Evaluation Model of Building Materials Suppliers Considering Carbon Emissions

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Abstract. In the study of AHP and grey relational degree model, this paper establishes four secondary indicators such as product competitiveness, enterprise performance, enterprise cooperation ability, enterprise environmental assessment and twelve tertiary indicators. Then the weight index system is determined by using the analytic hierarchy process, and the warrants of environmental assessment are added considering carbon emissions and other factors. Last the grey correlation analysis is used to determine the supplier correlation. In this paper, the mathematical model is used to carry out an example analysis, so as to evaluate suppliers, and then select low-carbon, economic, high-quality suppliers.

1. Introduction

With the rapid economic development of nations across the globe, there is proportionate increment in corresponding carbon footprint [1].With popularity of carbon footprint and an increase in the customers' environmental protection awareness, the customer, who purchases a product, pays attention to the carbon emissions of the product except for the price, i.e., carbon emissions-sensitive customer [2]. As a key emission industry, building materials should use market mechanism to promote the green transformation of building materials enterprises, so as to further optimize the industrial structure.

Building supply chains include a diverse range of actors - such as clients, users, investors, designers, contractors, sub-contractors, suppliers and manufacturers - that are usually involved sequentially in the project process [3]. Developing low carbon economy also challenges the supply chain management [4]. The supplier is at the source of the supply chain, and establishes the supplier evaluation and selection model, so as to improve customer satisfaction, save transaction costs and reduce cycle time. The combination of AHP method and grey relational analysis can better solve the problem that evaluation index is difficult to deal with. Based on the selection of traditional building materials suppliers, this paper takes carbon emissions as one of the important considerations, and then selects the environmental friendly suppliers.

2. Evaluation model of building materials suppliers

2.1. Establish material supplier evaluation index system

Literature emphasizes the importance of quality, product price, delivery time and other factors when constructing indicators. In addition to these factors, this paper also takes carbon emissions into account, and establishes a more comprehensive evaluation index. To guide future research considering the

relationship between SCO variables and supply chain performance outcomes, research is required which identifies the SCO variables which have the greatest impact on these external performance measures [5]. Considering the above basic principles, and a series of understanding and analysis of building materials suppliers, combined with the relevant papers of other domestic scholars, the evaluation index system of building materials suppliers as shown in Table 1 is established.

Table 1. Evaluation index system of building material suppliers

First grade index	Second grade index	third grade index	Measure method
selection of suppliers A	product competitiveness B1	Quality C11 Price C12 Delivery C13	product percent of pass product price order to delivery time
	enterprise performance B2	financial position C21 corporate earning C22 production flexibility C23 production scale C24	asset-liability ratio expert scoring expert scoring enterprise market share
	enterprise cooperation ability B3	information share C31 cooperation compatibility C32	expert scoring expert scoring
	evaluation of enterprise environment B4	sociocultural environment C41 environmental impact of carbon emissions C42 economic and technological environment C43	expert scoring carbon emission expert scoring

2.2. Use AHP method to determine index weight.

2.2.1. Establishing a hierarchical structure model. Taking the supplier selection as the decision-making goal, the target layer A for the selection of building material suppliers is formed. The four main factors, namely product competitiveness, enterprise performance, enterprise cooperation ability and enterprise environmental assessment, are considered as the standard layer B, and the sub-standard layer C is established according to the actual situation.

2.2.2. Constructing comparison judgement matrix. Compare each other and set up a matrix to determine the weights between various levels. In contrast, according to the relative scale, the difficulty of comparison between various factors can be reduced as much as possible. According to the analytic hierarchy process (AHP), the factors at each level are compared to determine their importance until they are compared to the first-class indicators.

The important comparison score is determined according to the 1~9 scale (see the Table 2).n×n Weight ratio constitution comparison judgement matrix, set $A = (a_{ij})n \times n,\ a_{ij} > 0,\ aij = 1.$

Table 2. Relative comparison scale

Ci and CJ comparison scale aij	Equal important		More important		important		Very important		Absolutely important
	1		3		5		7		9
		2		4		6		8	

2.2.3. Calculate the weight of each index under each criterion level. Summation method and root-square method are commonly used to calculate the relative importance of indicators. The root-square method is more suitable for the evaluation and selection of building materials suppliers. The formula is $W_i = (\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}} / \sum_{i=1}^{n} (\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}, i = 1,2, \dots, n.$

2.2.4. Evaluation of consistency under single criteria. The matrix element satisfies $a_{ij} \times a_{jk} = a_{jk}$ is the guarantee of matrix consistency checking. At the same time, in order to ensure the deviation consistency of the matrix within a reasonable range, it is necessary to judge the consistency index C_i of the matrix according to the formula $C_i = \frac{\lambda max - n}{n-1}, \lambda_{max} = \sum_{i=1}^{n} \frac{(BW)_i}{nw_i}$. Because the higher the order of the matrix is, the worse the consistency of the matrix is, so we use the RI correction value, as shown in Table 3.

Table 3. RI correction value

Matrix order	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41

The revised average $CR = \frac{CI}{RI}$ is used to form an index to measure the consistency of the judgment matrix. When the CR is less than 0.1, the satisfactory consistency is obtained.

2.2.5. Total ranking and total consistency check. Among them, $T = \sum_{j=1}^{n} w_i w_j, (i = 1, 2 \dots m)$, consistency ratio: $CR = \frac{CI}{RI}$, when the value of $CR < 0.1$, that is, through the consistency test, or that does not meet the consistency test.

2.3. Use the weight to analyze the grey incidence.
For factors between different systems, the measure of the magnitude of the correlation that varies with different objects is called the correlation degree. If the different factors have a consistent trend of change and a high degree of synchronization, it can be considered that there is a high degree of correlation between these factors. On the contrary, it is lower.

2.3.1. Standardization (dimensionless). Take the reference sequence (the number of the largest number) as the reference point. the data are standardized to data between 0 and 1.

2.3.2 The formula needs the value to generate the corresponding difference list, he content includes: Difference from reference sequence value (absolute value),maximum difference and minimum difference, ζ(Zeta)is the coefficient of resolution and $0 < \zeta < 1$ so $\zeta = 0.5$ can be set.

2.3.3 Correlation coefficient. $\xi_i(k)$: use $\xi_i(k) = \frac{\Delta min + \xi \Delta max}{\Delta oi(k) + \xi \Delta max}$,Calculate the correlation coefficient of the K reference point and the X0 reference point of the reference sequence on the comparison sequence Xi. Finally, the average value of each coefficient is the correlation degree between Xi and X0 RI.

2.3.4 Comparing the correlation degree. The larger the correlation degree is, the higher the correlation degree is.

3. Example analysis

In this paper, an example is demonstrated based on the mathematical model constructed.

3.1. Determine the weights of evaluation indicators.

3.1.1. Establish a hierarchical structure model. According to the evaluation index system of building materials suppliers shown in Table 1,the evaluation indexes of three alternative suppliers are established.

3.1.2. Constructing comparison judgement matrix. According to the previous evaluation method, we compare the relative importance of the index system ,The pairwise comparison matrices of the B layer relative to the A layer and the C layer relative to the B layer are matrix A and matrix respectivelyB1、B2、B3、B4,As follows:

$$A=\begin{bmatrix}1 & 4 & 5 & 3\\ 1/4 & 1 & 2 & 1\\ 1/5 & 1/2 & 1 & 1/2\\ 1/3 & 1 & 2 & 1\end{bmatrix}\ B1=\begin{bmatrix}1 & 3 & 5\\ 1/3 & 1 & 2\\ 1/5 & 1/2 & 1\end{bmatrix}\ B2=\begin{bmatrix}1 & 3 & 4 & 5\\ 1/3 & 1 & 2 & 1\\ 1/4 & 1/2 & 1 & 2\\ 1/5 & 1 & 1/2 & 1\end{bmatrix}$$

$$B3=\begin{bmatrix}1 & 2\\ 1/2 & 1\end{bmatrix}\ B4=\begin{bmatrix}1 & 2 & 2\\ 1/2 & 1 & 1\\ 1/2 & 1 & 1\end{bmatrix}$$

3.1.3. Calculate the weight of each index under each criterion level. The eigenvectors of each judgment matrix are calculated by summation and square root method. The square root method is more suitable for this calculation. The weight vector of matrix A can be obtained by square root method, $\omega^{(2)}=[0.556,0.168,0.095,0.181]^T$. Similarly, the weight vectors of matrices B1, B2, B3 and B4 can be obtained. $\omega_1^{(3)}=[0.648,0.230,0.122]^T,\omega_2^{(3)}=[0.562,0.182,0.143,0.113]^T,\omega_3^{(3)}=[0.667,0.333]^T,\omega_4^{(3)}=[0.500,0.250,0.250]^T$.

3.1.4. Evaluation of consistency under single criteria, Computing eigenvalues of judgment matrix A, $\lambda_{\max}$, according to the formula $\lambda_{max}=\sum_{i=1}^{n}\frac{(BW)_i}{nw_i}$

$$\mathrm{BW}=\begin{bmatrix}1 & 4 & 5 & 3\\ 1/4 & 1 & 2 & 1\\ 1/5 & 1/2 & 1 & 1/2\\ 1/3 & 1 & 2 & 1\end{bmatrix}\begin{bmatrix}0.556\\ 0.168\\ 0.095\\ 0.181\end{bmatrix}=\begin{pmatrix}2.246\\ 0.678\\ 0.381\\ 0.724\end{pmatrix}$$

then $\lambda_{max}=\sum_{i=1}^{n}\frac{(BW)_i}{nw_i}=1/4(\frac{2.246}{0.556}+\frac{0.678}{0.168}+\frac{0.381}{0.095}+\frac{0.724}{0.181})=4.02$.

The consistency of the judgement matrix is tested. Similarly, we can calculate the Characteristic root of B1, B2, B3 and B4 namely 3.005、4.164、2.001、3.

3.1.5. General ranking and total consistency check. The judgement matrix A of $\lambda_{max}=4.02$, $CI=\frac{\lambda max-n}{n-1}=\frac{4.02-4}{4-1}=0.0067$, $CR=\frac{CI}{RI}=\frac{0.0067}{0.9}=0.0074<0.1$.*Therefore, the judgement matrix is consistent and the weight is reasonable. Similarly, the CR values of the judgement matrices B1, B2, B3 and B4 are respectively 0.0034, 0.0611, 0.001, 0 these four values are all less than 0.1. It shows that the judgement matrix is consistent and the weight is reasonable. Finally, the weight of each three level index relative to the target layer can be obtained.* $W=$（0.360,0.128,0.068,0.094,0.031,0.024,0.019,0.063,0.032,0.091,0.045,0.045）

3.2. Calculating correlation degree

According to the index measurement method determined in the evaluation system, the indexes are quantified and scored. The scores of each index of the three suppliers participating in the evaluation are shown in Table 4.

Table 4. The scores of each index of the three suppliers

supplier	C11	C12	C13	C21	C22	C23	C24	C31	C32	C41	C42	C43
A	90	320	8	57	400	7	120	90	1	5	80	7

B	88	335	10	63	420	8	130	85	1	4	76	8
C	86	310	9	50	360	6	110	95	1	8	75	6

The data in the table are calculated according to the above gray correlation analysis steps, The specific calculation process adopts score of supplier A. The calculation process is as follows. The supplier correlation degree to be evaluated is calculated.

Table 5. The scores of each index of the three suppliers after standardization

Suppliers	C11	C12	C13	C21	C22	C23	C24	C31	C32	C41	C42	C43
A	0	10	0	7	20	1	10	5	0	3	5	1
B	2	25	2	13	0	0	0	10	0	4	1	0
C	4	0	1	0	40	2	20	0	0	0	0	1

The data in table 5 are processed dimensionless and the following results are obtained: {90|310|8|50|420|8|130|95|1|8|75|8}

According to the formula of correlation degree, respectively, the maximum difference between the two levels and the minimum difference are:

$\Delta_{min} = \min_i \min_k |X0(k) - Xi(k)| = 0, \Delta_{max} = \max_i \max_k |X0(k) - Xi(k)| = 1$,value $\xi = 0.5, \xi_1(1) = 40$, obtain the calculated value of $|X0(k) - Xi(k)|$: $\xi_1(1) = 1$, $\xi_1(2) = 0.67$, $\xi_1(3) = 1$, $\xi_1(4) = 0.74$, $\xi_1(5) = 0.50$, $\xi_1(6) = 0.95$, $\xi_1(7) = 0.67, \xi_1(8) = 0.80$, $\xi_1(9) = 1$, $\xi_1(10) = 0.87$, $\xi_1(11) = 0.8$, $\xi_1(12) = 0.95$,It can be calculated that the grey correlation degree of construction supplier A: $r1 = 0.360 * 1 + 0.128 * 0.67 + 1 * 0.068 + 0.074 * 0.74 + 0.031 * 0.5 + 0.024 * 0.95 + 0.019 * 0.67 + 0.063 * 0.8 + 0.032 * 1 + 0.091 * 0.87 + 0.045 * 0.8 + 0.045 * 0.95 = 0.875$.

Similarly, the grey correlation degree between B and C of construction suppliers can be obtained as follows: $r_2 = 0.809, r_3 = 0.903$.Based on the above grey correlation analysis, the following results can be obtained. The calculation correlation of building material supplier A is 0.875, The calculation correlation of building material supplier B is 0.809, The calculation correlation of building material supplier C is 0.903, So choose C, a building material supplier, as a partner.

4. Conclusion

This paper combines the AHP method with the grey relational degree analysis, through the example analysis of building materials supplier selection, provides the contractor with the qualitative and quantitative evaluation method and a new way for enterprises to make decisions. Therefore, this paper incorporates carbon emissions into the evaluation index system, which plays a good guiding role in selecting the most economical and environmentally friendly building materials suppliers for construction contractors. The example shows that according to the tradition of considering quality and price, the enterprise will choose supplier A. However, the highest correlation degree of supplier C is 0.903 when carbon emissions are included, and the enterprise will choose supplier C with the lowest carbon emissions of 75.Based on this model, the C supplier is selected successfully. Therefore, the mathematical model of carbon emissions into the supplier evaluation index system is feasible and reliable, which can provide reference for enterprises to choose green building suppliers in low carbon environment.

Reference

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