Research on Risk Evaluation of Low-Carbon Supply Chain in Construction Industry Based on Game Theory Combined Weighting-Cloud Model

Tiankai Zhen
School of Management, Shandong University of Technology, Zibo, China

Abstract: The global issue of extreme climate is severe, and the construction industry poses a serious challenge to the environment due to its high energy consumption and high emissions. Against this backdrop, the low-carbon transformation of the construction industry is extremely urgent, and the low-carbon supply chain in the construction industry has become a research hotspot. Based on literature research, 28 key risk factors in different stages of the low-carbon supply chain in the construction industry are identified, and a risk evaluation index system is established accordingly. A risk evaluation model for the low-carbon supply chain in the construction industry is established through the method of game theory combination weighting - cloud model. Taking G Construction Company as the case background, a comprehensive analysis of the overall low-carbon level and risks of its low-carbon supply chain is conducted, and a series of corresponding risk control countermeasures are proposed to verify the effectiveness and scientificity of the evaluation model, which has certain theoretical and practical significance for the low-carbon transformation of the construction industry.

Keywords: Low-Carbon Supply Chain; Game Theory; Cloud Model; Risk Assessment; Risk Management

1. Introduction

The problem of global climate change continues to intensify, and the negative impact of climate change has gradually emerged. Extreme climate events occur frequently, which seriously threaten the stability of the global ecosystem and human survival security. In order to deal with climate change, a wave of carbon emission reduction has been set off worldwide. With the advancement of urbanization, the construction industry has developed rapidly, but at the same time, it also poses severe challenges to the environment due to high energy consumption and high emissions. As one of the main sources of global energy consumption and carbon emissions, the low-carbon transformation of the construction industry is imminent. The next development trend of the construction industry will be comprehensive low-carbon transformation and sustainable development. If construction enterprises want to achieve long-term sustainable development, the internal driving force for maintaining smooth operation is low-carbon core competitiveness, making the decarbonization of its supply chain a critical goal for sustainable development[1]. Therefore, introducing the concept of low-carbon into the construction supply chain and discussing the construction of the construction industry's low-carbon supply chain and the evaluation of its low-carbon level can not only identify potential problems, but also provide the basis for formulating coping strategies, which is of great significance for promoting the low-carbon transformation of the construction industry.

2. Risk Factor Identification and Index System Construction

Based on the existing literature, expert opinions and the actual situation in China, this paper takes each link of the construction supply chain as the starting point, and comprehensively summarizes the risk factors of the low-carbon supply chain in the construction industry from the five aspects of planning and design, procurement and transportation, construction, recycling and supply chain coordination, and establishes the evaluation index system, so as to make a scientific, detailed, real and objective evaluation of the low-carbon level of the construction supply chain.

2.1 Planning and Designing Low Carbon Risk

The design and planning phase is a crucial step in determining the carbon emissions throughout the entire lifecycle of a project. This stage is mainly to clarify user needs and project positioning, complete site, economic and regulatory analysis, output feasibility reports, and translate requirements into technical solutions, including concept, system deepening and construction drawing design. The use of tax incentives refers to whether the tax incentives and subsidies related to low-carbon buildings are fully utilized. Compliance with regulations can reflect whether the project conforms to the latest low-carbon building regulations, standards and policies. Environmental protection goal setting refers to whether a clear environmental protection and low-carbon goal has been set and the implementation plan has been made, which is an important prerequisite for effectively controlling the low-carbon level of the supply chain. The low-carbon behavior and characteristics of partners will significantly affect the overall low-carbon level of the construction supply chain. The selection of supply chain partners can determine the upper limit of low-carbon risk control in the supply chain to a certain extent. Residential energy consumption is mainly to provide various services necessary for social life tasks such as heating, cooling and lighting [2]. Energy saving design refers to whether the energy-saving design such as thermal insulation, ventilation and lighting of buildings is in place, which is also the main influencing factor to determine the carbon emission level of buildings in the design stage. The low-carbon interactive design mechanism injects the low-carbon concept through the joint participation of the upstream and downstream entities of the supply chain in the design process, reducing unnecessary design changes, thereby affecting the low-carbon level of the construction supply chain.

2.2 Procurement and Transportation Low Carbon Risk

Procurement and transportation are the stages of controlling implicit carbon emissions, and systematic strategies can be implemented from three aspects: material selection, transportation optimization, and supply chain management. In the procurement and transportation phase, it is necessary to make plans, select suppliers and determine the transportation mode and route to ensure the timely, safe and compliant supply of materials. Low carbon certification refers to whether the supplier has low-carbon product certification or relevant environmental protection qualification. If the supplier does not have relevant qualification certification, it may seriously affect the low-carbon level of the supply chain. Quality control refers to the inspection of suppliers' quality management system and product quality. Cost benefit analysis refers to the benefit analysis of procurement costs to ensure the optimal cost performance. These two can indirectly determine the low-carbon capacity and stability of the supply chain. Low carbon materials refer to the selection of low-carbon, environmental friendly and renewable building materials. In order to save cost and sustainability, the focus is to reduce materials[3]. Low carbon transportation monitoring refers to the selection of low-carbon and environmental protection transportation mode, and the monitoring and recording of carbon emissions during transportation, so as to provide the basis for controlling the low-carbon level. Joint supply chain distribution refers to the rational planning of routes and distribution methods according to the actual needs of upstream and downstream enterprises and the actual inventory situation of suppliers, so as to reduce the phenomenon of no-load and circuitous distribution of distribution tools and reduce the carbon emission level during transportation.

2.3 Construction Low Carbon Risk

To achieve low-carbon goals in the construction phase of the construction industry, systematic measures need to be taken from multiple dimensions such as construction process optimization, resource recycling, and energy management. The construction stage includes construction preparation, foundation construction, main structure construction, decoration and equipment installation, completion acceptance and other contents, so as to ensure that the project is delivered on time according to quality. The formulation of low-carbon construction scheme refers to the formulation of a detailed low-carbon construction plan to ensure that the process is low-carbon and the construction schedule is controllable. Construction resource allocation refers to rational allocation of construction resources, improvement of construction efficiency and reduction of resource waste. Higher cost efficiency and resource allocation efficiency can be achieved by optimizing resource allocation[4]. Energy saving measures refer to taking energy-saving measures to reduce energy consumption and waste, such as using energy-saving equipment, optimizing construction process, etc. To a large extent, buildings cause climate change and other environmental hazards through resource utilization[5]. The energy and resource utilization efficiency of the construction process can be evaluated and improved through energy and resource utilization efficiency evaluation. Low carbon inspection during construction refers to the low-carbon level of the construction supply chain affected by the relevant parties of the construction supply chain through the development of low-carbon assessment standards and continuous follow-up.

2.4 Recycling Low Carbon Risk

The recycling of construction and demolition waste is an important means to curb environmental degradation[6].The main content of this stage is to identify and register waste materials, classify and collect recyclable (bricks, steel, etc.), recyclable (metals, plastics, etc.), hazardous waste and ordinary waste, develop transportation plans, clean, repair and reuse or hand over to professional institutions for treatment. Recycling is a key strategy to reduce the environmental impact related to the use of industrial resources[7]. The development of a detailed material recycling plan can ensure that the recovery rate reaches the standard and control the low-carbon risk in the recycling phase of construction projects. The ratio of surplus materials in the supply chain refers to the ratio of surplus unused materials in the supply chain to the total amount of materials supplied by suppliers, which reflects the utilization degree of materials in the construction supply chain. The recovery ratio of surplus materials in the supply chain refers to the proportion of surplus materials recycled and re invested in construction projects to the total amount of surplus materials in the supply chain. Harmless treatment of waste refers to taking harmless treatment measures for non recyclable waste, while recycling of waste refers to converting recyclable waste into construction materials and putting them back into construction projects to improve resource utilization.

2.5 Supply Chain Collaboration Low Carbon Risk

The escalating climate change stimulates supply chain companies to innovate low-carbon technologies[8]. The significance of low-carbon supply chain collaboration lies in integrating suppliers and partners to low-carbon strategies, coordinating low-carbon processes, reducing carbon in all links from design, procurement, construction to recycling, strengthening information sharing and process interoperability, sharing risks and resources, and achieving cost reduction and efficiency improvement in the whole chain. Establishing an information sharing platform to realize information sharing among the nodes of the supply chain can effectively respond to low-carbon risk challenges. Under non extreme conditions, it is always beneficial for enterprises to choose to share information on the platform[9]. The low-carbon risk sharing mechanism is a cooperation framework aimed at promoting the R&D and application of low-carbon technologies and reducing related risks, helping enterprises to clarify the risk responsibilities of each node and promoting multiple parties in the supply chain to share risks. Establishing a risk early warning system and maintaining the update frequency of information can ensure the timeliness and accuracy of information, and timely discover and respond to potential risks. Collaborative process optimization and collaborative resource allocation refer to the optimization of collaborative processes, the rational allocation of collaborative resources, and the improvement of collaboration efficiency to ensure the smooth progress of supply chain collaboration.

2.6 Construction of Low Carbon Supply Chain Risk Evaluation Index System

Build a low-carbon supply chain risk evaluation index system for the five aspects and 28 impact indicators identified above, and build a reasonable low-carbon supply chain risk evaluation index system for the construction industry, as shown in Table 1.

Table 1. Construction Industry Low Carbon Supply Chain Risk Evaluation Index System A

Target layer	Criterion layer	Index layer
Risk evaluation index system of low carbon supply chain in construction industry	Planning and designing low carbon risk A_1	Tax preference utilization A_{11} Regulatory compliance A_{12} Environmental protection goal setting A_{13} Supply chain partner selection A_{14} Energy saving design A_{15} Low carbon interaction design mechanism A_{16}
	Procurement and recycling low carbon risk A_2	Low carbon certification A_{21} Quality control A_{22} Cost benefit analysis A_{23} Material low carbon A_{24} Low carbon transport monitoring A_{25} Supply chain joint distribution A_{26}
	Construction low carbon risk A_3	Development of low carbon construction scheme A_{31} Construction resource allocation A_{32} Energy saving measures A_{33} Energy and resource utilization efficiency assessment A_{34} Low carbon inspection during construction A_{35}
	Recycling low carbon risk A_4	Material recovery plan A_{41} Supply chain surplus material ratio A_{42} Supply chain residual material recovery ratio A_{43} Waste recycling A_{44} Harmless treatment of waste A_{45}
	Supply chain collaboration low carbon risk A_5	Low carbon information sharing platform A_{51} Low carbon risk sharing mechanism A_{52} Information update frequency A_{53} Risk early warning system A_{54} Collaborative process optimization A_{55} Collaborative resource allocation A_{56}

3. Risk Assessment Model of Low Carbon Supply Chain in Construction Industry

3.1 Grey Relational Analysis

Grey Relational Analysis (GRA) measures whether the relationship between two vectors is close through mathematical methods. Each index has different roles in the comprehensive evaluation, so the weight value is different. The main steps of determining the weight by grey correlation analysis are as follows.

(1) Establish evaluation index system

(2) Collect data and build sample matrix

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \# \qquad (1)$$

$$(i = 1,2, \ldots n, j = 1,2, \ldots m)$$

Where: X_{ij} is the evaluation value of the jth index under the ith evaluation object.

(3) Dimensionless data processing

For dimensionless processing of data, the average method is adopted here, and the calculation formula is:

$$x_{ij} = \frac{x_{ij}}{\overline{x_j}} \# \qquad (2)$$

(4) Determine reference sequence

The reference sequence refers to the standard value, and the maximum value of the sample data is taken as the reference sequence value.

(5) Calculate correlation coefficient

$$\zeta_i(k) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \rho \cdot \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \cdot \max_i \max_k |x_0(k) - x_i(k)|} \# (3)$$

Where: $|X_{0j}-X_{ij}|$ is the absolute value of the difference between each sequence and the reference sequence, $\max_i \max_j |X_{0j}-X_{ij}|$ is the maximum value of the range, $\min_i \min_j |X_{0j}-X_{ij}|$ is the minimum value of the range, and is the resolution coefficient (usually 0.5).

(6) Calculate correlation

Calculate the average value of the correlation coefficient of each index to obtain the correlation degree of the index. The calculation formula is:

$$\gamma_j = \frac{1}{n} \sum_{i=1}^{m} \xi_{ij}, (j = 1,2, \cdots, n) \# \qquad (4)$$

(7) Calculate index weight

The proportion of the correlation degree of each indicator in the sum of the correlation degrees of all indicators is the weight value of each indicator. The calculation formula is:

$$\omega_j = \frac{\gamma_j}{\sum_{j=1}^{m} \gamma_j} \# \quad (5)$$

3.2 Best Worst Method

The Best Worst Method (BWM) was proposed by Rezaei J in 2015[10]. Experts (decision makers) select the best and the most important indicators and the worst and the least important indicators according to experience and actual needs of the project, and then compare the optimal indicators with other indicators in turn, and the other indicators with the worst indicators. The main steps of determining the weight by the best worst method are as follows.

(1) Establish index system

(2) Determine the best and worst indicators

BO indicates the relative importance of "the best indicator and each indicator", and OW indicates the relative importance of "each indicator and the worst indicator".

(3) Determine the relative importance of the optimal indicator and other indicators

c_{Bj} is used to indicate the importance of the optimal index relative to index j(j=1,2,⋯,n) , which is assigned as an integer between 1 and 9, and a comparison matrix $C_B = (c_{B1}, c_{B2}, \cdots, c_{Bn})$ is established. N is used to indicate the number of indicators.

(4) Determine the relative importance of the worst indicator and other indicators

Similarly, c_{Wj} is used to indicate that the importance of the worst indicator relative to indicator j(j=1,2,⋯,n) is assigned an integer between 1 and 9, and a comparison matrix $c_B=(c_{W1}, c_{W2}, \cdots, c_{Wn})$ is established.

(5) Solving the optimal index weight

The mathematical expression for solving the programming is:

$$min\epsilon \# (6)$$

$$S.t\begin{cases} \left|\frac{W_{best}}{W_j} - c_{Bj}\right| \le \epsilon \\ \left|\frac{W_j}{W_{worst}} - c_{Wj}\right| \le \epsilon \\ \sum_{j=1}^{n} W_j = 1 \\ W_j \ge 0 \quad j = 1,2,\cdots,n \end{cases} \# \quad (7)$$

Where: W_{best} represents the weight of the best indicator, W_{worst} represents the weight of the worst indicator, W_j represents the weight of an indicator, c_{Bj} represents the data of the jth indicator BO, c_{Wj} represents the data of the jth indicator OW, and ϵ represents the error.

3.3 Combination Weighting in Game Theory

The basic idea of combined weights in game theory is to find consistency and compromise for different weights of a certain evaluation index, and minimize the deviation between the possible weights and the basic weights.

(1) A total of L methods were used to determine the weights of N indicators:

$$\boldsymbol{\omega}_l = (\omega_{l1}, \omega_{l2}, \cdots, \omega_{ln}), l = 1,2,\cdots,L \# \quad (8)$$

Then the linear combination of L weight vectors can be expressed as:

$$\boldsymbol{\omega} = \sum_{l=1}^{L} \alpha_l \boldsymbol{\omega}_l^T (\alpha_l > 0) \# \quad (9)$$

Where: $\boldsymbol{\omega}$ is the combination weight vector and α_l is the linear combination coefficient.

(2) Based on the combination principle of game theory, the deviation between $\boldsymbol{\omega}$ and $\boldsymbol{\omega}_l$ is minimized, and the objective function is:

$$min\| \sum_{l=1}^{L} \alpha_l \boldsymbol{\omega}_l^T - \boldsymbol{\omega}_p^T \|_2, p = 1,2,\cdots,L \# (10)$$

(3) According to the matrix differential properties, the optimal first derivative condition of the above formula is:

$$\sum_{l=1}^{L} \alpha_l \boldsymbol{\omega}_p \boldsymbol{\omega}_l^T = \boldsymbol{\omega}_p \boldsymbol{\omega}_p^T, (p = 1,2,\cdots,L) \# (11)$$

The system of linear equations equivalent to the above formula is:

$$\begin{bmatrix} \boldsymbol{\omega}_1\boldsymbol{\omega}_1^T & \boldsymbol{\omega}_1\boldsymbol{\omega}_2^T & \cdots & \boldsymbol{\omega}_1\boldsymbol{\omega}_L^T \\ \boldsymbol{\omega}_2\boldsymbol{\omega}_1^T & \boldsymbol{\omega}_2\boldsymbol{\omega}_2^T & \cdots & \boldsymbol{\omega}_2\boldsymbol{\omega}_L^T \\ \vdots & \vdots & \vdots & \vdots \\ \boldsymbol{\omega}_L\boldsymbol{\omega}_1^T & \boldsymbol{\omega}_L\boldsymbol{\omega}_2^T & \cdots & \boldsymbol{\omega}_L\boldsymbol{\omega}_L^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_L \end{bmatrix} = \begin{bmatrix} \boldsymbol{\omega}_1\boldsymbol{\omega}_1^T \\ \boldsymbol{\omega}_2\boldsymbol{\omega}_2^T \\ \vdots \\ \boldsymbol{\omega}_L\boldsymbol{\omega}_L^T \end{bmatrix} \# (12)$$

(4) Solve the linear equations of the above formula to obtain the optimized combination coefficient a, and normalize it. Considering that there may be negative numbers in the optimized combination coefficient, the absolute value of the coefficient should be calculated before normalization.

$$\alpha_l^* = |\alpha_l| / \sum_{l=1}^{L} |\alpha_l| \# \quad (13)$$

(5) Calculate the combination weight:

$$\boldsymbol{\omega}^* = \sum_{l=1}^{L} \alpha_l^* \boldsymbol{\omega}_l^T, (l = 1,2,\cdots,L) \# \quad (14)$$

3.4 Cloud Model

The cloud model uses subordinate clouds, digital features and cloud generators to handle the uncertainty conversion between qualitative concepts and their quantitative descriptions. At present, it has been widely used in many fields, such as reliability assessment and emergency path selection. The specific implementation process is as follows[11-12].

(1) Establish comment set

On the premise of referring to the risk level division, this evaluation model aims to make the expert score have a relatively uniform standard

The risk level of low-carbon supply chain in the construction industry is divided into five levels according to the 0-100 score system, as shown in table 2. Where, [Cmin,Cmax] is the upper and lower bounds of the corresponding grade of each risk assessment interval.

Table 2. Risk Classification Table of Low Carbon Supply Chain in Construction Industry

Risk level	I	II	III	IV	V
State	Lower	Low	Commonly	High	Higher
[Cmin, Cmax]	[0, 25)	[25, 50)	[50, 75)	[75, 90)	[90, 100]

(2) Determine evaluation criteria cloud

The digital eigenvalue of the standard cloud corresponding to the ith comment interval $[x_i^{min}, x_i^{max}]$ is (Ex_i, En_i, He), and the calculation formula is:

$$\begin{cases} Ex_i = \left(x_i^{max} + x_i^{min}\right)/2 \\ En_i = \left(x_i^{max} - x_i^{min}\right)/6 \, \# \\ He = k \end{cases} \quad (15)$$

Where: k is a constant, which can be adjusted according to the actual situation, and the evaluation model is taken as 0.5.

(3) Cloud generator

Cloud model mainly uses cloud generator to establish the mapping relationship between qualitative and quantitative.

1) The positive cloud generator inputs the numerical feature (Ex ,En ,He) and the number of cloud droplets N, and outputs the normal cloud formed by N cloud droplets, as shown in Figure 1.

① Generate a normal random number x_i=G(Ex,En) with Ex as the expected value and En as the standard deviation;

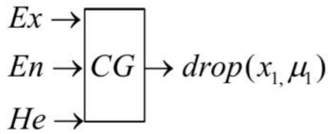

Figure 1. Forward Cloud Generator

② Generate a normal random number En'=G(En,He) with En as the expected value and He as the standard deviation;

③Calculate membership:

$$\mu_i = exp\left(-\frac{(x_i - Ex)^2}{2En'^2}\right) \quad (16)$$

④ Repeat ① to ③ until N cloud drops are generated.

2) Reverse cloud generator input: N cloud droplets x_i(i=1,2,...,n) ; output: numerical characteristic estimation value (Ex ,En ,He), as shown in Figure 2.

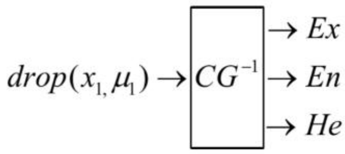

Figure 2. Backward Cloud Generator

(3) Determine index evaluation cloud

Collect the questionnaire of experts' Evaluation on indicators. Each column corresponds to an indicator, and each row corresponds to an expert to obtain the evaluation matrix. Assuming that there are I experts and j indicators, the dimension of the evaluation matrix Z is i × j, and the evaluation matrix is expressed as follows, where z_{ij} represents the evaluation value of expert i on indicator j.

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1j} \\ z_{21} & z_{22} & \cdots & z_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ z_{i1} & z_{i2} & \cdots & z_{ij} \end{bmatrix} \# \quad (17)$$

Then, the reverse cloud generator is used to calculate the digital feature $C_j(Ex_j, En_j, He_j)$ of the scoring results of all experts under each index, and the mathematical expression of its solution function is:

$$\begin{cases} Ex_j = \frac{1}{N}\sum_{i=1}^{N} z_{ij} \\ En_j = \sqrt{\frac{\pi}{2}} \times \frac{1}{N}\sum_{i=1}^{N} \left|z_{ij} - Ex_j\right| \\ S_j^2 = \frac{1}{N-1}\sum_{i=1}^{N} \left(z_{ij} - Ex_j\right)^2 \\ He_j = \sqrt{\left|S_j^2 - En_j^2\right|} \end{cases} \# \quad (18)$$

(4) Computing comprehensive evaluation cloud

The digital characteristics of the comprehensive evaluation cloud can be calculated by combining the index weight ω_j with the following formula:

$$\begin{cases} Ex = \sum_{j=1}^{n} \left(Ex_j \cdot w_j\right) \\ En = \sqrt{\sum_{j=1}^{n} \left(En_j^2 \cdot w_j\right)} \\ He = \sum_{j=1}^{n} \left(He_j \cdot w_j\right) \end{cases} \tag{19}$$

(5) Determination of risk assessment results

Draw the standard cloud chart and comprehensive evaluation cloud chart, and determine which rating of the comprehensive evaluation cloud chart is in the evaluation set based on the comparison between the comprehensive evaluation cloud chart and the standard cloud chart.

4. Case analysis

In order to verify the effectiveness of the selected model, G construction company was selected as an example for analysis, and 10 experts in related fields were invited to use the importance score of 10 points and the 1-9 scale method to score the weight of the indicators in the risk factors of its low-carbon supply chain. The weight of the indicators was calculated by the grey correlation method and the best worst method, and then combined with the game theory method to obtain the comprehensive index weight of the primary and secondary indicators.

4.1 Determining Index Weight by Game Theory

(1)Calculation of index weight by GRA

The weight of each risk index is assigned by the expert scoring method (10 points are important, and the more important the index is, the higher the score is). After constructing the sample matrix, the calculation results of the index weight of the grey correlation method can be obtained by using equations (1) to (4).

(2)Calculation of index weight by BWM

Through the expert scoring method (1-9 scale method, the larger the value, the more important the former is relative to the latter), the weight of each risk index is assigned, the judgment matrix of BO and OW is constructed, and the matrix is substituted into the excel solver to calculate the weight of the first level index of the best worst method according to equations (5) to (6).

(3)Game theory combined weighting to calculate the comprehensive weight of indicators

According to the index weights obtained by the grey correlation method and the best worst method, the two groups of weights are weighted by the combination of game theory methods according to equations (7) to (13), and the final comprehensive weights of each index are shown in Table 3.

Table 3. Weight of Risk Evaluation Index for Low Carbon Supply Chain in Construction Industry of Company G

Criterion layer	weight	Index layer	Absolute weight	Relative weight
A_1	0.1870	A_{11}	0.1562	0.0292
		A_{12}	0.1257	0.0235
		A_{13}	0.2107	0.0394
		A_{14}	0.1736	0.0325
		A_{15}	0.1683	0.0315
		A_{16}	0.1654	0.0309
A_2	0.2093	A_{21}	0.1919	0.0402
		A_{22}	0.1706	0.0357
		A_{23}	0.1256	0.0263
		A_{24}	0.1456	0.0305
		A_{25}	0.1816	0.0380
		A_{26}	0.1846	0.0386
A_3	0.1784	A_{31}	0.1747	0.0312
		A_{32}	0.2323	0.0414
		A_{33}	0.1640	0.0293
		A_{34}	0.2411	0.0430
		A_{35}	0.1880	0.0335
A_4	0.1575	A_{41}	0.1888	0.0297
		A_{42}	0.1508	0.0238
		A_{43}	0.2126	0.0335
		A_{44}	0.2633	0.0415
		A_{45}	0.1845	0.0291
A_5	0.2678	A_{51}	0.1662	0.0445
		A_{52}	0.1983	0.0531
		A_{53}	0.1725	0.0462
		A_{54}	0.2081	0.0557
		A_{55}	0.0869	0.0233
		A_{56}	0.1680	0.0450

4.2 Cloud Model Risk Assessment

Ten experts and experienced persons were invited to score the 28 risk indicators.

(1) Determine evaluation criteria cloud

Calculate the characteristic values of each parameter of the standard cloud according to the established comment set and equation (14).As shown in Table 4.

Table 4. Characteristic Values of Standard Cloud Parameters

Risk status	interval	Ex	En	He
Lower	[0 25)	12.5	4.167	0.5
Low	[25, 50)	37.5	4.167	0.5
Commonly	[50, 75)	62.5	4.167	0.5
High	[75, 90)	82.5	2.5	0.5
Higher	[90, 100]	95	1.667	0.5

Using the forward cloud generator, input the five comment sets obtained into Excel software for solution, generate N cloud drops, and draw the standard membership cloud graph. According to experience, n=3000 is set to make the cloud image presented clearer. Finally, the standard subordinate cloud image is obtained. As shown in Figure 3.

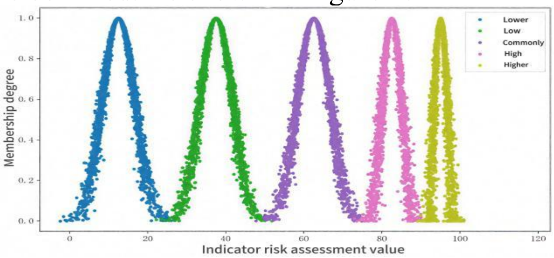

Figure 3. Standard Cloud Chart

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(2)Determine evaluation cloud and comprehensive cloud

After summarizing the results of expert scoring and processing the data through equations (6) to (17), it is concluded that the comprehensive evaluation cloud of G company's construction industry's low-carbon supply chain is (60.633, 2.901, 0.781). See Table 5 for the specific data of the evaluation cloud of each risk index.

(3)Analysis of evaluation results

Due to the large number of secondary indicators and the limited space, we won't go into details here. This article only shows the comprehensive evaluation cloud map of G company's construction industry's low-carbon supply chain.

The comprehensive evaluation cloud chart is obtained by superimposing the standard cloud and G company's construction industry low-carbon supply chain risk assessment cloud, as shown in Figure 4

Table 5. Evaluate Cloud Parameters

index	Ex	En	He
A_{11}	39.8	3.259	0.814
A_{12}	47.8	3.259	1.156
A_{13}	71.9	2.657	0.772
A_{14}	80.8	2.757	0.758
A_{15}	74.5	2.757	0.947
A_{16}	56	4.261	0.976
A_{21}	68.7	2.456	0.495
A_{22}	38.2	2.356	0.635
A_{23}	37.6	3.66	0.455
A_{24}	70.8	2.757	0.871
A_{25}	41.8	2.256	0.931
A_{26}	62.9	3.158	0.874
A_{31}	83.9	3.158	0.565
A_{32}	81.6	2.958	0.839
A_{33}	76.6	3.008	0.884
A_{34}	34	2.507	0.619
A_{35}	63.3	2.707	1.062
A_{41}	77.8	3.058	0.712
A_{42}	40.9	2.607	0.501
A_{43}	57.8	3.058	0.618
A_{44}	33.3	3.133	0.169
A_{45}	39.2	3.309	0.886
A_{51}	72.1	2.607	1.04
A_{52}	76.6	2.657	0.564
A_{53}	65.8	3.81	1.108
A_{54}	50.1	1.93	1.02
A_{55}	69	2.507	0.619
A_{56}	72.2	2.557	0.867

According to figure 4, the overall comprehensive risk of G company's low-carbon supply chain in the construction industry is a general risk level. The cloud droplets are concentrated in the "general risk" level of the standard cloud chart. According to the similarity between the first level indicator cloud and the standard cloud, the risk level of the first level indicator of G company's construction industry's low-carbon supply chain is ranked from large to small as follows: supply chain collaboration low-carbon risk A_5>construction low-carbon risk A_3>Planning and design low-carbon risk A_1>procurement and transportation low-carbon risk A_2>recycling low-carbon risk A_4. Among the second level indicators, the top three are low-carbon construction scheme formulation A_{31}, construction resource allocation A_{32} and supply chain partner selection A_{14}.

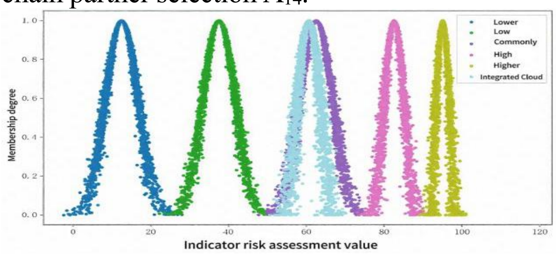

Figure 4. Comprehensive Evaluation Cloud Chart

The risk manager can formulate different management measures for the low-carbon supply chain of the construction industry of company G according to the risk degree of the primary and secondary indicators, so as to achieve the effect of risk control.

(4)Low carbon risk coping strategies

Based on the above evaluation results and the actual situation of G construction company's low-carbon supply chain, the following improvement strategies are proposed:

1) Promote low-carbon building design, maximize resource and energy conservation, and reduce environmental pollution and ecological damage. Considering the low-carbon factors in the process of architectural design, advanced green building design software tools, such as energy consumption simulation and analysis technology, can be used to model the building environment, systems and equipment, and calculate the hourly building energy consumption. Through the calculation results, the architectural design and specific technology are fed back, and optimization strategies are put forward.

2) Improve resource utilization efficiency and optimize construction resource allocation. By using advanced construction technology and equipment to improve the resource utilization efficiency and construction waste utilization rate in the construction process, we can not only reduce carbon emissions, but also save resources. Formulate a detailed low-carbon construction plan, and use clean energy such as solar energy and wind energy to reduce carbon emissions caused by the use of traditional fossil energy, save energy and reduce costs.

3) Select reliable partners and establish long-term cooperative relationships. Select supply chain partners with low-carbon and environmental protection awareness, strictly screen and evaluate them, inspect their production capacity, quality management system and supply capacity, and jointly promote the development of low-carbon buildings.

4) Establish a risk assessment and management mechanism. Comprehensively assess the low-carbon risks in the supply chain, use professional risk assessment tools and methods, effectively identify and analyze the potential risks in the supply chain, and take corresponding prevention and control measures. For the possible low-carbon risks, formulate emergency plans, clarify the response measures and division of responsibilities, and ensure rapid response and disposal when the risks occur.

5. Conclusion

This paper constructs a low-carbon supply chain risk assessment model of construction industry based on the combination weighting cloud model of game theory, and applies it in a specific enterprise g construction company to verify its practicability. The conclusions are as follows.

(1) Combining the weights of indicators obtained by GRA and BWM through game theory can effectively reduce the impact of subjective factors on weights. From the weight, it can be seen that supply chain collaboration low-carbon risk A_5 has the greatest impact on the low-carbon supply chain risk of the construction industry, and the degree of impact is in the order of supply chain collaboration low-carbon risk A_5>procurement and transportation low-carbon risk A_2>Planning and design low-carbon risk A_1>construction low-carbon risk A_3>recycling low-carbon risk A_4.

(2) According to the evaluation results of the game theory combination weighting cloud model method, the risk level of G construction company's construction industry's low-carbon supply chain is "general risk", and the cloud drops show a high degree of concentration in the comprehensive evaluation cloud chart, without obvious fluctuation, and the evaluation results have high reliability.

(3) Aiming at the index risk degree of G construction company's low-carbon supply chain risk assessment in the construction industry, this paper puts forward four risk coping strategies, including promoting low-carbon building design, selecting reliable partners, and establishing risk assessment and management mechanism, which improves the ability of G construction company to deal with low-carbon risks and provides a reference for the risk management of low-carbon supply chain in the construction industry.

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