weights of other indicators can be obtained. They are summarized in Table 2.

3.3.6. *Combination empowerment based on game theory.* The combination weight of each secondary index is determined using the game theory, and the first-level index weights are obtained through linear addition, as shown in Table 2. To facilitate calculation, MATLAB programming software is used to solve the problem.

TABLE 2. Weighted indices for primary and secondary criteria

Primary index	Subjective weight	Objective weight	Comprehensive weight	Secondary index	Subjective weight	Objective weight	Comprehensive weight
				A_{11}	0.2721	0.3396	0.0241
A_1	0.0861	0.1349	0.0876	A_{12}	0.6080	0.3585	0.0522
				A_{13}	0.1199	0.3020	0.0113
				A_{21}	0.2510	0.3546	0.0419
A_2	0.1644	0.1749	0.1647	A_{22}	0.6530	0.3751	0.1061
				A_{23}	0.0960	0.2703	0.0168
				A_{31}	0.2014	0.4543	0.0687
A_3	0.3364	0.2134	0.3326	A_{32}	0.7071	0.2198	0.2319
				A_{33}	0.0915	0.3259	0.0320
				A_{41}	0.2395	0.3003	0.0931
A_4	0.3848	0.4070	0.3855	A_{42}	0.1373	0.3336	0.0554
				A_{43}	0.6232	0.3661	0.2370
				A_{51}	0.5390	0.2571	0.0154
A_5	0.0284	0.0699	0.0297	A_{52}	0.2973	0.3260	0.0089
				A_{53}	0.1638	0.4170	0.0054

3.3.7. *Weight result analysis.* The calculation results in Table 2 reveal distinct weight distribution characteristics in the toughness evaluation of the assembled building supply chain for the Taohua shantytown project in Nanchang. Among the first-level indicators, the weights, in descending order, are: $A_4(0.3855), A_3(0.3326), A_2(0.1647), A_1(0.0876)$, and $A_5(0.0297)$. Additionally, the weight distribution of secondary indicators within the toughness evaluation system highlights the key factors affecting the supply chain resilience. Among them, transportation flexibility and supervision mechanism have the two largest weight ratios, at 0.2319 and 0.2370, respectively. These values are significantly higher than those of other secondary indicators, underscoring their importance in improving the toughness of the prefabricated building supply chain.

4. Conclusion

This paper conducts an in-depth study of the factors affecting the toughness of the prefabricated building supply chain and established a toughness index system for it. A model set for calculating the weight of indicators is proposed by combining EAHP and TOPSIS, enabling the quantification of each index's importance and the identification the key factors. The empirical results show that the model accurately identifies the key factors affecting the supply chain toughness of prefabricated buildings, providing strong support for their supply chain management.

References

[1] N. A. Z. Abidin and B. Ingirige *The dynamics of vulnerabilities and capabilities in improving resilience within Malaysian construction supply chain*, Construction Innovation **18** (2018), 412–432.

[2] Q. Cai, Y. Du and R. Wang, *Analysis on supply chain risk factors of prefabricated buildings using AHP-DEMATEL-ISM model*, Tehnički vjesnik **30** (2023), 1379–1386

[3] Z. Cao, Y. Liu, M. Li and D. Su, *Evaluation of prefabricated building green degree based on CRITIC and TOPSIS method*, Building Energy Efficiency **46** (2018), 37–40.

[4] E. Ekanayake, G. Q. Shen , M. M. Kumaraswamy, E. K. Owusu and A. B. Saka, *Modeling supply chain resilience in industrialized construction: A Hong Kong case*, Journal of Construction Engineering and Management **147** (2021): 05021009.

[5] J. Gao, W. Zhao and W. Liu, *Evaluation of influencing factors on the supply chain of prefabricated buildings under engineering procurement construction model: A case study in China*, Buildings **14** (2024): 1680.

[6] L. Li , G. Xie, K. Lin, J. Hong, W. Ma, X. Wang and H. Zhao *Investment efficiency assessment of distribution network for the high proportion of renewable energy: A hybrid multiattribute decision-making method*, Mathematical Problems in Engineering **2022** (2022): 2214235.

[7] W. Liu and Z. Liu, *Simulation analysis of supply chain resilience of prefabricated building projects based on system dynamics*, Buildings **13** (2023): 2629.

[8] X. Liu, J. Meng ang J. Wang, *Influencing factors and improvement strategies of supply chain resilience of prefabricated construction from the perspective of dynamic capabilities: The case of China*, Engineering, Construction and Architectural Management **32** (2025), 3465–3494.

[9] C. Lv, Z. Wu , Z. Liu and L. Shi, *The multi-level comprehensive safety evaluation for chemical production instalment based on the method that combines grey-clustering and EAHP*, International Journal of Disaster Risk Reduction **21** (2017), 243–250.

[10] T. J. Pettit, *Supply chain resilience: Development of a conceptual framework, an assessment tool and an implementation process*, The Ohio State University, 2009.

[11] Y. Wang, J. Ren, L. Zhang and D. Liu, *Research on resilience evaluation of green building supply chain based on ANP-fuzzy model*, Sustainability **15** (2022): 285.

[12] G. Wedawatta, B. Ingirige and D. Amaratunga, *Building up resilienc e of construction sector SMEs and their supply chains to extreme weather events*, International Journal of Strategic Property Management **14** (2010), 362–375.

[13] C. Zhang and K. He. and W. Zhang *Study on mechanism of factors affecting resilience of prefabricated building supply chain*, Advances in Civil Engineering **2023** (2023): 8870224.

[14] M. Zhang, Y. Liu and B. Ji *Influencing factors of resilience of PBSC based on empirical analysis*, Buildings **11** (2021): 467.

[15] T. Zhu and G. Liu, *A novel hybrid methodology to study the risk management of prefabricated building supply chains: An outlook for sustainability*, Sustainability **15** (2022): 361.

Manuscript received October 23, 2024
revised February 18, 2025

J. J.Li
College of City Construction, Research Center of Management Science and Engineering, Jiangxi Normal University, Nanchang, China
E-mail address: 15629052931@163.com

L. Luo
School of Public Policy and Administration, Nanchang University, Nanchang, China
E-mail address: mengling2391@163.com

Z. S. Liu
College of City Construction, Research Center of Management Science and Engineering, Jiangxi Normal University, Nanchang, China
E-mail address: xiaoliu8033@126.com

H. H. Su
School of Infrastructure Engineering, Nanchang University, Nanchang, China
E-mail address: 412500230101@email.ncu.edu.cn