Research on Green Risk Factors in the Prefabricated Construction Supply Chain Based on DEMATEL-ISM-MICMAC

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Abstract. With the increasing global demand for environmental protection and sustainable development, the concept of green building has received widespread attention in the construction industry. As an important form of green building, assembled building is regarded as a key path for the transformation of the industry due to its advantages of energy saving, emission reduction, and resource saving. However, due to the variety and complexity of supply chain links, the green supply chain management of assembled buildings faces many risks, which affect the realization of its sustainable development goals. In order to systematically identify and cope with these risk factors, this paper conducts an in-depth analysis from qualitative and quantitative perspectives to explore the logical relationship, evolutionary path and attribute characteristics among the risk factors. First, 15 major risk factors are extracted through literature review and expert interviews; then, the interactions among the factors are quantitatively analyzed using the DEMATEL method, and a multilevel recursive structure is constructed by combining with the ISM-MICMAC method to identify the key factors, outcome factors, and root factors. It is found that policy, technology, information, cooperation strategy and partner selection play an important role in promoting the development of green supply chain, and targeted countermeasures are proposed accordingly.

Keywords: assembly building, green supply chain, risk factors, DEMATEL-ISM-MICMAC

1 Introduction

Assembly buildings rely on factory prefabrication compared to traditional cast-in-place buildings, reducing waste and noise at the construction site, lowering carbon emissions, and improving construction quality. However, despite the environmental and resource efficiency advantages of assembly buildings, their supply chain system is more complex. The green supply chain includes design, production, logistics and assembly, and participants require a higher degree of collaboration, making coordination difficult and increasing risk. If a link fails to meet the expected environmental objectives, it may lead to resource waste, increased energy consumption and environmental pollution,

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affecting the overall green benefits. Therefore, effective identification and control of supply chain risks is a key issue for the sustainable development of assembly buildings.

In summarizing the existing studies, By categorizing the literature with respect to research methodology and findings, the current state of research on green supply chain risk in assembly buildings is systematically presented. Existing studies have adopted a variety of methods in identifying supply chain risk factors and analyzing their influence relationships. Boye[1] and Wang Hongchun[3], among others, used fuzzy-DEMATEL and DEMATEL-ISM models to reveal the causal relationships of the risk factors and visualize the logic of their roles; Wu Qunli[4], among others, combined the ISM-AHP-DEMATEL model to explore the risk factor of multi-level structural relationships, overcoming the limitations of a single model; while Fan Rui [5] et al. quantified the comprehensive evaluation of supply chain risk factors through FAHP and gray correlation analysis. These diverse approaches enhance the accuracy and comprehensiveness of risk identification.

In addition, some studies focus on the dynamic changes of supply chain risks. Wang [2] et al. used SEAIR model to simulate risk dynamics and proposed corresponding management countermeasures; Yang Yusheng [7] et al. constructed a dynamic assessment model to analyze the risk time changes and its key factors. This indicates that the risk of green supply chain of assembly building has dynamic characteristics.

In risk evaluation research, multiple perspectives are gradually emphasized. Zhang Ailin [6] combines the stakeholder and full life cycle perspectives, explores supply chain risk relationships through social network analysis, and proposes control measures; Li Naixu [8] and others use entropy and G1 methods to establish a risk evaluation system, and validate the effectiveness of the model. However, most of these studies focus on the stakeholder risk of traditional supply chains, and less consider the combination of environmental and resource efficiency objectives and stakeholder cooperation in green supply chains.

Although studies have been conducted to analyze risks in assembly building supply chains, there are still gaps in the interaction and dynamics of specific risk factors in green supply chains. Most studies have focused on risk control in traditional supply chains, ignoring the importance of environmental and resource efficiency objectives in green supply chains. In addition, current research lacks comprehensive and multi-level assessment tools to reveal the complex interactions of different factors in green supply chains, especially the dynamic characteristics of key drivers and dependencies.

Therefore, this study combines the DEMATEL-ISM-MICMAC model. DEMATEL realizes system analysis through graph theory and matrix tools, and is able to quantify the degree of influencing and being influenced by factors and their causality, but it is unable to hierarchize the factors. For this reason, ISM was introduced, which helps to analyze interactions in complex systems by categorizing and stratifying influencing factors through directed hierarchical diagrams, which visualize the hierarchical causal relationships among different factors.

However, ISM cannot recognize the degree of influence between factors within the same hierarchy. To solve this problem, the MICMAC method is introduced to identify the driving force and dependency factors through the cross-influence matrix, and to divide the influencing factors into four quadrants, so as to clarify the degree of each factor's role, and to solve the problem that ISM is unable to distinguish the primary and secondary relationships.

Through the DEMATEL-ISM-MICMAC model, the risk factors and their interrelationships in the green supply chain of assembled buildings are explored in depth from a systematic and dynamic perspective to enrich the existing research in the dynamic risk management of green supply chain.

2 The Construction of Factor System for Green Supply Chain Risk Impact of Assembly Building

In this paper, we first searched the keywords "green supply chain of assembly building" and "supply chain operation risk" in the Web of Knowledge and Web of Science databases. On this basis, it summarizes and analyzes the external risk, internal risk and inter-chain risk in the light of the characteristics of green supply chain of assembly building.

A reasonable supply chain risk evaluation index system for assembled buildings is constructed based on the three aspects identified above, as shown in Table 1.

Table 1. Risk factors in the green supply chain of prefabricated buildings

Risk category	risk factor	Serial number
External risk	Impact of the natural environment	S1
	Inadequate policy system	S2
	market risk	S3
Internal risk	Social greening service capacity	S4
	Incomplete technology	S5
	Insufficient experience in operational management	S6
	Supply chain resilience	S7
	Procurement risk	S8
	Creating risk	S9
	Component transportation risk	S10
	Component recovery risk	S11
Link risk	information asymmetry	S12
	Cooperation strategy risk	S13
	Insufficient risk-taking capacity	S14
	Partner selection risk	S15

3 Green supply chain risk evaluation model for assembly buildings

In this paper, DEMATEL-ISM-MICMAC method is applied to the research of green supply chain risk of assembly building in order to clarify the logical relationship between the influencing factors. DEMATEL-ISM-MICMAC method forms a systematic analytical framework by identifying the direct relationship, constructing the hierarchical structure and analyzing the driving force and dependency in depth. First, DEMATEL analyzes the direct and indirect influences between factors, constructs a direct influence matrix, and reveals the strength and direction of the association. Secondly, ISM is transformed into reachability matrix based on the direct influence matrix to form a multilevel structural model. Finally, MICMAC complements and deepens the ISM results to provide a deeper understanding of the mechanisms and interactions between factors through the driver-dependency matrix.

3.1 DEMATEL Analysis

Ten experts in the field of construction engineering were invited to score the relativity between the impact factors. On a scale of 0 to 3 (0: no impact, 1: mild impact, 2: moderate impact, 3: strong impact), an impact matrix was formed **K**.

$$\mathbf{K}=\begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 2 & 1 & 1 & 0 & 2 & 2 & 2 & 1 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
2 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 1 & 2 & 1 & 1 & 0 & 0 & 0 \\
1 & 0 & 1 & 1 & 0 & 0 & 2 & 1 & 2 & 1 & 1 & 1 & 0 & 2 & 1 \\
1 & 0 & 2 & 1 & 1 & 0 & 1 & 1 & 2 & 1 & 1 & 2 & 1 & 1 & 1 \\
0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 3 & 0 & 1 & 1 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0
\end{pmatrix}$$

First, the direct influence matrix K is standardized to obtain the normalized matrix N, and then the comprehensive influence matrix T is constructed to analyze the direct and indirect influences among factors. The sum of the rows and columns of T is calculated to obtain the combined influence (row and Di) and the influence value (column and Ri) of each factor. The degree of centrality (Di + Ri) thus reflects the importance of the factor, with a higher value indicating a greater driving force. The degree of causality (Di - Ri) reveals the causal properties of the factor, with a positive value indicating a causal factor and a negative value indicating an effect factor. See Table 2 for the results of the centrality and cause degree calculations.

Table 2. Centrality and causality of risk factors in the green supply chain of prefabricated buildings

contributing factor	D_i	R_i	Centrality	Cause	Driver	Dependence
S1	0.5833	0.3023	0.8856	-0.281	2	5
S2	0	1.3157	1.3157	1.3157	8	0
S3	0.4871	0.3608	0.8479	-0.1263	1	5
S4	0.2377	0.9013	1.139	0.6636	8	3
S5	0.2377	1.3273	1.565	1.0896	11	3
S6	0.0896	1.3122	1.4018	1.2226	13	1
S7	0.2546	0.3528	0.6074	0.0982	3	2
S8	0.8397	0.1748	1.0145	-0.6649	2	6
S9	0.8644	0.2655	1.1299	-0.5989	3	6
S10	0.73	0.5262	1.2562	-0.2038	5	5
S11	0.6343	0.1772	0.8115	-0.4571	2	6
S12	1.1801	0.1811	1.3612	-0.999	2	10
S13	0.7116	0.3442	1.0558	-0.3674	3	5
S14	0.4664	0.2655	0.7319	-0.2009	3	4
S15	0.6824	0.192	0.8744	-0.4904	1	6

In the green supply chain risk management of assembled buildings, key drivers such as imperfect policy system (S2), incomplete technology (S5), information asymmetry (S12), cooperation strategy risk (S13), and partner selection risk (S15) are at the center. These factors not only have significant influence on other factors, but also determine the risk stability of the whole supply chain. Effective management of these factors can significantly reduce the potential risks in the supply chain.

Important influencing factors, which do not directly affect the core of the system like the key drivers but have a greater influence on the stability of the supply chain, include inexperience in operation and management (S6) and manufacturing risk (S9). These factors directly affect the production and management process of assembled buildings, and if they are not effectively controlled, they may lead to risks such as product quality degradation and supply chain rupture. Therefore, in risk management, it is necessary to strengthen the training of supply chain operation and management, accumulate management experience, and improve the operation and management level within the enterprise

Affected factors such as natural environmental impact (S1), market risk (S3), and social green service capacity (S4) are often the result of other factors rather than a direct risk driver. Therefore, the management of these factors can be achieved indirectly by controlling key drivers and important influencing factors.

3.2 ISM Analysis

The Delphi method was used to identify the binary relationships between the influencing factors of risks in the green supply chain of prefabricated buildings, forming an adjacency matrix to represent the direct links between the factors. Then, Boolean algebra was used to convert the adjacency matrix into an reachability matrix, which reflects the transfer relationships between the factors. Based on the reachability matrix, the influencing factors of risks were structured by calculating the reachable set and the antecedent set, dividing the levels and constructing a directed acyclic graph (see Fig 1).

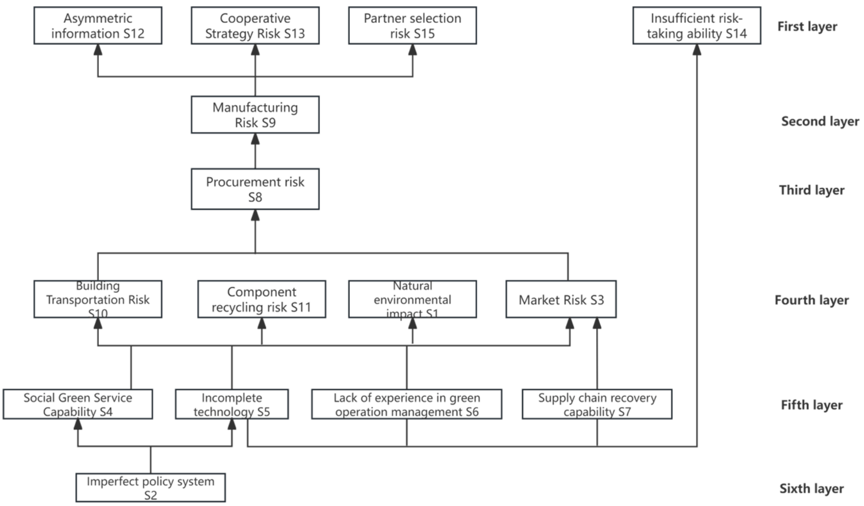

Fig. 1. Major risk factors in the green supply chain of prefabricated buildings: A hierarchical structure

Based on the hierarchical division of the influencing factors shown in Figure 1, the influencing factors were further categorized into three subgroups, namely, deep factor clusters (S2, S4, S5, S6, and S7), core factor clusters (S1, S3, S8, S9, S10, and S11), and surface factor clusters (S12, S13, S14, and S15).

Risks in the green supply chain for assembled buildings stem mainly from deficiencies in policy, social services, technology, management and resilience. These problems are reflected in imperfect institutional policies, shortcomings in technology and lack of experience in green operation and management. To reduce risks, the government and the industry need to formulate green policies, upgrade technology, and enhance the supply chain resilience of enterprises, which should be emphasized especially in the early stage of the industry to avoid chain reactions.

Meso-level risks, which include the natural environment, markets, sourcing, manufacturing, transportation and recycling, are closely related to bottom-level risks. For example, imperfect policies can exacerbate market risks, and lack of green management can affect manufacturing and recycling. Practical management needs to strengthen monitoring to ensure a smooth supply chain.

Surface-level risks such as information asymmetry, cooperation strategies, risk-taking capacity and partner selection most directly affect supply chains. These risks usually stem from bottom and middle tier problems. Addressing these risks requires addressing the root causes and gradually eliminating the deep-rooted problems.

3.3 MICMAC Analysis

The cross-matrix multiplication method clarifies the role of different factors in the system based on the principle of matrix multiplication, depending on their driving forces and dependencies. A high driving force means that solving the factor will solve other problems, while a high dependency means that other problems need to be solved first. Based on the reachability matrix, the drivers and dependencies of the factors are categorized into four groups: independent factor groups, linkage factor groups, dependency factor groups, and autonomous factor groups, which are shown in Fig 2.

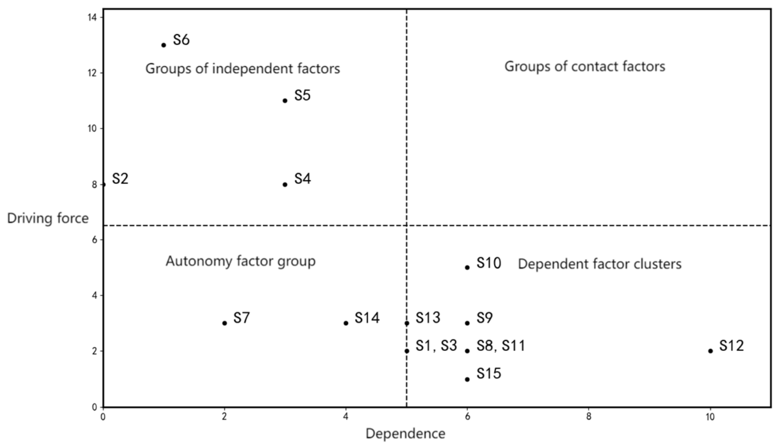

Fig. 2. Risk factor dependence, driving force, classification

The cluster of independent factors includes imperfect policy system (S2), social green service capacity (S4), incomplete technology (S5) and insufficient experience in green operation and management (S6). These factors are located in the region of high driving power and low dependence, indicating that they have strong driving power for the system but are not significantly influenced by other factors. These independent factors are key starting points for system optimization, and enhancing them can significantly reduce other risks in the system.

No factors in the figure fall into the cluster of linked factors, implying that no factor has both high driving power and high dependency. There is no single factor that is both a major driver and a major dependency among the factors in the green supply chain for assembled buildings. This indicates that all factors in the system work together through complex interactions and linkages, increasing the complexity of system management.

Supply chain resilience (S7) and insufficient risk-taking capacity (S14) are in the cluster of autonomous factors, representing that they are both less driven and less dependent. Although their roles in the system are relatively independent, their enhancement provides a solid safeguard for the supply chain in the face of unexpected events or uncertainties.

Dependent factor clusters are located in the area of low driving force and high dependency and include natural environment impact (S1), market risk (S3), sourcing risk (S8), manufacturing risk (S9), information asymmetry (S12), partner strategy risk (S13), partner selection risk (S15), as well as component transportation risk (S10) and component recovery risk (S11). These factors are dependent on changes in other factors in the system and rarely drive changes in the system directly. They are often managed in practice to reduce their impact indirectly by optimizing and controlling other independent and linked factors.

4 Conclusion

Through the comprehensive analysis of the three models, DEMATEL, ISM and MICMAC, we can classify the 15 supply chain risk factors into critical, important and dependent factors. The drivers, dependencies, and influences that these factors exhibit in each model help to clarify the prioritization of supply chain stability management.

The key factors include imperfect policy system (S2), incomplete technology (S5), information asymmetry (S12), cooperative strategy risk (S13) and partner selection risk (S15). In the DEMATEL analysis, these factors are the main drivers, significantly influencing the performance of the other factors. In the ISM model, they are located in the cluster of independent or core factors, indicating a strong driving capacity, which is crucial for system stability. At the same time, the MICMAC analysis shows that these factors have strong independence and driving power and are less dependent on other factors. Such key factors need to be prioritized and managed because the soundness of the policy system, the improvement of the technology level, the symmetry of information, and the optimization of cooperation strategies and partner selection all determine the long-term stability of the supply chain.

Important factors include inexperience in operational management (S6) and manufacturing risk (S9). In the DEMATEL model, they are important influences that have a direct impact on the production and management processes of the supply chain. In the ISM model, these factors mostly belong to the group of independent factors with a high degree of drive. The MICMAC analysis also shows that they possess relatively strong independence, but with a slightly higher degree of dependence, and need to be optimized for their performance by improving management experience and strengthening quality control. These factors, while not as central a driver as the key factors, are also critical to the day-to-day operation and stability of the supply chain.

The dependency factors contain market risks (S3), natural environmental impacts (S1), and social green service capabilities (S4), as well as supply chain autonomy factors (S7, S14) and other general dependency factors (S8, S10, S11). In the DEMATEL model, these factors are mostly influenced or autonomous factors that are directly dependent on the performance of the key factors. In the ISM model, these factors are located at the surface level or in a cluster of surface factors, indicating a weak driving force on the system, which is mainly influenced by other factors.The MICMAC analysis shows a high level of dependence, and fluctuations in these factors can be indirectly controlled by optimizing the key factors. Although these types of dependencies do not directly affect the core stability of the supply chain, their performance can be indirectly improved by adjusting the key and important factors in the system to ensure the overall balance of the supply chain.

In summary, through the comprehensive analysis of DEMATEL, ISM and MICMAC, policy, technology, information, cooperation strategy and partner selection constitute the key factors of supply chain stability, which need to be paid priority attention to; operation management and manufacturing risk are important factors, which directly affect the stability of the system; and the dependency factors are greatly affected by the system as a whole, and their risks can be indirectly controlled by optimizing the key and important factors to realize the The optimization of key and important factors can indirectly control their risks and realize the stability and sustainable development of the supply chain.

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