農村裝配式建築綠色供應鏈風險管理研究

STUDY ON RISK MANAGEMENT OF GREEN SUPPLY CHAIN OF RURAL PREFABRICATED BUILDING

福建農林大學
交通與土木工程學院
教授

李 曉 娟*
Xiao-Juan Li

福建農林大學
交通與土木工程學院

段 高 娜
Gao-Na Duan

福建農林大學
交通與土木工程學院

盧 家 婧
Jia-Jing Lu

摘　要

隨著時代飛速進步，傳統的管理模式已不符合農村裝配式建築發展需求，因此綠色供應鏈管理模式出現。由於綠色供應鏈結構復雜，參與方眾多等影響，因此農村裝配式建築綠色供應鏈管理風險性較高。為進壹步挖掘裝配式建築綠色供應鏈風險管理潛力，基於文獻統計和供應鏈運作參考模型 (Supply Chain Operations Reference model, SCOR)，模擬農村裝配式建築綠色供應鏈風險模型，確定農村裝配式建築綠色供應鏈風險指標體系，采用熵權法確定各風險因素權重值。根據計算所得權重值，識別裝配式建築綠色供應鏈關鍵風險，針對相關風險制定相應防範策略，為當地建築業綠色供應鏈管理研究提供重要參考意義。

關鍵詞：裝配式建築、綠色供應鏈、SCOR 模型、熵權法。

* 通訊作者，福建農林大學交通與土木工程學院教授
福建省福州市倉山區上下店路 15 號，xiaojuanli@fafu.edu.cn

JOURNAL OF TAIWAN AGRICULTURAL ENGINEERING
VOL. 69, NO. 1, MARCH 2023
DOI - 10.29974/JTAE.202303_69(1).0005

STUDY ON RISK MANAGEMENT OF GREEN SUPPLY CHAIN OF RURAL PREFABRICATED BUILDING

Xiao-Juan Li*
Fujian Agriculture and Forestry University
College of Transportation and Civil Engineering
Professor

Gao-Na Duan
Fujian Agriculture and Forestry University
College of Transportation and Civil Engineering
Master

Jia-Jing Lu
Fujian Agriculture and Forestry University
College of Transportation and Civil Engineering
Master

ABSTRACT

With the progress of the times, the traditional management mode is no longer suitable for rural prefabricated buildings, so the green supply chain management mode is proposed. Since the structure of the green supply chain is complex and there are many participants, the green supply chain management of rural prefabricated buildings is dangerous. To mitigate the potential for green supply chain risks, based on statistics from the literature and Supply Chain Operations Reference model (SCOR), this paper identifies the green supply chain risk model for rural prefabricated buildings.The green supply chain risk index system is adopted for rural prefabricated buildings, and then the weight value of each risk factor is determined in the entropy weight method. Based on the calculated weight value, the main risks of the green supply chain of rural prefabricated buildings are identified and countermeasures are put in place for the associated risks, which are of particular reference importance for research on green supply chain risk management for the local construction industry.

Keywords: Prefabricated building, Green supply chain, SCOR model, Entropy weight method.

Li, X.J., Duan, G.N., & Lu, J.J. (2023). "Study on Risk Management of Green Supply Chain of Rural Prefabricated Building" *Journal of Taiwan Agricultural Engineering,* 69(1), 55-69.
https://doi.org/10.29974/JTAE.202303_69(1).0005

1. Introduction

Nowadays, China is in an era of rapid development, and sustainable development strategy has become one of the main development concepts of contemporary society. Chinese construction industry has not only changed the development model of traditional architecture, but also provided a new way of thinking for the construction industry transformation. The traditional way of building not only wastes resources, but also pollutes the environment, which is contrary to the current requirements of environmental protection, energy conservation and sustainable development. Rural assembly construction is a construction technology vigorously promoted in China. Due to the characteristics of prefabricated parts construction technology standardization, industrial production and scientific management, the traditional construction production mode has changed [1]. Green supply chain management can better promote the core competitiveness of construction enterprises under such circumstances. To alleviate the contradiction between rural prefabricated buildings and economy, society and environment, green supply chain management attaches importance to the coordination between resource utilization and specific activities and the environment, and attaches importance to the environmental management among all links. In the past construction industry, although the green supply chain has a history of many years, it was limited by a variety of external factors and failed to play the maximum role. With the continuous development of the construction industry, the application of green supply chain in the construction industry is more and more extensive. The changes of its construction technology, production mode, management mode and the rapid development of modern information technology have brought great impetus to its application in the market. However, due to many external factors such as project cost and current standards, there are still many problems in the implementation of green supply chain, and there are also many problems with government departments and social needs. Therefore, there are many risks and challenges in the green supply chain operation of rural prefabricated buildings.

Related studies on green supply chain risk mainly focus on identifying risk factors, constructing risk evaluation system, and using different methods to carry out risk assessment. For example, the risk of green supply chain needs to formulate regulations [2], construct risk evaluation system [3][4], and GSCM performance evaluation system green supply chain risk [5]. In addition, there are a combination of qualitative and quantitative methods [6] such as ANP-Fuzzy [7], rough set method and grey theory [8], neural network and factor analysis method [9] to improve the theoretical system of green supply chain risk management [10]. In addition, the architecture development in the supply chain risk based on the risk classification of the structure of the construction risk management system [11], and to explore a new system of pressure regulation, norm and simulation is how to support the state-led and private leading construction of the supply chain risk management strategy [12], put forward building materials supply chain risk management is a form of modern management [13]. Building supply chain information collaboration mechanism based on vulnerability [14], using TOC constraint theory and other technologies to build a risk model [15], using AHP method, establishing a risk assessment model based on cloud model [16], and adopting corresponding risk prevention countermeasures [17]. The above studies rarely consider the cooperation between the participants in the construction supply chain management supply chain.

Therefore, based on the literature statistics method and considering the SCOR model of cooperation among the participants in the construction supply chain management supply chain, this paper establishes the green supply chain risk model of rural prefabricated buildings, constructs the green supply chain risk index system of rural prefabricated buildings, and then uses the entropy weight method to determine the weight value of each risk factor. According to the calculated weight value, the main risks of the green supply chain of rural prefabricated buildings are determined, and the corresponding risk countermeasures are put forward, which has certain referential significance for the research on the risk management of the green supply chain of domestic construction industry.

2. Risk factors analysis of green supply chain of rural prefabricated buildings

2.1 Rural prefabricated building supply chain

Prefabricated building in rural areas means that the components and accessories needed for the building are prefabricated by the factory according to the construction drawings in advance, and the materials are delivered to the construction site by means of transportation, and then assembled on site by the construction workers according to the construction method. Rural prefabricated buildings can be divided into five categories: block building, plate building, box building, skeleton plate building and floor building [18].

The green supply chain of rural prefabricated buildings refers to the introduction of the concept of green environmental protection into the traditional supply chain to make full use of resources and reduce environmental pollution. The green supply chain of rural prefabricated buildings has shifted from the simple perspective of logistics, information flow and capital flow to the support system of reverse logistics, knowledge flow and operation, focusing on the establishment of information sharing platform and operation management mode of supply chain [19].

2.2 Green supply chain risk management of rural prefabricated buildings

In the assembly green supply chain, there are many participants, including technology, system integration, organization, cost, management, ecology and so on. At the same time, there are also many constraints, such as externality, information asymmetry and member self-interest. Therefore, there are great risks in the application of green supply chain management in rural prefabricated buildings [20].

The research on the green supply chain risk management of rural prefabricated buildings can promote the development of rural prefabricated buildings, and corresponding measures should be taken to reduce the negative impact of the risk in the green supply chain of rural prefabricated buildings, so as to minimize the negative impact of the risk. The stability and effectiveness of the supply chain between enterprises is a good guarantee for the cooperative operation between enterprises [21], and the risk management steps are shown in Fig. 1.

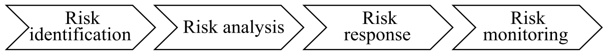

Fig. 1. The steps of risk management

(1) Risk identification

Risk identification refers to the identification of possible risks in the green supply chain of rural prefabricated buildings.

(2) Risk analysis

Risk analysis is to analyze the identified green supply chain risks of rural prefabricated buildings and determine the source of the risks. It should not only conduct qualitative analysis from the subjective perspective, but also conduct quantitative analysis according to the objective situation.

(3) Risk response

Risk response is to take corresponding measures to reduce the loss caused by the identified green supply chain risks of rural prefabricated buildings.

(4) Risk monitoring

Risk monitoring refers to the comprehensive monitoring of the development and change of risks in the operation process of the green supply chain of rural prefabricated buildings, and making corresponding responses when necessary.

2.3 Risk factors analysis of green supply chain of rural prefabricated buildings

2.3.1 Risk identification

The advantages and disadvantages of common risk identification methods are compared, as shown in Tab. 1.

Rural prefabricated construction in this paper, the study of green supply chain risk, to each link of supply chain risk identification. Firstly, the SCOR model is used to identify the internal risks of green supply chain of rural prefabricated buildings, secondly by literature

Tab. 1. Comparison of risk identification methods

Risk Identification Methods	Advantages	Disadvantages
SCOR Model	Find out the problems in supply chain comprehensively and evaluate them scientifically.	Requires cooperation between participants in the supply chain.
Risk Checklist Method	simplicity of operator, save both time and labor.	Due to the limitation of comparability, there are no identical projects, it is easy to miss items in risk identification.
Fault Tree Analysis	It can be used for qualitative risk identification and quantitative risk evaluation.	Investigators need to have high quality and master certain application technology.
Literature Statistical Method	Convenient and fast, strong operation, high efficiency, objectivity is strong.	The collection of data for similar projects is more difficult.

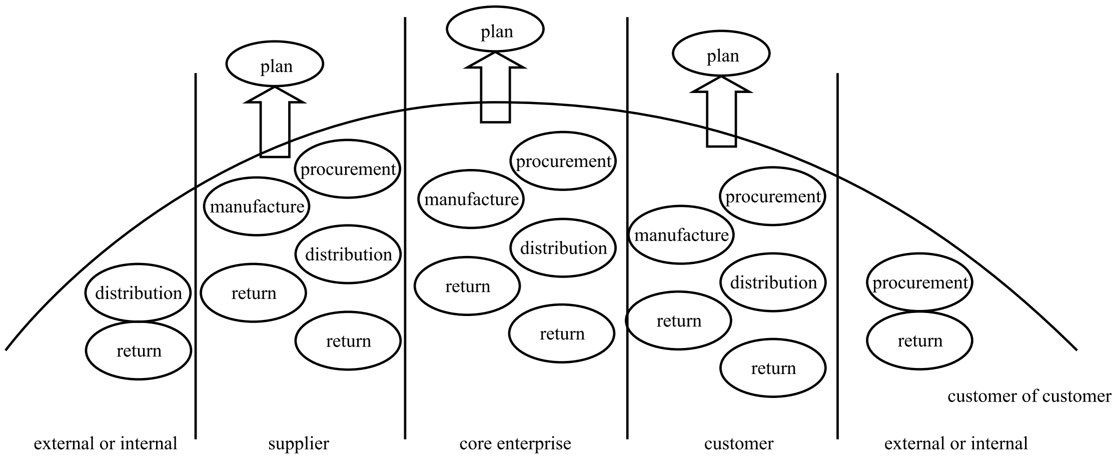

Fig. 2. SCOR model structure diagram

statistics, access to a large number of relevant literatures, select frequency high risk factors as prefabricated building green supply chain risk factors in the countryside.

2.3.2 Construct the green supply chain model of rural prefabricated buildings based on SCOR

SCOR model is a multifunctional supply chain process diagnosis tool that combines enterprise business process reengineering, benchmarking management and optimal industry analysis. It can diagnose problems in supply chain processes, objectively evaluate problems in processes, set goals and improve core competitiveness of enterprises [22], as shown in Fig. 2.

(1) Plan: According to the requirements of rural prefabricated building construction, formulate various target plans and so on. Provide guidance for the next step of construction and production through planning and design, and to ensure the smooth implementation of the project.

(2) Procurement: According to the requirements of the project or actual needs, find suitable suppliers and purchase the required materials and equipment.

(3) Manufacture: the process of producing components and accessories required for rural prefabricated buildings according to plans or actual needs.

(4) Distribution: explore the transportation routes in advance, make a reasonable plan for the transportation routes, and select appropriate means of transportation to complete the transportation of rural prefabricated building components.

(5) Return: Return the excess goods in stock or components that do not meet the standard to the supplier.

2.3.3 Risk index system of green supply chain of rural prefabricated buildings

Through literature review, reference to relevant

Tab. 2 Risk Assessment Index System

		Primary evaluation index	Secondary evaluation index	Number	Factor source
Risk factors of green supply chain in rural prefabricated buildings	External Risks A_1	Natural Environmental Risks	Natural Environment	A_{11}	[4][7][10]
		Political and Legal Risks	Policies, laws and regulations, rules and regulations	A_{12}	[12][15][17]
			Cumbersome and slow government approvals	A_{13}	
		Market Economy Risks	Influenced by market demand	A_{14}	[1][3][22]
			The public does not know much about rural assembly buildings	A_{15}	
			Inflation	A_{16}	
		Externality Risks	Consumer philosophy and approach	A_{17}	[7][9][19]
			Knowledge and Skills	A_{18}	
			Irrational supply chain structure	A_{19}	
	Internal Risks B_1	Green Program Risks	Lack of experience in green operation management	B_{11}	[2][5][6][8]
			Different strategic objectives	B_{12}	
			Lack of green commitment in the supply chain	B_{13}	
		Green Component Procurement Risks	Quality of purchased materials	B_{14}	[8][12][15][17]
			Supplier selection	B_{15}	
			Long material delivery time	B_{16}	
		Green Component Manufacturing Risks	Design Changes	B_{17}	[18][21]
			Design capacity development for designers	B_{18}	
		Green Component Assembly Risks	Project Quality	B_{19}	[13][23]
			Duration control	B_{20}	
			Safety accidents	B_{21}	
		Green Component Delivery Risks	Reasonableness of transportation standards	B_{22}	[3][10][15][24]
			Reverse logistics design risk	B_{23}	
			Difficult to recycle	B_{24}	

literature on supply chain risk assessment methods, based on the SCOR model above to identify the internal risk of rural prefabricated building green supply chain, the analysis shows that the prefabricated building green supply chain contains internal risk and external risk. External risks mainly involve natural environmental risks, political and legal risks, market economy risks and external risks. Internal risks mainly involve green program risks, green component procurement risks, green component manufacturing risks, green component assembly risks and green component delivery risks. Therefore, these nine types of risks are taken as the Primary evaluation index of the evaluation system, and the remaining 23 risk factors are taken as the Secondary evaluation index of the evaluation system, and the risk evaluation index system of green supply chain management of rural prefabricated buildings is established, as shown in Tab. 2.

(1) Natural environment risks

Rural prefabricated buildings are usually built outdoors during production and installation. Therefore, it will be affected by external environment, weather conditions, natural disasters, etc., which may lead to delay of construction period and increase of budget.

(2) Political and legal risks

The national control of the construction industry is very strict, and various policies have been introduced for rural assembled buildings. The policy launch affects the current development of rural assembled buildings, and various approval procedures are required during the construction of rural assembled building projects, which are cumbersome and will delay the project progress and increase the risk of the green supply chain.

(3) Market economy risks

The construction industry has a large capital flow, and the change of inflation, interest rate and exchange rate will cause difficulties in using project funds. Therefore, the change of market economy has a great impact on the construction industry.

(4) Externality risks

The rural prefabricated building is an emerging industry. The public does not know much about the rural prefabricated building, the knowledge and skills used in the rural prefabricated building, and the advantages and characteristics of the rural prefabricated building.

(5) Green program risks

There are many participants in the green supply chain of rural prefabricated buildings. Each participant has different positioning and strategic objectives. The operation of green supply chain of rural prefabricated buildings is based on the market demand. The change of market demand will lead to the change of the participants in the supply chain. In the green supply chain, all participants need to cooperate with each other, share information, cooperate with each other, and make reasonable planning methods according to the actual project system. In the green supply chain, the improper interest distribution will destroy the cooperative relationship between the participants. The reasonable and stable structure of the supply chain is one of the reasons that affect the normal operation of the supply chain.

(6) Green component procurement risks

The quality of construction materials is a major influencing factor in the quality control of construction projects, to ensure that the source of material channels is relatively safe and reliable, and the agreed materials are transported to the site on time according to the contract. After the materials come in, the professionals need to do a good job of storage management of various materials according to the characteristics of the materials.

(7) Green component manufacturing risks

Assembled components are standardized and produced in strict accordance with the design drawings. The design capabilities of designers will affect the subsequent production of components. Whether the produced components are consistent with the drawings determines whether normal assembly can be carried out at the construction site. The equipment and process of producing components will affect the quality of components. For components already produced, if design changes occur, the project cost will be increased and resources will be wasted.

(8) Green component assembly risks

Rural assembly building is a new industry with few construction units and a lack of professional construction teams. When assembly components are installed, a strict plan needs to be made. If the planning and design are not proper and there is no professional engineering team and professional equipment, it will have a certain impact on the quality and duration of the project. During the construction process of the project, the safety of all staff should be ensured, safety education and training should be done, and construction should be done according to specifications to avoid accidents.

(9) Green component delivery risks

In the transportation process, there is no reasonable planning of transportation routes in advance, which may increase the possibility of accidents. The current market does not have a sound logistics system. The existing transportation units are not advanced enough, which reduces the efficiency of transportation. Traditional means of transportation have high energy consumption, and the absence of standardized transportation standards can lead to more waste of resources and pollution of the environment. The implementation of circular economy will make all aspects of the business more complicated, thus making the business operation less efficient. The information uncertainty of reverse logistics and the

JOURNAL OF TAIWAN AGRICULTURAL ENGINEERING
VOL. 69, NO. 1, MARCH 2023
DOI - 10.29974/JTAE.202303_69(1).0005

contradiction between forward logistics and reverse logistics make enterprises deviate from the design concept and set some rules that are not conducive to recycling, thus restricting the reuse of products. The recycling of construction materials and components, and the disposal of construction waste can cause new environmental pollution. In the product design stage, the standardized manufacturing of assembled parts causes difficulty in disassembly of parts and low recycling efficiency.

3. Green supply chain risk evaluation index weights for rural assembled buildings

The entropy weight method mainly measures the importance of the index in the whole system according to the dispersion of each index in the system. The greater the information entropy, the lower the dispersion of the index, and the smaller the impact on the system. The advantage of this method is that it can overcome the influence of subjective factors on the results to some extent, so as to improve the accuracy of calculation.

In this paper, entropy weight method is used to determine the weight value of the risk of green supply chain of rural prefabricated buildings [25], and the steps are as follows:

(1) Construct numerical matrix

Assume that the evaluation system of a system has m samples and n indicators, and construct its initial evaluation matrix X where the assignment of the j-th indicator under the i-th sample.

$x_{ij} \geq 0$ i=1, 2, 3…m; j = 1, 2, 3…n.

(2) Standardization of data

All factors are normalized according to the number of each option. In order to avoid unnecessary impacts, data standardization should be carried out for each indicator. Indicators are divided into positive indicators and negative indicators, and data standardization is carried out by formula (1) and Formula (2), respectively. For positive indicators:

$$x'_{ij} = \frac{x_{ij} - min(x_{1j}, x_{nj}, \cdots x_{nj})}{max(x_{1j}, x_{nj}, \cdots x_{nj}) - min(x_{1j}, x_{nj}, \cdots x_{nj})} \quad \text{......(1)}$$

For the negative index:

$$x'_{ij} = \frac{max(x_{1j}, x_{nj}, \cdots x_{nj}) - x_{ij}}{max(x_{1j}, x_{nj}, \cdots x_{nj}) - min(x_{1j}, x_{nj}, \cdots x_{nj})} \quad \text{......(2)}$$

(3) Calculate the proportion of the j-th index in the i-th sample and regard it as the probability used in the calculation of information entropy:

$$y_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}} \quad \text{......(3)}$$

(4) Calculate the information entropy of each index and calculate the entropy value of the j-th index:

$$e_j = -\frac{1}{lnm} \sum_{i=1}^{m} y_{ij} ln(y_{ij}) \quad \text{......(4)}$$

Which $e_j \geq 0$. If $y_{ij} = 0$, define $e_j = 0$, and m is the number of influencing factors to be considered.

(5) Determine the weight of each indicator:

$$W_j = \frac{1 - e_j}{\sum_{j=1}^{n} 1 - e_j} \quad \text{......(5)}$$

4. Case Analysis

4.1 Case Overview

Yaogongbu Village, Zhibu Town, Zhuji City, Zhejiang Province, adopts the prefabricated construction method. The parts are produced on the factory assembly line and transported to the rural site to build “building blocks”. The construction method of Yaogongbu rural housing is like a realistic version of “playing with Lego”, with a total construction area of 7,980 m^2 and an overall assembly rate of over 87 %. In this paper, the SCOR model is used to identify the internal and external risks of the project, and the entropy weight method is used to identify and evaluate the green supply chain risks, calculate the weight value of each risk index, determine the main risks of the project, and propose targeted risk countermeasures.

4.2 Identification of green supply chain risks

Through data analysis of this project, according to the green supply chain risk evaluation index system of rural prefabricated buildings, see Tab. 3-2 above, SCOR model and literature statistics method are used to identify risks.

(1) External environmental risks of green supply chain

Yaogongbu village, Zhibu town, Zhuji City, Zhejiang Province, the mountainous terrain is complex, and the climate is pleasant. At present, China's rural assembled buildings have not been widely promoted, and there is still room for improvement in legal policies, norms and standards, etc. There was no market turmoil during the construction of the project t.

(2) Green planning stage

The project was a key livelihood project undertaken by Origin Construction at the end of 2017, with a tight schedule and a heavy task, so it was designed while under construction. After receiving the task, each supplier immediately went into construction and worked hard to produce the assembly parts and accessories needed for the project, and the prompt and reliable support and collaboration of the suppliers made it possible to complete the project more smoothly.

(3) Green component procurement stage

Rural required components of prefabricated construction quality directly affect the quality of the engineering construction, in order to make the project smoothly to carry out the need to carefully selected suppliers of building materials, strictly control the quality of building materials, strengthen the select material of each process, to ensure that the selected standard of building materials to the use of material, in order to avoid unnecessary problems of quality and safety.

(4) Green component manufacturing stage

The production quality of rural prefabricated building components has a great relationship with the project cost. Therefore, it is necessary to keep in touch with the manufacturer during the production process to ensure that the quality of the products meets the requirements. The project has high requirements on the construction of nodes and the quality of components. It is necessary to ensure that the product quality, specifications and models meet the specific requirements of the project construction.

(5) Green component assembly stage

Before manufacturing structures and accessories, we should carefully analyze the drawings and check the raw materials of structures and accessories strictly according to the requirements. After the production of the components, the performance test should be carried out to ensure that the quality meets the required standard and reduce the probability of rework. Before the assembly, the feasibility of the construction technical scheme should be reviewed and demonstrated by experts, and technical exchange meetings should be held regularly, so as to effectively reduce unnecessary costs and losses. In addition, before assembly, a comprehensive analysis of various risk factors before, during and after assembly should be carried out.

(6) Green component delivery stage

After the production of parts, it is inevitable to pass through some places with complicated road conditions or very bad road conditions in the transportation process, which may lead to traffic jams and cause great inconvenience to the construction of rural prefabricated buildings. Due to the winter construction, the adverse weather conditions will affect the safety of materials and whether materials can reach the construction on time. In the process of rural prefabricated building construction, the recycling of building materials, components and the disposal of construction waste will cause new environmental pollution. In the stage of product design, the standardized manufacture of assembled parts makes it difficult to disassemble and assemble parts and low recovery efficiency.

4.3 Green supply chain risk assessment

The entropy weight method was used to calculate the weight of risk factors, and the method of online questionnaire survey was adopted. The respondents (experts) were practitioners with senior titles or more than 8 years of work experience, including institutions of higher learning, construction companies, construction companies, etc. Finally, data analysis was conducted on the survey results, as shown in Tab. 3.

Tab. 3. Impact indicator degree scoring table

	Expert A	Expert B	Expert C	Expert D	Expert E	Expert F
A_{11}	80	82	79	78	83	83
A_{12}	80	82	79	80	80	80
A_{13}	83	79	82	81	82	82
A_{14}	80	80	82	80	82	82
A_{15}	82	79	80	75	80	78
A_{16}	82	80	79	80	79	79
A_{17}	74	75	78	76	77	75
A_{18}	79	80	77	77	82	83
A_{19}	90	87	85	85	75	85
B_{11}	83	77	86	86	77	86
B_{12}	88	85	86	77	85	86
B_{13}	75	86	87	85	86	87
B_{14}	77	86	79	84	86	79
B_{15}	85	82	80	86	87	80
B_{16}	86	82	85	86	85	85
B_{17}	86	80	85	87	85	85
B_{18}	87	79	80	79	80	79
B_{19}	79	85	82	80	82	80
B_{20}	80	85	82	80	82	80
B_{21}	80	80	80	79	80	79
B_{22}	79	82	79	84	79	84
B_{23}	84	82	76	86	86	82
B_{24}	82	80	76	87	87	80

(1) Construct the data matrix

According to the data in Tab. 3, the evaluation matrix of each stage is constructed. C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8 and C_9 are respectively used to represent the evaluation matrix of natural environmental risk, political and legal risk, market economy risk, externality risk, green plan risk, green procurement risk, green manufacturing risk, green assembly risk and green delivery risk.

$$C_1=\begin{bmatrix}80\\82\\79\\78\\83\\83\end{bmatrix}\quad C_2=\begin{bmatrix}80&83\\82&79\\79&82\\80&81\\80&82\\80&82\end{bmatrix}\quad C_3=\begin{bmatrix}80&82&82\\80&79&80\\82&80&79\\80&75&80\\82&80&79\\82&78&79\end{bmatrix}$$

$$C_4=\begin{bmatrix}74&79&90\\75&80&87\\78&77&85\\76&75&85\\77&82&75\\75&83&85\end{bmatrix}\quad C_5=\begin{bmatrix}83&88&75\\77&85&86\\86&86&87\\86&77&85\\77&85&86\\86&86&87\end{bmatrix}$$

$$C_6=\begin{bmatrix}77&85&86\\86&82&82\\79&80&85\\84&86&86\\86&87&85\\79&80&85\end{bmatrix}\quad C_7=\begin{bmatrix}86&87\\80&79\\85&80\\87&79\\86&80\\85&79\end{bmatrix}$$

$$C_8=\begin{bmatrix}79&80&80\\85&85&80\\82&82&80\\80&80&79\\82&82&80\\80&80&79\end{bmatrix}\quad C_9=\begin{bmatrix}79&84&82\\82&82&80\\79&76&76\\85&86&87\\79&86&87\\84&82&80\end{bmatrix}$$

(2) Data standardization

Using formula (1), the matrices C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8 and C_9 are standardized, and the standardized matrices D_1, D_2, D_3, D_4, D_5, D_6, D_7, D_8 and D_9 are obtained.

$$D_1=\begin{bmatrix}2/5\\4/5\\1/5\\0\\1\\1\end{bmatrix}\quad D_2=\begin{bmatrix}1/3&1\\1&0\\0&3/4\\1/3&1/2\\1/3&3/4\\1/3&3/4\end{bmatrix}\quad D_3=\begin{bmatrix}0&1&1\\0&4/7&1/3\\1&5/7&0\\0&1&1/3\\1&5/7&0\\1&3/7&0\end{bmatrix}$$

$$D_4=\begin{bmatrix}0&1/3&1\\1/4&1/2&4/5\\1&0&2/3\\1/2&0&2/3\\3/4&5/6&0\\1/4&1&2/3\end{bmatrix}\quad D_5=\begin{bmatrix}2/3&1&0\\0&5/7&8/9\\1&5/6&1\\1&0&5/6\\0&5/7&8/9\\1&5/6&1\end{bmatrix}$$

$$D_6=\begin{bmatrix} 0 & 5/7 & 1 \\ 1 & 2/7 & 0 \\ 2/9 & 0 & 3/4 \\ 7/9 & 6/7 & 1 \\ 1 & 1 & 3/4 \\ 2/9 & 0 & 3/4 \end{bmatrix} \quad D_7=\begin{bmatrix} 6/7 & 1 \\ 0 & 0 \\ 5/7 & 1/8 \\ 1 & 0 \\ 5/7 & 1/8 \\ 5/7 & 0 \end{bmatrix}$$

$$D_8=\begin{bmatrix} 0 & 0 & 1 \\ 1 & 1 & 1 \\ 1/2 & 2/5 & 1 \\ 1/6 & 0 & 0 \\ 1/2 & 2/5 & 1 \\ 1/6 & 0 & 0 \end{bmatrix} \quad D_9=\begin{bmatrix} 0 & 4/5 & 5/9 \\ 3/5 & 3/5 & 3/8 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 1 \\ 1 & 3/5 & 3/8 \end{bmatrix}$$

(3) Calculate the proportion of j-th index in the i-th sample

After obtaining the standardized matrices D_1, D_2, D_3, D_4, D_5, D_6, D_7, D_8 and D_9, formula (3) is used to calculate the ratio of the j-th index under the i-th sample, and the matrices E_1, E_2, E_3, E_4, E_5, E_6, E_7, E_8 and E_9 are obtained.

$$E_1=\begin{bmatrix} 1/9 \\ 2/9 \\ 1/9 \\ 0 \\ 2/7 \\ 2/7 \end{bmatrix} \quad E_2=\begin{bmatrix} 1/9 & 2/7 \\ 2/7 & 0 \\ 0 & 2/9 \\ 1/9 & 1/7 \\ 1/9 & 2/9 \\ 1/9 & 2/9 \end{bmatrix} \quad E_3=\begin{bmatrix} 0 & 2/7 & 2/7 \\ 0 & 1/6 & 1/9 \\ 2/7 & 1/5 & 0 \\ 0 & 0 & 1/9 \\ 2/7 & 1/5 & 0 \\ 2/7 & 1/8 & 0 \end{bmatrix}$$

$$E_4=\begin{bmatrix} 0 & 1/9 & 2/7 \\ 1/9 & 1/7 & 2/9 \\ 2/7 & 0 & 1/5 \\ 1/7 & 0 & 1/9 \\ 2/9 & 1/4 & 0 \\ 1/9 & 2/7 & 1/5 \end{bmatrix} \quad E_5=\begin{bmatrix} 1/5 & 2/7 & 0 \\ 0 & 2/9 & 2/7 \\ 2/7 & 1/4 & 2/7 \\ 2/7 & 0 & 1/4 \\ 0 & 2/9 & 2/7 \\ 2/7 & 1/4 & 2/7 \end{bmatrix}$$

$$E_6=\begin{bmatrix} 0 & 1/5 & 2/7 \\ 2/7 & 1/9 & 0 \\ 1/9 & 0 & 2/9 \\ 2/9 & 1/4 & 2/7 \\ 2/7 & 2/7 & 2/9 \\ 1/9 & 0 & 2/9 \end{bmatrix} \quad E_7=\begin{bmatrix} 1/4 & 2/7 \\ 0 & 0 \\ 1/5 & 0 \\ 2/7 & 0 \\ 1/5 & 0 \\ 1/5 & 0 \end{bmatrix}$$

$$E_8=\begin{bmatrix} 0 & 0 & 2/7 \\ 2/7 & 2/7 & 2/7 \\ 1/7 & 1/9 & 2/7 \\ 0 & 0 & 0 \\ 1/7 & 1/9 & 2/7 \\ 0 & 0 & 0 \end{bmatrix} \quad E_9=\begin{bmatrix} 0 & 2/9 & 1/6 \\ 1/6 & 1/6 & 1/9 \\ 0 & 0 & 0 \\ 2/7 & 2/7 & 2/7 \\ 0 & 2/7 & 2/7 \\ 2/7 & 1/6 & 1/9 \end{bmatrix}$$

(4) Calculate the entropy weight and entropy value of each index

The entropy weight and weight of each index are calculated in Excel according to equations (4) and (5), and the calculation results are shown in Tab. 4.

According to the weight value of each indicator in Tab. 4, the weight proportion of the first-level indicator is calculated, as shown in Fig. 3.

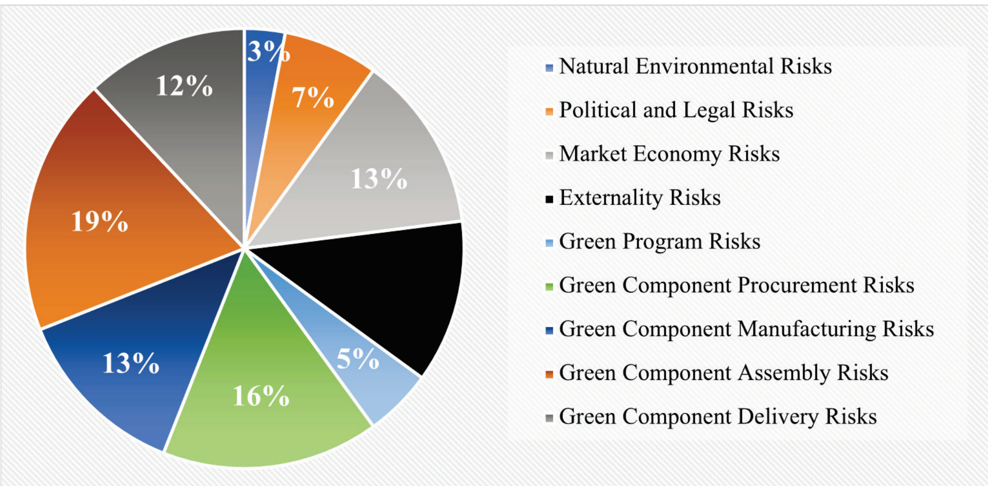

Fig. 3. Percentage of weight value of primary indicators

JOURNAL OF TAIWAN AGRICULTURAL ENGINEERING
VOL. 69, NO. 1, MARCH 2023
DOI - 10.29974/JTAE.202303_69(1).0005

Tab. 4. Entropy weight and entropy value of each index

		Primary evaluation indicators	Secondary evaluation indicators	Number	Entropy value e_j	Weight W_j
Risk factors of green supply chain in rural prefabricated buildings	External Risks A_1	Natural Environmental Risks	Natural Environment	A_{11}	0.82530694	0.031756807
		Political and Legal Risks	Policies, laws and regulations, rules and regulations	A_{12}	0.709176792	0.052867678
			Cumbersome and slow government approvals	A_{13}	0.916453125	0.015187678
		Market Economy Risks	Influenced by market demand	A_{14}	0.602648888	0.072232993
			The public does not know much about rural assembly buildings	A_{15}	0.879743905	0.021860912
			Inflation	A_{16}	0.455029877	0.038337574
		Externality Risks	Consumer philosophy and approach	A_{17}	0.758515802	0.043898522
			Knowledge and Skills	A_{18}	0.677630587	0.058602347
			Irrational supply chain structure	A_{19}	0.925772846	0.013493481
	Internal Risks B_1	Green Program Risks	Lack of experience in green operation management	B_{11}	0.780942311	0.039821689
			Different strategic objectives	B_{12}	0.951731228	0.008774602
			Lack of green commitment in the supply chain	B_{13}	0.988579301	0.002076127
		Green Component Procurement Risks	Quality of purchased materials	B_{14}	0.789106379	0.099068109
			Supplier selection	B_{15}	0.69384641	0.055654532
			Long material delivery time	B_{16}	0.960004488	0.007270637
		Green Component Manufacturing Risks	Design Changes	B_{17}	0.943575118	0.010257271
			Design capacity development for designers	B_{18}	0.336438881	0.120626329
		Green Component Assembly Risks	Project Quality	B_{19}	0.680546366	0.058072298
			Duration control	B_{20}	0.481916767	0.09418044
			Safety accidents	B_{21}	0.80353185	0.03571522
		Green Component Delivery Risks	Reasonableness of transportation standards	B_{22}	0.572606975	0.077694202
			Reverse logistics design risk	B_{23}	0.933457639	0.01209649
			Difficult to recycle	B_{24}	0.832473299	0.030454061

The fig. 3. shows that prefabricated construction in rural areas the level of green supply chain risk indicators for sorting, can get the green component assembly > green component procurement risk > green component manufacturing risk > external risk market economy > green component delivery risk > political legal risk green project risk > natural environment risk. By comparing the weights, it can be seen that the weight value of the assembly risk of green components is the largest, while the weight value of the natural environment risk is the smallest. Among the secondary indicators, the weight value of purchased material quality is the largest, which has the greatest impact on the risk of green procurement.

4.4 Green supply chain risk control

According to the ranking result of the first level risk index weight value, the corresponding risk control measures are put forward.

(1) Green component assembly risks control

Before the component parts are manufactured, the drawings are carefully analyzed in detail, and the raw materials of the components are inspected in strict accordance with the requirements. After the manufacture of the components is completed, their mechanical properties are tested to ensure the quality of the components and to reduce the possibility of rework. Before the assembly is carried out, a technical delivery should be made, an expert discussion on the feasibility of the construction technology plan should be conducted, and technical training should be carried out, so as to effectively reduce unnecessary costs and losses. In addition, a comprehensive risk assessment should be conducted before, during and after the assembly. During the assembly period, always pay attention to the installation of the project, find problems, immediately point out and correct.

(2) Green procurement risk control

The quality of construction materials directly affects the quality of construction projects, so it is necessary to choose reliable material suppliers to ensure the relatively safe and reliable source of materials. Professional personnel are required to store and manage all kinds of materials according to the characteristics of materials. In the process of material management, it is necessary to formulate some reasonable, perfect and applicable rules and regulations, and arrange professional personnel to regularly check the quality of materials to avoid quality problems.

(3) Green manufacturing risk control

Rural prefabricated building components need to be standardized and produced in strict accordance with the design drawings to improve the working ability of designers and avoid design changes. The equipment and process of components produced by suppliers need to be upgraded to improve the production capacity of suppliers.

(4) Green program risks control

Only when the market is in demand can the green supply chain of rural prefabricated buildings operate. Therefore, enterprises should always pay attention to the market dynamics. Rural prefabricated construction enterprises according to their needs, set goals plan, in the green supply chain, all the participants according to rural prefabricated construction enterprise target planning their own goal programming, formed a good partnership, set up information sharing platform, in order to obtain greater profits, reduce the risk caused by inconsistent target.

(5) Green component delivery risk control

Establish their own logistics and transportation team, formulate reasonable transportation plan, select appropriate means of transportation, survey transportation routes in advance, in order to save costs and reduce the occurrence of accidents. Determine the relevant information of reverse logistics, reduce the contradiction between forward logistics and reverse logistics, and formulate relevant regulations conducive to recycling. In the process of recycling construction waste, attention should be paid to protecting the environment and reducing the pollution to the environment.

(6) Green external risk control

For the natural environment, political, legal risk and other external risk, risk transfer can be done by purchasing project risk, natural disasters happened in the process of project construction, and results in cost, schedule delay, etc., these can be through the engineering insurance to reduce the loss of the enterprise itself, to achieve the purpose of risk transfer.

The policies, laws and regulations of rural prefabricated buildings are not perfect enough. The government needs to formulate corresponding laws and regulations and improve the policy guidance mechanism. Therefore, relevant enterprises should always pay attention to the latest policies issued by the government, deepen the understanding of policies, laws and regulations, and make the green supply chain of rural prefabricated buildings run better.

5. Conclusion

This paper researches the problem of green supply chain risk in rural assembled buildings, combines relevant literature at home and abroad, constructs a green supply chain operation model for rural assembled buildings based on SCOR, establishes a green supply chain risk evaluation index system, conducts an empirical analysis of its green supply chain risk factors, and draws the following conclusions:

(1) Through literature review and understanding of relevant theoretical knowledge, on the basis of SCOR model, the operation model of green supply chain of rural prefabricated buildings is established to identify the risks in the green supply chain, among which there are 9 primary evaluation indicators. It includes natural environment risk, political and legal risk, market economy risk, externality risk, green program analysis, green component procurement risk, green component manufacturing risk, green component assembly risk, and green component delivery risk. Secondary risk indicators include 23 factors, such as natural environment, policies, laws and regulations, rules and regulations, cumbersome and slow government approval, influenced by market demand, little public understanding of rural prefabricated buildings, and inflation.

(2) The entropy weight method is used to calculate the weight value of each index, and the risk of the first level index in the green supply chain of rural assembled buildings is ranked, and the green component assembly risk > green component procurement risk > green component manufacturing risk > market economy risk > externality risk > green component delivery risk > political and legal risk > green plan risk > natural environment risk, in which the quality of procurement materials has the greatest influence on the green component procurement risk, and the corresponding risk countermeasures are proposed for each risk factor, which has certain significance for the research of green supply chain risk management in the domestic construction industry.

References

1. Bi, L.N., Xue, X.F. Construction of Information Collaboration Mechanism in Construction Supply Chain - an Analysis Based on Supply Chain Vulnerability [J]. *Finance and Accounting Monthly*, No. 3, pp. 172-176, 2018.
2. Chen, J., Zhu, L.B., Xu, X.J. Incentive Game Analysis of Green Supply Chain Management for Assembled Buildings [J]. *Engineering Construction*, Vol. 53, No. 10, pp. 66-72, 2021.
3. Chen, W.B., Li, X.J., Yang, T. Research on Supply Chain Risk Management of Assembled Construction Enterprises [J]. *Shanghai Energy Conservation*, No. 12, pp. 1418-1426, 2020.
4. He, M.S., Gao, L.R. *et al*. Research on Risk Control of Assembled Buildings Based on Supply Chain [J]. *Shanxi Architecture*, Vol. 47, No. 24, pp. 194-195, 2021.
5. Hou, W.B. Study on Green Supply Chain Risk Management in Zhongwang Aluminum Industry [D]. *Lanzhou: Lanzhou University of Technology*, pp. 33-35, 2021.
6. Hou, Z.W. A Study on Risk Management of Assembled Building in Construction Step Section [D]. *Zhengzhou: North China University of Water Resources and Electric Power*, pp. 23-54, 2021.
7. Huang, G.L., Zhang, C. SNA-based Green Supply Chain Risk for Assembled Buildings [J]. *Journal of Civil Engineering and Management*, Vol. 37, No. 2, pp. 41-49, 2020.
8. Huang, G.L., Zhang, C., Wei, X.L. Study on Green Supply Chain Model for Assembled Buildings [J]. *Construction Economics*, Vol. 40, No. 7, pp. 48-52, 2019.
9. Kazancoglu, Y., Kazancoglu, I., & Sagnak, M. A New Holistic Conceptual Framework for Green Supply Chain Management Performance Assessment Based on Circular Economy [J]. *Journal of cleaner production*, Vol. 195, pp. 1282-1299, 2018.
10. Liu P.F. A Study on Green Supply Chain Game Model Considering Government Intervention and Risk Preference Under Fuzzy Uncertainty [D]. *Shanghai: Shanghai Ocean University*, pp. 56-58, 2021.
11. Ma, R.M., Yao, L.F., & Huang, R. The Green Supply Chain Management Risk Analysis [J]. *In Advanced Materials Research*, Vol. 573, pp. 734-739, 2012.
12. Mangla, S.K., Kumar, P., & Barua, M.K. Risk Analysis in Green Supply Chain Using Fuzzy AHP Approach: A Case Study [J]. Resources, Conservation and recycling, Vol. 104, pp. 375-390, 2015.

13. Obayi, R., Ebrahimi, S.N. A Neo-institutional View of the Transaction Cost Drivers of Construction Supply Chain Risk Management [J]. Supply Chain Management: An International Journal, Vol. 26, No. 5, pp. 592-609, 2021.
14. Qiao, B. Research on Green Supply Chain Risk Evaluation of Apparel Enterprises [D]. Qin Huangdao: Yanshan University, pp. 56-57, 2021.
15. Senthil, J., Muthukannan, M. Development of Lean Construction Supply Chain Risk Management Based on Enhanced Neural Network [J]. *Materials Today: Proceedings*, Vol. 56, pp. 1752-1757, 2022.
16. Srivastava, S.K. Green Supply-chain Management: A State-of-the-art Literature Review [J]. *International Journal of Management Reviews*, Vol. 9, No. 1, pp. 53-80, 2007.
17. Sun, Y.F., Dai, X., Guo, S. Exploration of Whole Life Cycle Risk Evaluation Methods for Green Building Projects [J]. *Journal of Shandong Institute of Business and Technology*, Vol. 35, No. 5, pp. 52-60, 2021.
18. Tah, J.H.M., Carr, V. Towards a Framework for Project Risk Knowledge Management in the Construction Supply Chain [J]. *Advances in Engineering Software*, Vol. 32, No. 10-11, pp. 835-846, 2001.
19. Wang, J.H. Research on Dynamic Feedback Management of Risk in the Supply Chain of Assembled Buildings [D]. Qingdao: Qingdao University of Technology, pp. 33-34, 2019.
20. Wang, X.B., Liu, H. Research on Green Supply Chain Risk Evaluation of Automobile Manufacturing Enterprises Based on Grey Rough Set Theory [J]. *Neijiang Science and Technology*, Vol. 4, No. 2, pp. 122-124, 2019.
21. Wu, S.F., Mao, J. Analysis of the Current Problems and Countermeasures of Green Supply Chain [J]. *China Collective Economy*, Vol. 28, pp. 103-104, 2021.
22. Yan, C.L. Research on Green Supply Chain Risk Evaluation of Hubei Automotive Manufacturing Industry Based on ANP-Fuzzy [D]. *Yichang: China Three Gorges University*, pp.13-14. 2018.
23. Zhang, C. Research on Green Supply Chain Risk Management for Assembled Buildings [D]. Harbin: Northeast Forestry University, Vol. 2, pp. 10-11, 2020.
24. Zhang, F.Y., Xie, J.Y. Cloud-based Model for Evaluating the Supply Chain Risk of Assembled Buildings [J]. *Intelligent Building and Smart City*, No. 3, pp. 123-124, 2020.
25. Zhang, X.S., Wang, L.K. *et al*. Study on the Mechanism of Green Supply Chain Vulnerability Risk Propagation [J]. *Finance and Trade Research*, Vol. 28, No. 3, pp. 104-109, 2017.

收稿日期：民國 111 年 11 月 18 日
修改日期：民國 112 年 02 月 02 日
接受日期：民國 112 年 02 月 09 日