ISSN 2616-5902 Vol. 5, Issue 5: 152-163, DOI: 10.25236/AJBM.2023.050522

Green Supply Chain Performance of Prefabricated Construction from the Perspective of Collaborative Innovation

Penghui Zhang

School of Management Engineering and Business, Hebei University of Engineering, Handan, China
Hui802@yeah.net

Abstract: *In order to implement the new development concept and improve the performance evaluation system of green supply chain of prefabricated Constructions in my country, a performance evaluation of green supply chain of prefabricated Constructions from the perspective of collaborative innovation is proposed. First, draw lessons from the balanced scorecard theory and apply it to construct a performance evaluation index system for the green supply chain of prefabricated Constructions based on the balanced scorecard. Meta-extension model. Then, the performance evaluation grade is determined by the asymmetric closeness of the matter element to be evaluated about the evaluation grade of each index and the characteristic value of the grade index. Finally, the established evaluation model is applied to a green supply chain of a prefabricated Construction, and the results prove the validity of the model.*

Keywords: *Green supply chain of prefabricated Constructions; Collaborative innovation; Balanced scorecard; Improved matter-element extension model; Closeness*

1. Introduction

Under the guidance of the new development concept, my country's new-type building industrialization drives the construction industry to usher in a new transformation and upgrading, and the construction technology of construction enterprises is changing from reinforced concrete cast-in-place construction to prefabricated construction. In recent years, due to the guidance of national policies, the manufacture of prefabricated components of prefabricated Constructions has gradually developed towards high-quality development in the direction of design standardization, industrialization of manufacturing, and green environmental protection. The performance of the prefabricated Construction supply chain is becoming an important factor to measure the development level of the prefabricated Construction supply chain. It is foreseeable that competition in the supply chain of prefabricated Constructions will become an important factor in the strength of construction companies. For the supply chain as a whole, collaborative innovation among enterprises in each node of the supply chain is the main support for its sustainable development. The state and local governments are actively promoting the implementation of the "14th Five-Year Plan for National Cleaner Production Implementation Plan", and the construction industry is transforming into a green transformation of the whole process of engineering construction. Green" transition. Therefore, in order to promote the development of Prefabricated Construction Green Supply Chain (PCGSC) and promote green construction, it is necessary to establish a scientific evaluation index system to evaluate the green supply chain performance of prefabricated Constructions from the perspective of collaborative innovation.

2. Literature Review

Supply chain and collaborative innovation are interdependent, and supply chain node enterprises using collaborative innovation to integrate resources can produce performance improvements that cannot be achieved by a single enterprise. Zhou Shuiyin and others believe that the collaborative innovation of supply chain node enterprises has a positive impact on enterprise performance, and supply chain synergy affects product innovation and process innovation [1]. Based on the knowledge sharing perspective, Wang Limei and others studied the collaborative innovation among supply chain node enterprises and concluded that sufficient knowledge sharing is a necessary condition for

ISSN 2616-5902 Vol. 5, Issue 5: 152-163, DOI: 10.25236/AJBM.2023.050522

collaborative innovation among supply chain enterprises [2]. Wang Haijun et al. introduced strategic modular suppliers to combine with enterprises and participated in the whole process of collaborative innovation, forming a benign collaborative innovation, thereby improving the efficiency of supply chain operations [3]. Through empirical analysis, Zhang Feiyan concluded that dynamic capabilities can promote collaborative innovation in supply chains, thereby improving overall supply chain performance [4]. Ding Yingying et al. explored the moderating effect of the relationship between supply chain collaboration and innovation performance by introducing resource integration and knowledge appreciation as situational variables [5]. Based on cognitive behavior theory, Shang Yanjie et al. analyzed the relationship between strategic consensus among supply chain enterprises, knowledge sharing, and technological innovation performance of supply chain collaborative enterprises, and found that strategic consensus among supply chain enterprises had an impact on knowledge sharing and technological innovation performance of enterprises have a promoting effect [6]. Through hypothesis testing, Wu Yali and others concluded that collaborative knowledge, technology, and management innovation of retail enterprises are positively correlated with sustainable supply chain performance [7].

Based on the research of scholars, the research results of supply chain collaborative innovation and supply chain performance are relatively rich, but they focus on theoretical analysis, and the evaluation of supply chain performance in specific industries needs to be further studied. As an engineering construction model that can achieve green environmental protection and improve construction quality, prefabricated Constructions play an important role in promoting the development of the construction industry from the perspective of collaborative innovation. Therefore, based on the perspective of collaborative innovation, this paper evaluates the performance of PCGSC, and expects to provide scientific guidance for the development of green supply chain of prefabricated Constructions.

3. Definition of Relevant Concepts

3.1 Connotation of Collaborative Innovation

Collaborative innovation can be defined as: under the background of gradual systematization and networking of innovation, heterogeneous innovation subjects jointly participate in innovation and development activities for common goals, and actively promote new processes During the development and application of new products, each subject will use formal or informal contacts to give full play to the advantages of the subject, and combine the resources of the network where the enterprise is located to achieve a win-win situation, which effectively promotes the progress of enterprise technology and the improvement of innovation capabilities between networks [1]. The heterogeneous innovation subjects of the prefabricated Construction supply chain from the perspective of collaborative innovation mainly include: the government, design units, cooperative universities, suppliers, manufacturers, scientific research institutions, general engineering contractors, developers, intermediaries, etc. Associated node composition. Combining the viewpoints of previous scholars [8][9][10], the basic characteristics of collaborative innovation are as follows:

(1) Under the synergistic effect of multiple innovation subjects, various innovation elements communicate and apply processes, thereby promoting resources in heterogeneous innovation flow between innovative entities.

(2) Collaborative innovation can make close connections between heterogeneous participants, making it have a relatively stable knowledge sharing function.

(3) The communication, interaction and cooperation between heterogeneous innovation entities from the perspective of collaborative innovation can realize the efficient output of innovative enterprises in the supply chain, promote the common development of enterprises in the supply chain, and improve the performance of the entire supply chain.

3.2 Prefabricated Constructions

Prefabricated Constructions refer to heterogeneous innovative entities, in order to better complete construction projects, through formal or informal information communication and resource sharing, some or all components are standardized design, and after the completion of factory standard manufacturing It is transported to the construction site for assembly, then standardized decoration can be carried out, and the building can be managed intelligently production methods.

3.3 Prefabricated Construction Green Supply Chain (PCGSC)

The development of prefabricated Constructions has accelerated the research on the prefabricated Construction supply chain. Yang Chang et al. proposed and analyzed the green building supply chain operation reference model [12]. In recent years, Huang Guilin, Zhang Chuang, etc. introduced the concept of green supply chain into the prefabricated Construction supply chain system, integrated the SCOR model, and constructed the PCGSC model, which is in line with the trend of green development in the industry [13]. However, looking back at the existing research, PengFZ et al. used DEA to construct an evaluation index system of green building supply chain from the perspective of greenness and evaluate it, verifying the feasibility of the evaluation model, and providing ideas for green supply chain evaluation [14] . An Hui et al. expounded the factors affecting supply chain integration by establishing a SEM model and ranked the importance of the drivers, thus providing a reference for supply chain integration [15].

Based on the existing research on the supply chain of prefabricated Constructions and the content of green supply chain management [16], the connotation of PCGSC from the perspective of collaborative innovation is defined as follows: PCGSC is the integration of "green environmental protection" elements into the supply chain of prefabricated Constructions. In the chain, the project general contractor is the core, involving the government, designers, general contractors, suppliers, manufacturing subcontractors, construction subcontractors, owners, financial institutions and other heterogeneous innovative entities to participate in the entire prefabricated construction. For engineering projects, integrate the internal and external resources of the supply chain according to its own advantages, so that the internal resources of the supply chain can be optimally allocated. The work tasks mainly cover design, manufacturing, transportation, assembly, maintenance, recycling and other services. For the entire life of the entire prefabricated engineering project a dynamic innovation-building network composed of cycles.

Incorporating the concept of collaborative innovation into PCGSC management can effectively solve the problems of node enterprise collaboration, resources, personnel, and research and development in green supply chain management, and has a great impetus to realize and improve the collaborative and innovative capabilities of green supply chains. Therefore, it is relatively novel to study supply chain performance from the perspective of collaborative innovation. The green supply chain of prefabricated Constructions from the perspective of collaborative innovation presents the following characteristics:

(1) From the perspective of collaborative innovation, PCGSC, in addition to meeting the needs of owners, pays special attention to the synergy and innovation capabilities of node enterprises, abandoning the disadvantages of low efficiency and untimely information communication in the previous supply chain management process, and more emphasis on the overall supply chain.

(2) When studying PCGSC, factors such as "resources" and "environment" of each node enterprise should be considered to meet PCGSC requirements and conform to the concept of sustainable development. Each node enterprise should give full play to the innovation ability of node enterprise in the whole process of PC (Prefabricated Components, PC) component production, and realize the coordinated development of PCGSC economic benefit and ecological environment by coordinating the innovation investment and environmental protection investment of node enterprise.

3.4 PCGSC Performance

From the perspective of collaborative innovation, green supply chain performance refers to the overall operating efficiency of the supply chain when the supply chain meets customer needs, and the performance can be analyzed from the aspects of behavior and results.

Behavioral performance refers to the scientific control of production, manufacturing, logistics and transportation processes through information sharing for each node subject involved in the supply chain, and then to achieve the corresponding management goals. Result performance is the sum of value created for related enterprises through the management of supply chain node enterprises. Innovation performance refers to the increase in the profits of supply chain enterprises through the research and development of new technologies, new processes, new materials and other innovative behaviors and subsequent use. Qu Fuqiang et al. constructed the PCSC collaborative evaluation index system based on literature summarization and combined with the characteristics of the prefabricated Construction supply chain, and evaluated the index system based on the ANP-Fuzzy model, and then studied the

ISSN 2616-5902 Vol. 5, Issue 5: 152-163, DOI: 10.25236/AJBM.2023.050522

collaborative performance of the supply chain [17]. Zhang Yujia et al. constructed a performance evaluation index system based on six aspects of procurement, production, distribution, assembly, and customer service, and combined FANP to calculate a performance evaluation model to optimize the evaluation results [18].

From the perspective of collaborative innovation, PCGSC performance is a heterogeneous innovation subject in the supply chain centered on the general contractor of prefabricated construction projects. Environmental factors are considered and strengthened at each node in the supply chain, and by controlling logistics, information flow, capital flow, The management process of knowledge flow, talent flow, etc., which constitutes collaborative innovation to create value and measure the various activities taken in order to achieve the goal of the supply chain. The focus of PCGSC performance evaluation pays more attention to the strategic management of green supply chain from the perspective of development. By reducing resource waste, compressing response time, improving supply chain flexibility, and improving supply chain collaborative innovation capabilities, and then improving supply chain profitability, so as to achieve PCGSC profits maximize.

In view of this, this paper selects PCGSC as the research object, based on the perspective of collaborative innovation, combined with the characteristics of supply chain operation, chooses "behavioral performance", "result performance" and "innovation performance" as the basis for the construction of performance theory, in order to integrate the supply chain The balanced scorecard of the reference model (SCOR) is used as the model framework to establish the performance evaluation index system of the prefabricated Construction green supply chain (PCGSC). The entropy weight method and the Analytic Hierarchy Process (AHP) method are used to combine the weighting of the indicators to be evaluated, so as to weaken the influence of a single weighting method on the final weight, and use the asymmetric closeness to replace the maximum membership degree, so as to avoid the matter-element extension model relying on the maximum degree of membership. When the membership principle is used to select the index value, there is a risk that the evaluation result will be invalid due to the lack of information. Based on the PCGSC performance evaluation model established above, and based on the evaluation results, the indicators that affect the performance of PCGSC can be improved from the root, so that the performance of PCGSC is more effective, objective and scientific. Provide scientific reference for efficient development.

3.5 Performance Theory Analysis of PCGSC from the Perspective of Collaborative Innovation

The Balanced Scorecard (BSC) was developed by American scholars Robert S. Kaplan and David P. Norton in 1992. Dimension sets performance appraisal goals, so as to achieve the long-term strategic goals of the enterprise [19]. The supply chain balanced scorecard can build an evaluation index system based on the PCGSC management strategy, so as to comprehensively reflect the overall performance of the supply chain operation. It regards financial indicators, owner indicators, operation processes, learning and growth as important aspects that affect supply chain performance, and can comprehensively reflect the supply chain operation process and PC component (Prefabricated Components, PC) suppliers, manufacturers and owners, through the learning and growth of the supply chain to promote the acquisition of innovation performance of the supply chain, which can systematically, real-timely and effectively reflect the implementation of the strategy from the strategic perspective of the prefabricated Construction supply chain. In addition to the above advantages, PCGSC performance from the perspective of collaborative innovation can fully consider the collaborative innovation, achievement transformation, and self-capacity building of supply chain innovation entities.

(1) The supply chain financial perspective: In the PCGSC performance evaluation, the supply chain balanced scorecard still regards financial indicators as the most basic indicators. Qu Jianhua believes that the direction of supply chain improvement leads to financial goals, so as to highlight the competitive value of the supply chain and maximize the profitability of supply chain partners [20]. Therefore, PCGSC members should not only pursue their own interests, but also consider the green benefits of all parties. In order to highlight the performance of the green supply chain, green inputs such as "energy saving" and "environmental protection" should be included in the financial indicators. Therefore, the financial indicators of PCGSC, namely, the return on total assets, the total asset-liability ratio, the operating growth rate, and the total cost of delivery (green Purchasing costs, green transportation costs, green production costs, green assembly costs), and the ratio of environmental protection capital investment to judge the economic results achieved by the supply chain while achieving strategic goals, so as to promote the development of the green supply chain of prefabricated Constructions.

ISSN 2616-5902 Vol. 5, Issue 5: 152-163, DOI: 10.25236/AJBM.2023.050522

(2) The perspective of supply chain owners: Wu Fang et al. proposed that the customer-oriented supply chain performance evaluation is based on the observation of the value change process of the supply chain, and the information in the value exchange process is obtained and classified [21]. In PCGSC, the needs of developers represent the development orientation of the green supply chain of prefabricated Constructions, which reflects the green supply chain's ability to respond to external changes, adaptability and innovation. For the entire PCGSC, the entire supply chain is in on the premise of ensuring "green", it is its long-term goal to build high-quality buildings for the owners. Therefore, when evaluating PCGSC performance, the indicators that need to be considered from the perspective of the owner should be some leading indicators, such as the on-time delivery level of prefabricated components, the yield rate of PC components, and the level of green assembly. Satisfaction with supplier service, etc.

(3) Supply chain operation process: Zhao Lina, based on the idea of supply chain management, strengthens the operation process of the supply chain to avoid damage to the overall interests of the supply chain due to short-term interests of supply chain node enterprises [22]. The indicators of the green supply chain operation process of prefabricated Constructions reflect the substantive indicators of supply chain performance. The decision-making of the supply chain operation process is closely related to the performance from the financial point of view and the performance of the owner. The control of costs at each stage of the operation process is related to finance, and a good operation process can obtain more customers, thereby enabling supply Chain members learn and grow better. Therefore, enterprises at PCGSC nodes can cooperate and communicate with each other, reduce the impact on the environment by using green materials, green transportation, etc., and improve resource utilization through the circulation of PC components, the repair of damaged PC components, and the recycling of discarded PC components rate, and ultimately improve the core competitiveness of PCGSC. Therefore, in evaluating the operation process of PCGSC, the selection of indicators needs to be carried out from the aspects of publicity, transportation, inventory turnover, and node coordination.

(4) Supply chain learning and growth: With the development of industrialized buildings, the competition in the green supply chain of prefabricated Constructions will become more intense, and the innovation potential of PCGSC is related to the core competitiveness of the supply chain. Therefore, in order to enhance the core competitiveness of PCGSC, each member of the green supply chain should maintain the original creativity, improve the job satisfaction of employees, and then continue to increase investment in green innovation and the cultivation of innovative talents.

To sum up, based on the theoretical analysis of the balanced scorecard, it can be concluded that the impact of PCGSC performance from the perspective of collaborative innovation is not isolated, but mutually restricts and forms a positive feedback loop. Increase. PCGSC pays attention to the research and development of green technology, green innovation ability, scientific research and management personnel investment, PCGSC node enterprise process will gradually smooth, so as to gain the favor of developers, so that the project progresses smoothly, the construction period is shortened, the entire market scale is expanded, and PCGSC financial Income increases and vice versa.

4. Construction of the performance matter-element extension model of PCGSC

4.1 Construction principles of PCGSC performance evaluation index system

Due to the numerous and complex factors that affect the performance of PCGSC, and the number of related indicators and indicators, the selection of evaluation indicators should adhere to the following principles: The principle of scientific rationality

(1) The selection process of evaluation indicators should adhere to scientificity and rationality, and be in line with practical significance, so that the established PCGSC performance evaluation index system can not only truly reflect PCGSC performance, but also Able to provide scientific guidance for the promotion of PCGSC.

(2) Systematic and comprehensive PCGSC performance evaluation indicators should be selected in consideration of the systematicness and comprehensiveness of the indicators, and representative indicators should be selected, so as to construct a PCGSC performance evaluation system with complete content and sufficient scientific basis.

(3) The selection of data availability evaluation indicators should pay attention to the availability, authenticity and quantification of data. Quantitative indicators are simple to measure and easy to obtain,

and qualitative indicators can be quantified by expert scoring methods.

4.2 PCGSC performance evaluation index system

By combing literature, according to GB/T39257-2020, interviews with supply chain experts, and surveys of prefabricated Construction supply chain node enterprises, the PCGSC performance evaluation index model is constructed from the perspective of collaborative innovation, according to BSC as the theoretical framework, four first-level indicators are selected from the perspective of supply chain finance, the perspective of supply chain owners, supply chain operation process, and supply chain learning and growth. The selection of second-level indicators aims to serve the entire supply chain strategy, so as to four first-level index factors and 20 second-level index factors can be obtained. According to the PCGSC performance evaluation model under the collaborative innovation obtained above, the details are shown in Table 1.

Table 1: Performance evaluation index system of PCGSC

target layer	Criterin layer	Comprehensive weight	Indicator layer	Comprehensive weight
Performance evaluation index of prefabricated Construction green supply chainX	Financial point of view X1	0.220	ROA X11 total gearing ratio X12 operating growth rate X13 total asset turnover X14 cost saving rate X15	0.224 0.166 0.179 0.193 0.238
	Owner's point of viewX2	0.270	product satisfaction X21 service satisfaction X22 On-time delivery X23 Greenness of the environment X24 PC component yield X25	0.203 0.171 0.208 0.248 0.196
	Operation processX3	0.193	PC component inventory turnover rate X31 Recycling rate of components X32 Types of prefabricated components X33 PCGSC enterprise closeness X34 The winning rate of PCX35	0.188 0.188 0.210 0.172 0.243
	learn and growX4	0.316	PC component development level X41 Number of researchers X42 Green innovation capability X43 R&D investment level X44 Industry green recognition X45	0.184 0.150 0.253 0.204 0.203

4.3 The PCGSC performance rating

In view of the characteristics of the green supply chain of prefabricated Construction with many participants, large investment amount, and overall coordination, according to the excellent performance evaluation criteria GB/T19580-2012, relevant literature, and the opinions of supply chain experts are also solicited and combined with the performance levels commonly used in the supply chain. The division method, the PCGSC performance evaluation level is set as a 5-level metric, and the established PCGSC performance evaluation level domain is: Rj={R1,R2,R3,R4,R5}={[0,0.2), [0.2,0.4), [0.4,0.6), [0.6, 0.8), [0.8,1]}, see Table 2 for details.

Table 2: Green supply chain performance level domain of prefabricated Construction

performance level	Grade interval	Grade evaluation
I	[0,0.2)	Difference
II	[0.2,0.4)	poor
III	[0.4,0.6)	medium
IV	[0.6,0.8)	good
V	[0.8,1]	excellent

4.4 Matter-element extension model

The concept of extenics is a basic science based on extension mathematics and matter-element analysis proposed by Chinese scholar Professor Cai Wen [23]. Its core idea is matter-element theory,

ISSN 2616-5902 Vol. 5, Issue 5: 152-163, DOI: 10.25236/AJBM.2023.050522

and the three most important elements of matter-element are the name N of the thing, the characteristic C that responds to the thing, and the magnitude range X of C. From this, an ordered triple with the PCGSC performance level as the thing N can be formed, that is, R=(N, C, X).

4.4.1 Determining the Classical Domain, Section Domain, and Matter-Element to be Evaluated

Assuming that the classical domain matter-element matrix of PCGSC performance is Rj, then:

$$R_j = \left(R_j, C_j, X_j\right) = \begin{bmatrix} R_j & c_1 & \left(a_{j1}, b_{j1}\right) \\ & c_2 & \left(a_{j2}, b_{j2}\right) \\ & \vdots & \vdots \\ & c_n & \left(a_{jn}, b_{jn}\right) \end{bmatrix} \tag{1}$$

Section Domain Matrix for Determining PCGSC Performance, Let Rp be the node field of R, then:

$$R_p = \left(R_p, C_i, X_p\right) = \begin{bmatrix} R_p & c_1 & \left(a_{p1}, b_{p1}\right) \\ & c_2 & \left(a_{p2}, b_{p2}\right) \\ & \vdots & \vdots \\ & c_n & \left(a_{pn}, b_{pn}\right) \end{bmatrix} \tag{2}$$

Matter-element matrix for determination of PCGSC performance R0, Let R0 be the matter-element of R to be evaluated, then;

$$R_0 = \left(R_0, C_i, X_i\right) = \begin{bmatrix} R_0 & c_1 & a_{p1} \\ & c_2 & a_{p2} \\ & \vdots & \vdots \\ & c_n & a_{pn} \end{bmatrix} \tag{3}$$

4.4.2 PCGSC performance evaluation index weighting based on entropy weight method

The entropy weight method is an objective assignment method to objectively determine the index weight [24]. The specific steps are as follows:

Step 1: Standardize the original data. First of all, the normal range standardization is adopted for the processing of the original data, that is, Xij is set to represent the original data of the jth performance evaluation index factor level of the ith index.

$$x'_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} (+) \tag{4}$$

$$x'_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} (-) \tag{5}$$

Step 2: The weight Pij of the jth evaluation index in the ith evaluation index value

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{6}$$

Step 3: Entropy value ej of the jth index

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{7}$$

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Where ej≥0, if pij=0, then ej=0.

Step 4: Objective weight wj.

$$w_j = \frac{1-e_j}{\sum_{i=1}^{n}\left(1-e_j\right)} \tag{8}$$

4.4.3 PCGSC performance evaluation index weighting based on AHP

Analytic Hierarchy Process (AHP) was proposed by American operations researcher Professor T.L.saaty. It has developed into a very mature index weighting method. The weight value is represented by wi, and the specific process will not be elaborated. See References [25].

4.4.4 Combination weight determination

In order to solve the influence of a single weight on the final weight and improve the accuracy of the combined weight, this paper introduces a combined weighting model to determine the final weight. That is, the analytic hierarchy process (AHP) and the entropy weight method can calculate the subjective weight and objective weight of PCGSC performance respectively, and combine the subjective and objective weights according to the idea of linear programming, so as to obtain the combined weight of the evaluated indicators.

Step 1: Build the objective function to find α and β

$$\max x_i = \alpha\, w_i + \beta\, w_j \tag{9}$$

$$s.t.\begin{cases}\alpha,\ \beta > 0\\ \alpha^2+\beta^2=1\end{cases} \tag{10}$$

Step 2: Find the combined weight of each indicator

$$w = \alpha\, w_i + \beta\, w_j \tag{11}$$

4.4.5 Proximity calculation

When using the principle of maximum membership for grade evaluation, there are risks such as information loss, resulting in invalid evaluation results. Therefore, according to Zhang Xiaoping's research, the principle of maximum membership degree of association degree can be replaced by asymmetrical degree of closeness [26]. Therefore, according to the existing research, the asymmetric closeness Nj (R0) of the matter element R0 to be evaluated with respect to the PCGSC performance evaluation level j is established as follows:

$$N_j(R_0) = 1 - \frac{1}{n(n+1)}\sum_{i=1}^{n}\rho_j\left(a_i\right)w\left(x\right) \tag{12}$$

$$\rho\left(a_i, b_{jn}\right) = \left|a_i - \frac{a_{jn}+b_{jn}}{2}\right| - \frac{b_{jn}-a_{jn}}{2} \tag{13}$$

In the formula: N is the degree of closeness, ρj(ai) is the distance between the matter-element to be evaluated and the classical domain, w(x) is the combined weight of the evaluated indicators, and n is the number of evaluation indicators.

4.4.6 Rating

The formula for calculating the performance evaluation level j0 of the matter element RO to be evaluated is as follows:

$$N_{j0}(R_0) = \max\left\{N_j(R_0)\right\} \tag{14}$$

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$$\overline{N}_j(R_0)=\frac{N_j(R_0)-\min N_j(R_0)}{\max N_j(R_0)-\min N_j(R_0)} \tag{15}$$

then

$$j^*=\frac{\sum_{j=1}^{m} j\overline{N}_j(R_0)}{\sum_{j=1}^{m}\overline{N}_j(R_0)} \tag{16}$$

Among them, j* is the eigenvalue of the grade variable of the PCGSC matter-element R0 to be evaluated, which can be used to judge the degree to which the matter-element to be evaluated is biased towards adjacent grades.

5. Empirical Analysis

5.1 Project Overview

The city real estate project was won by a China Construction Bureau, and the planned assembly rate of the project exceeded 56%. The basement is a frame structure, the main part is a fabricated shear wall structure, and the PC components mainly include PC exterior wall panels, PC balconies, PC stairs, PC laminated panels, PC interior wall panels, etc. According to the PCGSC performance evaluation system established in this paper and the extension model is used to evaluate the PCGSC performance of the project.

5.2 Data sources

For quantitative indicators, the PCGSC formed by the prefabricated project was selected for the article through interviews, telephone inquiries, project reports, etc., and the real data of upstream, mid-stream and downstream enterprises were used as the data for the corresponding quantitative indicators; for qualitative indicators, Using the expert assignment method, invite experts to participate in the project, use the 10-point scoring method to score them, and collect the scoring data. For the qualitative index data and the data collected by the expert assignment method, the conventional data range standardization process is carried out, see formula (4) and formula (5), and the final data obtained is the sample score.

5.3 PCGSC Performance Extension Evaluation

Table 3: Performance evaluation index classification and sample value

Evaluation indicators	performance rating					Sample Score
	I	II	III	IV	V	
X11	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	8.35
X12	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.65
X13	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.75
X14	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.55
X15	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.3
X21	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	6.75
X22	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.9
X23	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.55
X24	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.75
X25	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.3
X31	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.6
X32	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.95
X33	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	8.4
X34	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	8.1
X35	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	8.05
X41	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.45
X42	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	8.3
X43	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	8.15
X44	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.4
X45	[0,2)	[2,4)	[4,6)	[6,8)	[8,10]	7.6

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The classical domain matrix Rj (j=1, 2, 3, 4, 5) can be determined by taking the grade range of the performance indicators of grades I to V, and the matter-element matrix R0 to be evaluated is determined according to the full range of the performance grade and the node domain matrix Rp according to Table 3.

$$R_1 = \begin{bmatrix} R_1 & X_{11} & [0,0.2) \\ & X_{12} & [0,0.2) \\ & \vdots & \vdots \\ & X_{45} & [0,0.2) \\ & X_{46} & [0,0.2) \end{bmatrix} R_2 = \begin{bmatrix} R_2 & X_{11} & [0.2,0.4) \\ & X_{12} & [0.2,0.4) \\ & \vdots & \vdots \\ & X_{45} & [0.2,0.4) \\ & X_{46} & [0.2,0.4) \end{bmatrix} R_3 = \begin{bmatrix} R_3 & X_{11} & [0.4,0.6) \\ & X_{12} & [0.4,0.6) \\ & \vdots & \vdots \\ & X_{45} & [0.4,0.6) \\ & X_{46} & [0.4,0.6) \end{bmatrix}$$

$$R_4 = \begin{bmatrix} R_4 & X_{11} & [0.6,0.8) \\ & X_{12} & [0.6,0.8) \\ & \vdots & \vdots \\ & X_{45} & [0.6,0.8) \\ & X_{46} & [0.6,0.8) \end{bmatrix} R_5 = \begin{bmatrix} R_5 & X_{11} & [0.8,1) \\ & X_{12} & [0.8,1) \\ & \vdots & \vdots \\ & X_{45} & [0.8,1) \\ & X_{46} & [0.8,1) \end{bmatrix} R_p = \begin{bmatrix} R_p & X_{11} & [0,1) \\ & X_{12} & [0,1) \\ & \vdots & \vdots \\ & X_{45} & [0,1) \\ & X_{46} & [0,1) \end{bmatrix}$$

$$R_0 = \begin{bmatrix} R_0 & X_{11} & 8.35 \\ & X_{12} & 7.65 \\ & \vdots & \vdots \\ & X_{45} & 7.4 \\ & X_{46} & 7.6 \end{bmatrix}$$

5.4 Determine the comprehensive weight of evaluation indicators

Table 4: Rank distances and index weights

ρj(ai)	j=1	j=2	j=3	j=4	j=5	w
i=11	6.35	4.35	2.35	0.35	-0.35	0.224
i=12	5.65	3.65	1.65	-0.35	0.35	0.166
i=13	5.75	3.75	1.75	-0.25	0.25	0.179
i=14	5.55	3.55	1.55	-0.45	0.45	0.193
i=15	5.3	3.3	1.3	-0.7	0.7	0.238
i=21	4.75	2.75	0.75	-0.75	1.25	0.203
i=22	5.9	3.9	1.9	-0.1	0.1	0.171
i=23	5.55	3.55	1.55	-0.45	0.45	0.208
i=24	5.75	3.75	1.75	-0.25	0.25	0.248
i=25	5.3	3.3	1.3	-0.7	0.7	0.196
i=31	5.6	3.6	1.6	-0.4	0.4	0.188
i=32	5.95	3.95	1.95	-0.05	0.05	0.188
i=33	6.4	4.4	2.4	0.4	-0.4	0.210
i=34	6.1	4.1	2.1	0.1	-0.1	0.172
i=35	6.05	4.05	2.05	0.05	-0.05	0.243
i=41	5.45	3.45	1.45	-0.55	0.55	0.184
i=42	6.3	4.3	2.3	0.3	-0.3	0.150
i=43	6.15	4.15	2.15	0.15	-0.15	0.253
i=44	5.4	3.4	1.4	-0.6	0.6	0.204
i=45	5.6	3.6	1.6	-0.4	0.4	0.203

Since the listed individual evaluation indicators involve commercial secrets or some indicators are not easy to quantify, when the entropy weight method and AHP are used to calculate the weight factors of the combined indicators, an expert group is formed by inviting technical experts, supply chain management experts and university scholars to participate in the project. Score on a ten-point scale. Specifically, 4 technical experts in the field of prefabricated engineering, 3 prefabricated supply chain management experts and 3 university scholars are invited. The weights determined by the two weighting methods are shown in Table 4.

5.5 Determine indicator closeness

According to the classical domain matrix and the matter-element matrix to be evaluated, the rank distance can be calculated according to formula (15). See Table 4 for details. According to formulas (14) and (16), the asymmetric closeness of the grade to be evaluated can be calculated, and the characteristic value j* of the grade variable can be calculated according to formulas (17) and (18). See Table 5 for details.

Table 5: Rank closeness and eigenvalues of rank variables

performance	closeness of each level					j*
R0	I	II	III	IV	V	
	9.9450	9.9642	9.9833	10.9332	9.9975	3.9781

5.6 Analysis of PCGSC Performance Evaluation Results

From the level of closeness and the eigenvalue of the level variable j*=3.9781>3.5, it can be seen that the performance evaluation level of the green supply chain of the prefabricated project is level IV, which is a good state, and the degree of bias towards level V is large. It shows that the prefabricated green supply chain has a good performance and can meet the needs of the project well, which is consistent with the actual situation, indicating the validity and scientificity of the established model.

6. Conclusion and Outlook

At this stage, my country's construction industry is in a stage of rapid transformation. The prefabricated Construction conform to the "new development concept" due to the characteristics of standard construction, large-scale manufacturing, and green environmental protection. Therefore, the evaluation of PCGSC performance is in line with the development of the times and in line with "double carbon". The goal is to guide the selection of green supply chain for prefabricated Construction in real production.

(1) Based on the perspective of collaborative innovation, this paper builds the PCGSC performance evaluation system based on the balanced scorecard, and uses the improved matter-element extension model to construct the PCGSC evaluation model for evaluation, which avoids the problem of inaccurate evaluation results.

(2) Through the evaluation of the green supply chain of a prefabricated building through the model established in this paper, it is found that the performance evaluation level of the green supply chain of the project is level IV and the degree of bias towards level V is large, and the evaluation results are scientific, effective and in line with reality.

(3) With the development and improvement of PCGSC from the perspective of collaborative innovation, there may be some differences in its index system in the future, so the performance evaluation method of PCGSC needs to be further studied and discussed in the future.

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