Research on the Selection of Construction Supplier in the Construction Supply Chain Environment

Wei-yan Xie and Xing Bi

Abstract Guided by supply chain management thinking, the paper discusses the principles that the supplier evaluation index system should follow. Combined with the characteristics of the construction works, a specific index system is established. After the comparison of several evaluation methods, the paper points out that the grey relational analysis is more suitable for selecting construction suppliers. In the last part of the paper, a numerical example is used to illustrate the rationality and feasibility of the method. The content stated in the paper provides scientific basis for construction enterprises to select suppliers.

Keywords Construction supply chain • Gray relational analysis • Index system • Supplier selection

1 Introduction

Supply chain is a concept that has originated and flourished in the manufacturing industry. In 1980s, Koskela Professor made a speech that applied the manufacturing supply chain model to the construction industry when he was a visiting scholar at Stanford University [1]. Since then, the prototype of the supply chain management mode in the construction industry formed. Nowadays, the competition between the enterprises has turned into the competition between the supply chains. Therefore,

W. Xie (✉) • X. Bi
Department of Management and Economics, Tianjin University, Tianjin, China
e-mail: xieweiyan008427@163.com

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the scientific and rational selection of partners is more important than before. The construction materials consumed often account for more than 50 % of the project investment. The material supply situation of the supplier directly influences the project schedule, quality and cost control. So it is really important to select the proper supplier to improve the competitiveness of the entire supply chain. Therefore, how to properly evaluate and select the appropriate construction suppliers is at the top of the priority list.

2 The Establishment of the Supplier Evaluation Index System

2.1 The Principles of the Evaluation Index System

Supply chain management must be properly formulated, strategically planned, organized and executed [2]. The application of supply chain management model has put forward higher requirements on the supplier's product quality, manufacturing flexibility, timeliness of delivery and the capability of rapidly responding to the changing needs. Thus, a set of scientific index system is definitely necessary to conduct a comprehensive study of the supplier's overall strength. There are several principles that a supplier evaluation index system should follow.

1. *Principle of being systematic and comprehensive*: The index system should be able to fully reflect the comprehensive strength of the suppliers. Associated with the total target of the supply chain, it should be a hierarchical system that each index is functioning adequately to ensure the comprehensiveness and effectiveness of the evaluation results.
2. *Principle of being flexible and practical* [3]: Each project has its own characteristics, which requires the supplier evaluation system to be flexible, enabling the construction enterprises to adjust the index system according to the specific application environment. In addition, the index system should also have a moderate scale that meets the evaluation needs.
3. *Principle of combining qualitative indexes and quantitative indexes*: The overall strength of the suppliers is influenced by a lot of factors. The quantitative indexes are more operational and comparable, but there are still some factors that can't be fully reflected by quantitative indexes, such as the corporate reputation, development potential. Therefore, the index system should combine the quantitative indexes with the qualitative indexes together to achieve the comprehensive evaluation of the supplier.
4. *Principle of being reconfigurable and scalable* [4]: The demand for suppliers will change with the changing market environment, so the index system should be reconfigurable, enabling the construction companies to make the necessary

Table 1 The supplier evaluation index system

Goal layer	Criterion layer	Index layer	Index type
Supplier evaluation index system	Product system	ISO certification rate [5]	Quantitative
		Rate of qualified products	Quantitative
		Quality inspection and test conditions	Qualitative
		Price reasonableness	Quantitative
		Logistics costs	Quantitative
	Supply capacity	On-time delivery rate	Quantitative
		Order lead time [6]	Quantitative
		Flexibility	Quantitative
	Technology research and development	R&D funds rate	Quantitative
		New product R&D capabilities	Quantitative
		Ability to adapt to new technology	Qualitative
	Comprehensive evaluation	Financial condition [7]	Qualitative
		Social benefits	Qualitative
		Cooperation capacity	Qualitative
		Corporate reputation	Qualitative
		Status of industry	Qualitative

adjustments depending on the actual situation. In addition, with the continuous development of the construction industry, new demand for suppliers will show up, so the supplier evaluation index system should be scalable.

2.2 The Supplier Evaluation Index System

Combined with the characteristics of the construction industry, we constructed a supplier evaluation index system with three levels under the guidance of the above principles, as specified in Table 1 below.

1. *The product system*: ISO certification rate is the ratio of the number of ISO-certified to the number of ISO-certifications needed. Rate of qualified products means the ratio of the number of qualified products to the total procurement. Quality inspection and test condition means the level of soundness of the relevant systems, such as the scientific methods used, advanced tools adopted. Price reasonableness means the ratio of the price of product evaluated to the average price in the industry. And the logistics costs include ordering costs, transportation costs and inventory costs.
2. *The supply capacity*: The supply capacity of the supplier is directly related to the smooth and effective running of the entire supply chain. On-time delivery rate can be measured by the ratio of the number of on-time delivery to the total

number of delivery over a period of time. The on-time delivery rate is directly related to the level of the safety stock of construction companies. Order lead time means the interval between the proposed order and received order. The shorter this interval, the stronger the response capacity of the supply chain to customer demand. The flexibility reflects the response capacity of the supplier to the objective environment, including the production flexibility and delivery flexibility. The formulas are given as follows.

The production flexibility reflects the capacity of changing the level of output to meet the changing needs of the construction enterprises which can be expressed by the probability of changes in demand. Assuming that demand of the construction enterprise is a random variable that obeys the normal distribution. It can be expressed as, $D \sim N(\mu, \sigma_D^2)$. And the production flexibility can be calculated by the formula: $f = \Phi\left(\frac{Q_{max}-d}{S_d}\right) - \Phi\left(\frac{Q_{min}-d}{S_d}\right)$, Q_{max} and Q_{min} in the formula respectively means the maximum and minimum yield on the basis of profit. d is the average demand of the N-periods. And S_d is the standard deviation of d.

The delivery flexibility reflects the capacity of changing the planned delivery time which can be measured by the ratio of the slack time of the delivery to the entire delivery period. Assuming that there are $j = 1,2, \ldots J$ tasks in the system. And t is the current time, L_j is the latest time of task j, E_j is the earliest time of task j. Then, the delivery flexibility can be calculated by the formula: $f = \frac{\sum_{j=1}^{J}(L_j - E_j)}{\sum_{j=1}^{J}(L_j - t)}$.

3. *Technology research and development*: The fund invested provides the economic basis to enhance the innovation capability which can be measured by the proportion of the fund invested to the sales revenue during the same period. New product research and development capacity refers to the ability of bringing new products to the market through research and development activities. And it can be measured by the ratio of sales of new products to the total sales of the products during a certain period of time. The ability to adapt to the new technology is the ability of timely adopting the new technologies and new techniques which can be measured by expert scoring method.
4. *Comprehensive Evaluation* [8]: The financial condition reflects the management capacity of the suppliers which can be evaluated by the financial indexes, such as the total assets turnover, asset-liability ratio and return on total assets. Indexes of social benefits evaluation reflect the requirements of the development of recycling economy and green supply chain which can be evaluated by environmental impact degree, energy consumption, recycling utilization, and environmental reputation. Cooperation capacity includes cooperate attitude, communication effectiveness and the information management level. Corporate reputation and status of industry can be evaluated by experts.

The above content is a brief explanation of the indexes and the construction enterprises can make appropriate adjustments if necessary to choose the right suppliers.

3 Evaluation Methods

After the establishment of the supplier evaluation index system, the next step is to select the appropriate evaluation method to select the right supplier. The evaluation results may be different due to the different methods selected. After a simple research of the common methods of evaluation and selection of suppliers, the paper proposes the grey relational analysis method which is based on the gray theory.

3.1 Common Methods

An appropriate evaluation method is the theoretical basis of the scientific selection of suppliers. Nowadays, commonly used methods include qualitative methods, quantitative methods and the combination of qualitative and quantitative methods.

The qualitative methods commonly used include intuitional judgment, bidding and negotiation. These methods rely mainly on the past experience and the strong subjectivity fails to truly reflect the actual situation of the suppliers evaluated, so these methods are not commonly used in the practice.

Common quantitative methods include procurement cost method, ABC cost method. These methods mainly consider the cost factors. However, there is also some significant information that can not be quantified. Because of the limitation, these methods fail to meet the construction enterprises' need to select suppliers.

The last category of methods includes analytic hierarchy process, artificial neural network method, data envelopment analysis and integrated scoring method. Because of the advantage of being able to fully reflect the actual situation of the suppliers evaluated, these methods are used more frequently. However, these methods also have their own problems. For example, the judgment matrix in analytic hierarchy process is influenced by subjective factors and the consistency of judgment matrix is difficult to achieve. The artificial neural network is too complex to apply in practice and lack of operability. Based on the comprehensive consideration, this paper chooses the comprehensive evaluation method based on gray relational analysis to evaluate and select suppliers.

3.2 Supplier Evaluation Model

Gray relational analysis is a comprehensive evaluation method based on gray theory which determines the relevance by determining the closeness of geometric curves of the reference sequence and the comparative sequences. The relevance of geometric curves is reflected by gray related degree. The greater the degree of relevance, the better the evaluation result. If a comparability sequence translated from an alternative has the highest grey relational grade between the reference sequence and

itself, that alternative will be the best choice [9]. The detailed modeling process can be described as follows [9, 10]:

1. Determine the evaluation standard (reference sequence) and the evaluation objects (comparative sequences). Assuming that there are m evaluation objects and n evaluation index, the comparative sequences:

$$X_i = \{X_i(k) \,|k = 1, 2, \ldots, n\}, i = 1, 2, \ldots, m$$

   The dimensionless and standardized data is necessary to conduct the later analysis to get the comparable data. The formula (1) is for the benefits indexes and the formula (2) is for the costs indexes. And $\max X_i(k)$ and $\min X_i(k)$ in the formula respectively represents the minimum and maximum value of the k index among the m evaluation objects.

$$X_i(k) = \frac{X_i(k) - \min X_i(k)}{\max\limits_i X_i(k) - \min\limits_i X_i(k)} i = 1, 2, \ldots, m; k = 1, 2, \ldots, n \quad (1)$$

$$X_i(k) = \frac{\max X_i(k) - X_i(k)}{\max\limits_i X_i(k) - \min\limits_i X_i(k)} i = 1, 2, \ldots, m; k = 1, 2, \ldots, n \quad (2)$$

2. Determine the corresponding weight of each index.
   The optional methods include the analytic hierarchy process, entropy weight method [11] and so on.
   The corresponding weight of each index: $W_k = \{X_k | k = 1, 2, \ldots, n\}$. W_k is the corresponding weight of the k evaluation index.
3. Calculate the gray relational coefficients.
   The formula:

$$\xi_i(k) = \frac{\min_i \max_k |X_0(k) - X_i(k)| + \xi \max_i \max_k |X_0(k) - X_i(k)|}{|X_0(k) - X_i(k) + \xi \max_i \max_k |X_0(k) - X_i(k)||} \quad (3)$$

   $\xi_i(k)$ is the relative difference between comparative sequence X_i and reference sequence X_0 in the k evaluation index. Generally ξ takes 0.5.
4. Calculate the gray weighted incidence degree.
   The formula:

$$r_i = \frac{1}{n} \sum_{k=1}^{n} W_k \xi_i(k) \quad (4)$$

   r_i is the gray weighted incidence degree of the i evaluation object. Sort the evaluated objects according to the correlation degree and select the best evaluation object.

Supplier selection is widely considered to be one of the most important responsibilities of management. Having different criteria including conflicting criteria such as quality and price can create more complexity to the supplier selection decision, which is a multicriteria decision making problem [12].

The above content gives the basic principles of the gray relational analysis. A brief introduction of steps of conducting grey relational analysis is presented. Our objective here is to implement and examine the method in the numerical example to illustrate the feasibility and practicality of the method.

4 Numerical Example

A project purchasing department intends to conduct a comprehensive evaluation of four alternative suppliers and the results of the evaluation will be used for the supplier selection decision. According to the company's specific circumstance and requirements of the project, the purchasing department adopts the following evaluation index system. The values of the index of the suppliers are given according to the index formula and evaluation criteria of qualitative indexes previously described. The data has been standardized by formula (1) and formula (2), as shown in Table 2 [13, 14].

Table 2 Standardized index value

Evaluation indexes	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Optimal value
ISO certification rate	0.6250	1	0.8438	0	1
Rate of qualified products	0.3333	1	0.6667	0	1
Quality inspection and test conditions	0.9912	0	1	0.4425	1
Price reasonableness	0.7143	1	0.4286	0	1
Logistics costs	0.6667	0.3333	0	1	1
On-time delivery rate	0.5000	1	0	0.5000	1
Order lead time	0.6429	0.9286	0	1	1
Flexibility	0.6667	0.3333	0	1	1
R&D funds rate	0.6563	1	0	0.3438	1
New product R&D capabilities	0.2941	0.8431	1	0	1
Ability to adapt to new technology	0.3333	0.6667	0	1	1
Financial condition	0	1	0.6863	0.5882	1
Social benefits	0	0.7000	1	0.5000	1
Cooperation capacity	0	0.7143	0.4286	1	1
Corporate reputation	0.5000	0	1	0.5000	1
Status of industry	0.6252	1	0.4018	0	1

Table 3 Correlation coefficient

Evaluation index	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Optimal value
ISO certification rate	0.5714	1	0.7619	0.3333	0.5714
Rate of qualified products	0.4286	1	0.6000	0.3333	0.4286
Quality inspection and test conditions	0.9826	0.3333	1	0.4728	0.9826
Price reasonableness	0.6364	1	0.4667	0.3333	0.6364
Logistics costs	0.6000	0.4286	0.3333	1	0.6000
On-time delivery rate	0.5000	1	0.3333	0.5000	0.5000
Order lead time	0.5833	0.8750	0.3333	1	0.5833
Flexibility	0.6000	0.4286	0.3333	1	0.6000
R&D funds rate	0.5926	1	0.333	0.4324	0.5926
New product R&D capabilities	0.4146	0.7612	1	0.3333	0.4146
Ability to adapt to new technology	0.4286	0.6000	0.3333	1	0.4286
Financial condition	0.3333	1	0.6145	0.5484	0.3333
Social benefits	0.3333	0.6250	1	0.5000	0.3333
Cooperation capacity	0.3333	0.6364	0.4667	1	0.3333
Corporate reputation	0.5000	0.3333	1	0.5000	0.5000
Status of industry	0.5715	1	0.4553	0.3333	0.5715

Calculate the correlation coefficient of the suppliers in each index according to formula (3) and get the specific values, as shown in Table 3.

The later analysis is based on the given weight [15]: $\omega_j = (0.0793,0.0582,0.0663,0.0470,0.0657,0.0690,0.0839,0.0394,0.0491,0.0696,0.0804,0.0570,0.0470,0.0841,0.0470,0.0570)$, The gray correlation values of suppliers obtained: (0.5230, 0.7569, 0.5765, 0.6225)

From the result, we can see that the second supplier is the best choice. The purchasing department should cooperate with the second supplier.

5 Conclusion

Construction supply chain management mode puts forward higher requirements to supplier's products, adaptability and sustainable development. The choice of suppliers relates to the competitiveness of the entire supply chain. The paper proposes the principles of the scientific establishment of supplier selection index system. And a specific evaluation index system is established. By comparing a variety of evaluation methods, the paper selects the gray relational analysis method based on gray theory. The gray relational analysis method is suitable for multi-criteria decision making problems. The gray relational analysis combines qualitative

and quantitative methods together to exclude the subjective arbitrariness of the decision makers in the certain extent. Besides that, the method simplifies the complex decision-making problems with a small amount of calculation. In the last part of the paper, a numerical example is used to illustrate the rationality and feasibility of the method. The content of this paper provides a scientific basis for construction enterprises to select the proper supplier.

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