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Comprehensive Performance Evaluation of Green Building Supply Chain Based on Optimal Combination of Game Theory

Cheng Zhang, Yuqing Du

School of Management, Shanghai University of International Business and Economics, Shanghai, China

Abstract: *In recent years, there are more and more policies and researches on green building, but there are few researches on constructing a comprehensive performance evaluation system for the supply chain of this industry. To fill this gap, this paper uses the objective entropy method and the subjective analytic hierarchy process. This research is an innovative approach to constructing an evaluation system for this field by optimally combining them through game theory. This study provides a basis for practitioners or researchers to analyze the comprehensive performance of each supply chain in this industry through the results of this study.*

Keywords: *Green building supply chain, Performance evaluation, Entropy method, Analytic hierarchy process, Game theory group joint optimization*

1. Introduction

The construction industry is an integral part of the national economy and occupies a very important position because of its often-huge scale. The traditional construction industry has shifted to using a supply chain management model [1]. However, management specifically for the green building supply chain is not common. This study aims to contribute to this gap by establishing a comprehensive performance evaluation index system for the green building supply chain through a game-theoretic optimization combination, which provides a reference for a combination of objective and subjective evaluation for the green building industry,

Zhang Yujia et al [2] used fuzzy network hierarchy analysis to establish an evaluation system for the performance of the assembly building supply chain. Xie et al [3] focused on the green supply chain in the construction industry and found that environmental regulations and government support are necessary for the green supply chain. And RezaHoseini et al [4] used bi-objective linear programming to evaluate the green building supply chain while considering the pollution emissions in the transportation process. Most of the existing studies on green building focus on the relationship and the degree of coordination among its members, but there is no performance evaluation system about the industry. Therefore, this study fills the gap in this area and constructs a comprehensive performance evaluation system for the green building supply chain specifically applicable to this industry.

In summary, there are few existing studies on green building supply chains, and few evaluation systems have been constructed for them. This study makes the following contributions to this point. (1) A set of comprehensive performance evaluation indexes is tailored for the green building supply chain. (2) This study also uses a game-theoretic combination weighting approach that combines subjective and objective methods.

2. Model Introduction

In this study, three methods of entropy weight method, Analytic Hierarchy Process and game theory combination optimization will be used to conduct the research. The entropy weighting method can objectively and rigorously analyze the weighting that each index in the green building industry should have. The Analytic Hierarchy Process is more subjective and can take experts' experience into consideration. The game theory combination optimization can integrate the two, so as to construct the most reasonable index system for the target.

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2.1. Entropy method

Entropy weight method is an objective evaluation method that calculates entropy weight and judges the size of the information contained in each index, so as to derive the weight of each index. Linlin Xie et al [5] also pointed out that the use of entropy weighting method in the practical process often leads to more objective results.

2.2. Hierarchical analysis

Analytic Hierarchy Process (AHP) is a decision-making method proposed by American Professor Satie in the 1970s. Yang J. and Li Hongyan [6] also pointed out that the Analytic Hierarchy Process is an effective means to deal with difficult to quantify problems.

2.3. Game-theoretic weight optimization

Game theory-based weight optimization takes Nash equilibrium as the goal, reduces the conflict between different weights. Wei et al. [7] pointed out that by using this method, it is possible to consider the weights derived from both subjective and objective methods. With this method, the results obtained from the entropy weight method and the Analytic Hierarchy Process are combined to obtain an ideal performance evaluation system. Specific implementation steps are as follows.

Step1: Construct the weight set.

There are L total number of a-assignment methods, where the weight set of each method is u_k :

$$u_k = \{u_{k1}, u_{k2}, ..., u_{km}\}, \mathrm{k} = 1, 2, ..., \mathrm{L} \tag{1}$$

The linear combination of each weight set is u , L combined weight set of species weight sets.

$$u = \sum_{k=1}^{L} a_k \cdot u_k^T, a_k > 0 \tag{2}$$

Step2: Discrepancy Minimization

In order to minimize the conflict between the weights, the discrepancy between the set of weights and the set of combined weights is minimized.

$$\min \left\| \sum_{j=1}^{L} a_j \cdot u_j^T - u_i \right\|_2, i = 1, 2, ..., L \tag{3}$$

The conditions under which the optimal first-order derivative of a matrix can be derived from its differential properties are as follows.

$$\sum_{j=1}^{L} a_j \cdot u_i \cdot u_j^T = u_i \cdot u_j^T, i = 1, 2, ..., L \tag{4}$$

After solving to derive a, normalization is performed and the combination weights a are derived.

$$a_j^* = \frac{a_j}{\sum_{j=1}^{L} a_j} \tag{5}$$

$$\mathrm{u}^* = \sum_{j=1}^{L} a_j^* \cdot u_j^T \tag{6}$$

3. Example Measuremen

3.1. Index system construction

The supply chain of the construction industry is very different from the traditional industry. Green

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building will pay more attention to resource conservation, environmental protection, emission reduction and other environmentally friendly matters (Figure1).

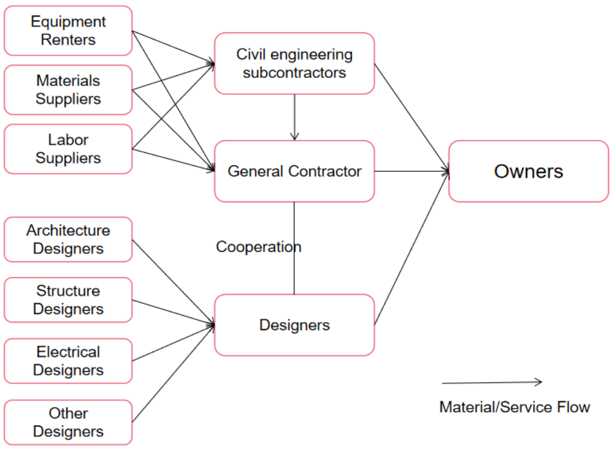

Figure 1: Diagram of green building supply chain

Li et al [8] established a set of index system suitable for supply chain performance evaluation in China, pointing out that the comprehensive performance of supply chain includes agility, operational capability, etc. In this study, the research results of each literature were comprehensively referred, and the following index system was constructed (Table 1).

Table 1: Comprehensive performance level of green building supply chain

Objectives	Tier 1 Indicators	Secondary indicators	Source	Qualitative/ Quantitative metrics	Incremental (+)/ Decremental (-) Metrics
Green Building Supply Chain Integrated Performance Level A	Agility A1	Supply chain response time A11	Reference [18]	Quantitative metrics	-
		Market responsiveness A12		Qualitative metrics	-
		Lead time A13	Reference [15]	Quantitative metrics	-
		Production flexibility A14		Qualitative metrics	+
	Operating Capability A2	Engineering Contracting Capability A21	Reference [18]	Quantitative metrics	+
		Cash turnover period A22		Quantitative metrics	-
		Current asset turnover ratio A23		Quantitative metrics	+
	Profitability A3	Return on Investment A31	Delphi method	Quantitative metrics	+
		Engineering profitability A32		Quantitative metrics	+
		Labor productivity A33		Quantitative metrics	+
	Customer satisfaction A4	Product excellence rate A41	Reference [18]	Quantitative metrics	+
		On-time completion rate A42		Quantitative metrics	+
		Follow-up maintenance level A43	Delphi method	Qualitative metrics	+
	Level of inter-company cooperation A5	Supplier on-time delivery rate A51	Reference [18]	Quantitative metrics	+
		Qualification rate of suppliers' products A52		Quantitative metrics	+
		Inter-company information communication level A53		Qualitative metrics	+
	Level of environmental friendliness A6	Solid waste emissions/ton*thousand square meters A61	Reference [16]	Quantitative metrics	-
		Liquid waste emissions/ton*000 m2 A62	Delphi method	Quantitative metrics	-
		Exhaust gas emissions/ton*sqm A63	Reference [16]	Quantitative metrics	-
		Water saving rate/% A64		Quantitative metrics	-
		Low carbon material utilization rate/% A65		Quantitative metrics	-
		Renewable energy utilization rate/% A66		Quantitative metrics	-
		Building greening rate/% A67		Quantitative metrics	-

Agility A1 refers to the speed of change and adjustment ability of the whole supply chain. This indicator includes four secondary indicators. A11, which refers to the number of days it takes from the time the owner contracts out a project or makes changes to a project until all supply chain members involved adjust. A12 is the ability of the supply chain to respond to changes in the market environment, and can be measured by the winning bid rate in the green building supply chain. A13 shows the extent to which the supply chain is proactive. A14 is a subjective factor to be judged by those who know enough about the target supply chain.

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Operational capacity A2 refers to the ability of the supply chain to use internal resources and production materials. A21 can be measured by the maximum number of projects it can contract. A22 refers to the time spent from paying cash for raw materials to recovering accounts (Equation 18). A23 is an indicator to evaluate the utilization of the enterprise's assets (Equation 19).

$$\text{Cash Flow Rate}=\text{Accounts Receivable Turnover Ratio} - \text{Accounts Payable Turnover Ratio}+\text{Inventory Turnover Ratio} \tag{7}$$

$$\text{Current asset turnover ratio}=\text{Net income from main business} / \text{Average total current assets} \tag{8}$$

Profitability A3 refers to a firm's ability to earn profits. A31reflects the ability of the enterprise to earn profit from investment (Equation 20). A32 reflects the ability of enterprises to obtain profit and control cost. Labor productivity A33 shows the use of human resources in the supply chain (equation 22).

$$\text{Return on Investment}=\text{Profit before tax} / \text{Total Investment} \tag{9}$$

$$\text{Labor productivity}=\text{Project amount} / \text{Number of employees} \tag{10}$$

Customer satisfaction A4 reflects the situation that the supply chain meets the market demand. In the context of this study, the customer is the owner, so it is only necessary to judge the owner's satisfaction with the project. A41 reflects the ratio of a supply chain's completed projects that have been well received by the owner over the years. A42 reflects whether the supply chain often has delays and is not completed on time. A43 is an indicator specific to the construction industry.

The level of inter-firm cooperation A5 also determines the performance of a supply chain. A51 and A52 reflects the most critical segment of the supply chain. A53 reflects the degree of information sharing in the entire supply chain. This indicator is more subjective and therefore relatively difficult to measure, requiring the owner, contractor and designer to evaluate the level of information communication with other supply chain members separately.

The degree of environmental friendliness A6 is a very important indicator for the green building industry. A61 to A66 are all common environmental indicators. In addition, the green building rate/%A67 is an indicator specific to green buildings. Although a green building does not necessarily mean that the building is covered with greenery, it is a plus in terms of environmental friendliness if it is covered with greenery.

3.2. Optimization of weights based on game theory combination

Table 2: The weights of each indicator combined by game theory

Indicator	Weights (entropy weighting)	Weights (AHP)	Weights(combined)
A11	0.0455	0.0339	0.0490
A12	0.0389	0.0303	0.0413
A13	0.0200	0.0408	0.0274
A14	0.0442	0.0306	0.0485
A21	0.0497	0.0604	0.0442
A22	0.0754	0.0843	0.0791
A23	0.0422	0.0398	0.0421
A31	0.0613	0.0711	0.0559
A32	0.1250	0.1040	0.1165
A33	0.0541	0.0547	0.0531
A41	0.0431	0.0498	0.0394
A42	0.0935	0.0867	0.0939
A43	0.0170	0.0304	0.0184
A51	0.0832	0.0689	0.0767
A52	0.0473	0.0473	0.0461
A53	0.0247	0.0258	0.0248
A61	0.0314	0.0188	0.0298
A62	0.0324	0.0261	0.0341
A63	0.0150	0.0244	0.0109
A64	0.0071	0.0191	0.0098
A65	0.0281	0.0152	0.0274
A66	0.0019	0.0162	0.0121
A67	0.0189	0.0215	0.0195

After finding the weights of each indicator by entropy and hierarchical analysis respectively, game

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theory is used to combine the weights of the two, so that the results are both objective and subjective (Table 2).

3.3. Analysis of results

Figure 2 shows the final weights of the indicators for the comprehensive performance evaluation of green building supply chains. From this, we can understand which indicators are more important in this field, which can be used to evaluate the comprehensive level of different supply chains, and can also make suggestions for improvement for a specific supply chain.

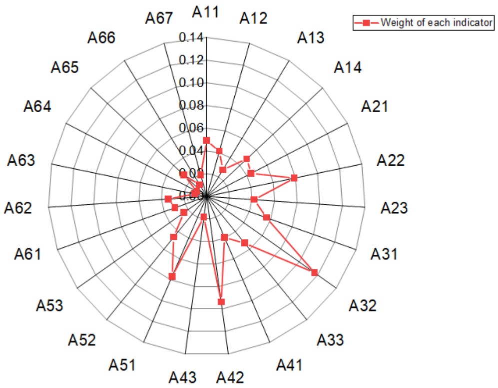

Figure 2: The weights of each indicator derived from the game theory combination weights

Engineering profitability is the core of the profitability of a supply chain, which directly determines the profitability of all enterprises in the supply chain and is related to the life and death of enterprises. On-time completion rate means the stability of production capacity on one hand, and also determines customer (owner) satisfaction on the other hand, and the on-time rate gets a high weight because of the frequent delay in construction industry.

The weights of the first-level indicators are roughly the same, and it is worth noting that the weights of the two relatively abstract and unnoticed indicators, inter-enterprise cooperation level A5 and environmental friendliness A6, are similar to those of operational capability A2. This reflects close cooperation among enterprises is very important in today's supply chain. Enterprises should pay more attention to the cooperation among enterprises. Besides, in the green building industry, the degree of environmental friendliness is indeed very important.

In short, in the green building supply chain, the first thing to focus on is still the profitability represented by the project profitability. In addition, we should pay attention to all indicators instead some of them.

4. Conclusion

In order to solve the gap that there is no index system to evaluate the comprehensive performance of the supply chain in the green building industry, this paper innovatively used game theory, combined with hierarchical analysis and entropy method to build a combination of subjective and objective evaluation system for it. The results show that profitability is the most important in this industry, and the engineering profitability is the indicator with the greatest weight. The level of cooperation between supply chains and the degree of environmental friendliness, both of which are more easily neglected, are equally important. The results of this study enable practitioners or researchers to use this index system derived from this paper to evaluate the comprehensive performance of a particular green building supply chain for their work or research.

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