The Selection of Prefabricated Components Supply Partners Based on BOCR-TOPSIS Method

Yanyan Wang1,2
1School of construction management and real estate, Chongqing University, Chongqing, China
2School of management and engineering, Shandong Jianzhu University, Jinan, China

Abstract
The quality, cost, production capacity, technology R&D ability of prefabricated components in industrialized building will greatly affect the project performance, so it is especially important for choosing the the prefabricated components supplier owing strong comprehensive strength. It proposes a fuzzy BOCR-TOPSIS approach for partner selection for prefabricated components supplier. Firstly it adopts the BOCR evaluation criterion classification method by the literature and market research. Then it uses the scoring method of the triangular fuzzy number for the paired comparison to quantify the weight value of each criterion by expert groups based on control criteria and evaluation criteria. Five comprehensive evaluation methods of BOCR and TOPSIS method are used to sort the candidate partners respectively; and then the comparative analysis method is used to select the most suitable partner from the six kinds of sorting scheme. Finally sensitivity analysis is applied to determine the effect of criterion weights and scoring method for sorting the results.

Keywords: Building industrialization, prefabricated components supplier selection, BOCR, TOPSIS

1. INTRODUCTION

Prefabricated construction has received a great deal of attention in China. The Government densely promulgated relevant policies and documents in order to standardize and guide the implementation of the industrial building. According to the statistical bulletin for national economic and social development issued by China's national bureau of statistics, real estate development investment is totaled 9.5979 trillion yuan in 2015, 7.72 million houses had been built and 7.83 million houses have under construction. Large-scale urbanization construction need to build a way to solve the inherent defect of traditional wet construction, including quality defects, aerial work, field workers, produce more waste and pollution to the environment, safety accidents, and so on. The advantages of building industrialization mode include efficient production efficiency, effectively controlling quality, shortening the construction period, reducing the complexity of site construction, less construction personnel participation, improving resource utilization ratio, reducing waste, improving health and safety performance, more closely integrated supply chain and economies of scale, etc.. The construction pattern has gradually popularized and the effect is remarkable in Japan, the United States, Germany, Singapore, Hong Kong and other places. This interest can be mainly attributed to the perceived advantages involved, such as time and cost savings, improved quality, higher safety standards and resource leveling. Different from the traditional construction and supply mode, the industrialization construction mode needs a large number of prefabricated components and parts, such as precast columns, precast beams, prefabricated floor panels and composite panels. Prefabricated components are usually designed, produced and assembled on different sites by various parties, and design errors are often found during installation. After producing prefabricated components, it is almost impossible to modify them, leading to rework, time delays and cost overruns in the event of mistakes . So quality, production supply capacity, technology maturity degree and the construction collaboration of the prefabricated components will greatly affect the project operation. In 1998 a survey for 750 CEOs revealed that, partner selection is the most weak part in strategic alliance experience in the United States. One of the main reasons for failure is that the excellent partners were not been choosed. It is critical to select the prefabricated component supplier with a strong comprehensive strength for the success of project operation.

There are a lot of researches on partner selection methods. Wu et al. presented a model for green partner selection and supply chain construction by combining analytic network process (ANP) and multi-objective programming (MOP) methodologies. Chen applied the variation coefficient method of objective weighting to determine the weights of evaluation criteria and used the multi-objective decision optimization compromise model for the selection of prefabricated components supplier in industrialized housing. Luo et al. put forward the evaluation index system for cooperative partners in strategic alliance of large-scale complex project, and established the grey relational model based on the combined weight by using the information entropy and AHP method. Liang et al. proposed a strategic alliance partner selection and devaluation model based on the Dempster-Shafer theory which choosed the evaluation criteria from four aspects including complementary, compatibility, commitment and risk. Liu et al. explored the like parameters and qualitative parameters of the symbiotic unit in industry alliance cooperation partners choice, applying AHP method for the selection and evaluation system of industrial alliance partners to analysis the real strength of the partners and the intrinsic
strength of the industrial alliance. Based on the degree of satisfaction of individual decisions, Song et al. induced the individual’s degree of satisfaction and the group’s aggregated satisfaction through weighting and then proposed a rule that the group compromised solution is the one maximizing the degree of the group’s aggregation satisfaction who participates in PPP project. Yan et al. established the evaluation criteria system of giant project organization alliance partner selection from three aspects of the project, ability, relationship, using cloud model and the uncertainty reasoning of single rule cloud to quantify the factor level of criteria and then applying the gray relational degree analysis theory for the comprehensive evaluation. Lu et al. regarded the corporate reputation as the effective recognition information, and he chose three criteria including stability of corporate reputation, reputation fitting degree of corporate and leader enterprise and the maximum entire reputation of supply chain and applied genetic algorithm for the optimal choice of the supply chain partners.

The discussion and application of the above evaluation method provide the better theoretical support for the selection of partners, but the evaluation criterion system is more focus on the positive factors in the cooperation, without considering the possible negative factors, and that they emphasizes the uniqueness evaluation conclusion. Although there are many researches on partner in China, there are few studies on the evaluation criteria and methods of prefabricated components selection. The main aim of this paper is to study the selection of industrialization project partners from two aspects of theory and practice through the combination of different multi-objective decision-making methods.

2. BASIC THEORY

2.1 Fuzzy AHP methods

Fuzzy analytic hierarchy process (FAHP) integrated fuzzy set theory and AHP has been widely used by many researchers to effectively capture the human perception and uncertainty. For measuring the fuzzy extent, Chang’s method is the most popular and preferred one. First of all, it applied the triangle fuzzy numbers to evaluate criteria and alternative programme for the language score, then introduced the extent analysis method (EAM) for the synthesis extent values of pairwise comparisons. Compared to the other fuzzy analytic hierarchy process, EAM is relatively easy and less time consuming, and it can overcome the deficiency of the conventional AHP. This approach not only can adequately deal with the inherent uncertainty and imprecision of the human decision-making process but also can provide the robustness and flexibility needed for decision-makers to understand the decision problem. EAM’s brief introduction is as follows:

Assume $X = \{x_1, x_2, \ldots, x_n\}$ is an object set and $U = \{u_1, u_2, \ldots, u_m\}$ a goal set. According to the EAM, an extent analysis is performed individually for each goal, $g_i$, considering each object. Consequently, we can get $m$ extent analysis values for each object, with the following signs:

$$M^1_i, M^2_i, \ldots, M_m^i, \quad i = 1, 2, \ldots, n$$

Where all $M_j^i$ ($j=1, 2, \ldots, m$) are TFNs, represented as $M(m^1, m^2, m^3)$. These parameters mean the least possible value, the most possible value, and the highest possible value. The value of fuzzy synthetic extent with respect to the $i$-th object is defined as:

$$S_i = \left[ \sum_{j=1}^{m} M_j^i \right]^{-1}$$

$$M_j^i = \left[ M^-_j, M_0^+, M^-_j + \sum_{j=1}^{m} M_j^i \right]^{-1}$$

$$\sum_{j=1}^{m} M_j^i = \left[ \sum_{j=1}^{m} M_j^i + \sum_{j=1}^{m} M_j^i \right]^{-1}$$

$$V(S_i \succeq S_j) = \frac{S_j - S_i}{S_j - S_i} - \frac{S_i - S_j}{S_j - S_i}$$

The comparison of two triangular fuzzy numbers is carried out. Supposed $S_1 \succeq S_2$, $S_1 \succeq S_2$, $S_1 \succeq S_2$, $S_1 \succeq S_2$, $V(S \succeq S_i)$ can be calculate using the formula as follows:

$$V(S_2 \succeq S_1) = hgt \left( S_1 \cap S_2 \right) = \frac{s_{1} - s_{2}^*}{(s_{2} - s_{2}^*) - (s_{1} - s_{1}^*)}$$

To compare S1 and S2. We need both the values of $V(S_1 \succeq S_2)$ and $V(S_2 \succeq S_1)$. The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $S_i$ can be expressed as follows:

$$V(S \succeq S_1, S_2, \ldots, S_k) = \min_{i=1, 2, \ldots, k} V(S \succeq S_i), i = 1, 2, \ldots, k$$
Suppose that 
\[
d' (A_1) = \min V(S_i \geq S_k), k = 1, 2, \cdots, n; k \neq i
\] . Then, the weight vector is derived from the following equation:
\[
W' = (d'(A_1), d'(A_2), \cdots, d'(A_n))^T
\] (7)

Where \( A_i \) are n elements. The normalized weight vectors can be obtained after normalization as follows:
\[
W = (d(A_1), d(A_2), \cdots, d(A_n))^T
\] (8)

2.2 BOCR methods

In complex projects’ decisions, it may sometimes need to consider the opposite criteria, such as criteria in benefits versus those in costs, and criteria in opportunities versus those in risks. Saaty proposed five ways to combine the scores of each alternative under B, O, C and R. They are as follows:

Additive:
\[
P_i = b_i \cdot B_i + o_i \cdot O_i + c_i (1 - C_i) + r_i (1 - R_i)
\] (9)

where \( B_i, O_i, C_i \) and \( R_i \) represent the synthesized results of alternative \( i \) under merits \( B, O, C \) and \( R \), respectively, and \( b, o, c \) and \( r \) are normalized weights of merit \( B, O, C \) and \( R \), respectively.

Probabilistic additive:
\[
P_i = b_i \cdot B_i + o_i \cdot O_i + c_i (1 - C_i) + r_i (1 - R_i)
\] (10)

Subtractive:
\[
P_i = b_i \cdot B_i + o_i \cdot O_i - c_i \cdot C_i - r_i \cdot R_i
\] (11)

Multiplicative priority powers:
\[
P_i = B_i \cdot O_i \left[(1/C_i)_{\text{Normalized}} \right] \left[(1/R_i)_{\text{Normalized}} \right]
\] (12)

Multiplicative:
\[
P_i = B_i \cdot O_i / C_i R_i
\] (13)

2.3 TOPSIS methods

Hwang et al. first proposed the TOPSIS method which is used to sort the alternatives by the ideal solution and the negative ideal solution of multi-attribute problem. The alternatives are defined as an n-dimensional Euclidean space, where each alternative represents a point in this space. In order to define the positive and negative ideal solution, a basic assumption is that the characteristics of each attribute are monotonically increasing or decreasing. Then, the Euclidean distance from each solution to the positive and negative ideal solutions is calculated respectively. And it is the optimum scheme which it has the nearest distance to positive ideal solution and simultaneously has the furthest distance to negative ideal solution. It can thus sorting the alternatives. According to Lin et al, TOPSIS method includes the six steps which are as follows:

Step 1: Establish a normalized decision matrix. Let \( Y \) denote a normalized decision matrix representing the relative performance of the generated design alternatives, with typical element \( Y=(y_{ij})_{mn} \).

Step 2: Calculate the weighted decision matrix. Let \( Z \) denote a weighted decision matrix, then:
\[
Z = (z_{ij})_{mn} = \left( \omega_j \cdot y_{ij} \right)_{mn}
\] (14)

Where \( \omega_j \) is the weight of jth criteria.

Step 3: Determine the positive-ideal solution (PI) and the negative ideal solution (NI) according to the weighted decision matrix \( W \). The PI and NI are defined as:
\[
\text{PI} = \left( \max \{ d^+ \} | j \in S \right) \text{ or } \left( \min \{ d^- \} | j \in S \right) = \{ d^+_1, d^+_2, \cdots, d^+_m \}
\] (15)
\[
\text{NI} = \left( \min \{ d^- \} | j \in S \right) \text{ or } \left( \max \{ d^- \} | j \in S \right) = \{ d^-_1, d^-_2, \cdots, d^-_m \}
\] (16)

where \( S \) is associated with the beneficial customer requirements, and \( S' \) is associated with the cost-effective customer requirements.

Step 4: Measure the separation distance of each competitive design alternative from the positive-ideal solution and the negative-ideal solution. An Euclidean distance method was used in this research. Let \( d^+_j \) and \( d^-_j \) represent the distance of the \( j \)th design alternative from the PI and NI, respectively.
\[
d^+_j = \sqrt{\sum_{i=1}^{m} (d_{ij} - d^+_i)^2}, j = 1, 2, \cdots, m
\] (17)
\[
d^-_j = \sqrt{\sum_{i=1}^{m} (d_{ij} - d^-_i)^2}, j = 1, 2, \cdots, m
\] (18)
Step 5: Calculate the relative closeness or similarity degree to the ideal solution for each competitive design alternative. Let RS denote an s-dimensional column vector describing the coefficient of relative closeness to the ideal solution for competitive design alternatives, with typical element RSj:

$$RS_j = \frac{d_j}{d_1} \quad , j = 1, 2, ..., m \quad 0 \leq RS_j \leq 1$$

Step 6: Sorting the priority of candidates in accordance with the RSj from large to small, and the front is better than the back.

2.4 Optimization method based on BOCR-TOPSIS

The BOCR method can not only consider the influence of the positive factors, also consider the influence of the negative factors. The main advantages of the BOCR method are embodied in: the first is that the BOCR method can overcome the shortcomings of the evaluation criteria in the analytic hierarchy process. The selection of appropriate evaluation factors is one of the main difficulties in the research of AHP. The selection of factors is even more difficult in the field, especially in the areas that have not been studied before, or have no similar experience. Second is the BOCR method can comprehensively consider the negative evaluation criteria. In a decision problem, AHP tends to consider only positive aspects, while in some decision problems, negative factors must be taken into account, such as benefit cost analysis. TOPSIS method is a simple, mature and effective method for multi-attribute decision making which has been widely used for supplier selection.

The combined evaluation method of BOCR and FAHP has been widely used for wind power investment project selection and evaluation, selecting hydrogen production methods, the TFT-LCD supplier selection in Taiwan. The combined evaluation method of BOCR and FANP is used to evaluate multi-objective, multi-participation high-tech alternatives, select the company information system supplier. The combined evaluation method of TOPSIS and AHP is used for green supply chain supplier evaluation and selection, mining connection scheme optimization of the village, integration capability evaluation of enterprise technology dynamically, plan optimization of oil gas development project, and so on.

Based on the theoretical analysis above, this paper intends to adopt specific ideas for prefabricated components supply partner selection, and a combined method is based on BOCR, FAHP and TOPSIS. First, BOCR method is applied to establish the criteria system of evaluation of supply partners for industrialized construction project and then it uses the FAHP method by experts on criteria system and partner evaluation to get corresponding weight value and value evaluation, respectively. Then the BOCR five comprehensive evaluation score methods and TOPSIS methods are used to sort the candidates, to select the best partner, and sensitivity analysis is carried out. Finally, the effectiveness and feasibility of the method is verified by case analysis.

3. CONSTRUCT THE EVALUATION CRITERION SYSTEM

Partner evaluation criterion system should be designed according to the following principles: purposefulness, scientificity, comprehensiveness, quantitative and qualitative combination, expansibility, flexibility and so on. Criteria of individual partners (hard criterion) and of the partnership (soft criterion) must be considered in the partner's selection. Partner criterion selection should consider the compatibility between organizations (compatibility of enterprise strategy, the symmetric of the size and scope, management and organizational culture, mutual trust and commitment), technology capability (production capability, product development and improved ability, innovation and invention ability, skills application), R&D resources (R&D investment, R&D experience, R&D team, R&D efficiency), financial status (rate of return on investment, debt repayment reserve ratio, profitability and growth potential of nearly five years). According to the characteristics of the project other researchers selected the corresponding evaluation criterion, considering the quality, cost, price, service, cooperation intention, research and development ability, the logistics level, service level[8], also including long-term partnership, strategic goal match, communication cooperation ability, rapid response ability, management level, and the organization stability, strain capacity, management ability, cooperation intention, interaction between the groups, and so on.

For the industrialization construction projects, cooperation can be a variety of forms, such as a big organization including owner, designer, general contractor and component manufacturers also only two or three parties, such as between constructor and designer or only general contractor and component suppliers. The cooperative forms depends on the needs of the project and the development of the company. For each evaluation criterion of BOCR, the single criterion evaluation which has great impact on the important events may lead to the unreasonable evaluation results, and the weight of each BOCR criterion should be considered and integrated for comprehensive evaluation. Evaluation criteria are the basic criteria used by individuals and organizations in order to assess the decisions in the face of many choices in their daily operations. Evaluation criteria don’t depend on any particular priority of the candidates, but the assessment of their goals and values according to the individual or organization.
According to the literature review and the expert consultation classification rules of BOCR, the evaluation criteria are divided into four parts, each of which is subdivided into a number of sub-criteria, and the specific contents are shown in Table 1.

**Table 1. Supply partner selection criterion system**

<table>
<thead>
<tr>
<th>Merit</th>
<th>Sub-criteria</th>
<th>Detailed definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefit</td>
<td>H1-Quality control</td>
<td>The quality reliability of component production; the ability to provide quality assurance</td>
</tr>
<tr>
<td></td>
<td>H2-Duration matching</td>
<td>Ability to cooperate with the ongoing sexual intercourse plan</td>
</tr>
<tr>
<td></td>
<td>H3-Deliver on time</td>
<td>Ability to deliver on time</td>
</tr>
<tr>
<td></td>
<td>H4-Supply capacity</td>
<td>Production capacity of diverse products; mass production capacity; emergency response capacity</td>
</tr>
<tr>
<td></td>
<td>H5-Service capability</td>
<td>The response speed and service quality of product service</td>
</tr>
<tr>
<td>Opportunites</td>
<td>H6-Quick market response ability</td>
<td>Enhance the competitive strength, the risk sharing, improve the comprehensive strength of the bid</td>
</tr>
<tr>
<td></td>
<td>H7-Comprehensive strength of innovation</td>
<td>Technology complementary, joint R&amp;D technology and products</td>
</tr>
<tr>
<td></td>
<td>H8-Professional organization and management level</td>
<td>Complementary of organization management level, professional management mode</td>
</tr>
<tr>
<td></td>
<td>H9-Stable cooperation relationship</td>
<td>Good communication, long-term and stable cooperation relationship</td>
</tr>
<tr>
<td>Costs</td>
<td>H10-Production and transportation costs</td>
<td>Purchasing cost of raw materials; transportation cost</td>
</tr>
<tr>
<td></td>
<td>H11-Construction cost</td>
<td>Site storage cost, mechanical hoisting cost, storage cost, equipment coordination cost</td>
</tr>
<tr>
<td></td>
<td>H12-Repair cost</td>
<td>Component failure rates, repair costs, delay cost</td>
</tr>
<tr>
<td></td>
<td>H13-Relationship cost</td>
<td>The establishment and maintenance of the cooperative relationship</td>
</tr>
<tr>
<td>Risks</td>
<td>H14-Performance risk</td>
<td>Cooperation fails to achieve the set goals.</td>
</tr>
<tr>
<td></td>
<td>H15-Relationship risk</td>
<td>Opportunistic behavior of cooperative members</td>
</tr>
<tr>
<td></td>
<td>H16-Conflict of organizational culture</td>
<td>The conflict of different management mode and organizational culture between companies</td>
</tr>
</tbody>
</table>

### 4. CASE STUDY

#### 4.1 case profiles

In the context of promoting industrial assembly building in China, improving the competitiveness in the bidding and construction process a construction contractor enterprise intends to select a prefabricated parts supplier owing strong comprehensive strength as the partner. Therefore, the general contracting enterprise first carries on market research and selects three enterprises of larger scale and better reputation as candidate partners, then it forms three experts groups of technology, cost and management to analysis and evaluate the partner selection.

#### 4.2 Model application

(1) Construct the AHP model for evaluating the weight of BOCR

Through the comprehensive analysis expert group tends to select suppliers according to the four control criteria including component quality, production capacity, component cost and technology R&D ability. The control hierarchy is shown in Fig. 1.
Figure 1: Control hierarchy for supplier selection

The fuzzy linguistic variables corresponding to the quantitative scale of the 1-9 proposed by Saaty are shown in Table 2. The fuzzy numbers of the table are used to evaluate the evaluation criteria and the candidate partners.

Table 2: Characteristic function of the fuzzy numbers

<table>
<thead>
<tr>
<th>Linguistic term</th>
<th>Fuzzy number</th>
<th>Reciprocal of fuzzy numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equally important</td>
<td>(1,1,3)</td>
<td>(1/3,1,1)</td>
</tr>
<tr>
<td>Slightly important</td>
<td>(1,3,5)</td>
<td>(1/5,1/3,1)</td>
</tr>
<tr>
<td>Obviously important</td>
<td>(3,5,7)</td>
<td>(1/7,1/5,1/3)</td>
</tr>
<tr>
<td>very important</td>
<td>(5,7,9)</td>
<td>(1/9,1/7,1/5)</td>
</tr>
<tr>
<td>extremely important</td>
<td>(7,9,9)</td>
<td>(1/9,1/9,1/7)</td>
</tr>
</tbody>
</table>

(2) Evaluate the weight of each control rule

The three expert groups A1, A2, A3 on the four control rules for pairwise comparison of the triangular fuzzy scoring, derived from the fuzzy judgment matrix is the matrix A1, A2, A3.

\[
A1 = \begin{pmatrix}
(1,1,1) & (1,1,3) & (1,1,3) \\
(1,3,1) & (1,1,1) & (1/7,1/5,1/3) \\
(1/7,1/5,1/7) & (3,5,7) & (1,1,1) \\
(1/9,1/7,1/5) & (1/7,1/5,1/3) & (1,1,1)
\end{pmatrix}
\]

\[
A2 = \begin{pmatrix}
(1,1,1) & (1,3,5) & (1,3,5) \\
(1/7,1/5,1/3) & (1,1,1) & (1,1,3) \\
(1/5,1/3,1) & (1/9,1/7,1/5) & (1,1,1) \\
(1/7,1/5,1/3) & (1/9,1/7,1/5) & (1/7,1/5,1/3)
\end{pmatrix}
\]

\[
A3 = \begin{pmatrix}
(1,1,1) & (1,3,5) & (3,5,7) \\
(1/7,1/5,1/3) & (1,1,1) & (1,3,5) \\
(1/9,1/7,1/5) & (1/5,1/3,1) & (1,1,1) \\
(1/7,1/5,1/3) & (1/9,1/7,1/5) & (3,5,7)
\end{pmatrix}
\]

The consistency of the pairwise comparison results of each expert group is examined first. Fuzzy importance weights for control criteria are established based on the pairwise comparison results [22]. For example, the pairwise comparison results between component quality and component cost for the three expert groups in fuzzy numbers are (1,1,3) , (1,3,5) , (3,5,7). The synthesized fuzzy number is calculated using the Eq. (21)-(22). It will achieve: \( n=1.4142, n=2.466, n^*=4.718 \). The fuzzy pairwise comparison of the control criteria is shown in Table 3.

\[
n^* = \left( \prod_{i=1}^s n_{ji} \right)^{\frac{1}{s}}, j = 1,2, \cdots, s
\]

\[
n = \left( \prod_{i=1}^s n_{ji} \right)^{\frac{1}{s}}, j = 1,2, \cdots, s
\]

\[
n^* = \left( \prod_{i=1}^s n_{ji} \right)^{\frac{1}{s}}, j = 1,2, \cdots, s
\]
The fuzzy synthetic degree values of control criterion can be calculated as follows:

\[
\sum_{j=1}^{n} \sum_{i=1}^{m} M_{ij} = (1,1,1) + (1,0,0,2,0,80,0,4,217) + \cdots (1,1,1) = (12,900,20,275,32,647)
\]

\[
\left[ \sum_{j=1}^{n} \sum_{i=1}^{m} M_{ij} \right]^{-1} = (1/32,647,1/20,275,1/12,900) = (0,031,0,049,0,078)
\]

\[
\sum_{j=1}^{n} M_{ij} = (4,884,931,1.5) \quad \sum_{j=1}^{n} M_{ij} = (3,792,596,046)
\]

The fuzzy synthetic degree values of control criterion can be calculated as follows:

\[
S_1 = \sum_{i=1}^{n} M_{i} \otimes \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij} \right]^{-1} = (4,884 \times 0,031,9,103 \times 0,049,15,528 \times 0,078) = (0,151,0,446,1,211),
\]

\[
S_2 = (0,118,0,029,61) \quad S_3 = (0,077,0,188,0,430) \quad S_4 = (0,054,0,11,0,245)
\]

\[
V(S_1 \geq S_2) = 1 \quad V(S_1 \geq S_3) = 1 \quad V(S_1 \geq S_4) = 1
\]

\[
V(S_2 \geq S_1) = 0,722 \quad V(S_2 \geq S_3) = 1 \quad V(S_2 \geq S_4) = 1
\]

\[
V(S_3 \geq S_1) = 0,52 \quad V(S_3 \geq S_2) = 0,834 \quad V(S_3 \geq S_4) = 1
\]

\[
V(S_4 \geq S_1) = 0,219 \quad V(S_4 \geq S_2) = 0,476 \quad V(S_4 \geq S_3) = 0,683
\]

The weights vectors are calculated as follows:

\[
d(A_1) = \min(i, (F_1 \geq F_2, F_3, F_4)) = \min(i, (1,1,1)) = 1 \quad d(A_1) = \min(0,722,1,1) = 0,722
\]

\[
d(A_2) = \min(0,520,0,834,1) = 0,520 \quad d(A_1) = \min(0,219,0,476,0,683) = 0,219
\]

\[
W = [d(A_1), d(A_2), d(A_3)]^T = (1,0,722,0,520,0,219)^T
\]

After normalization, the normalized weight vector of control criteria is:

\[
W = (0,406,0,293,0,211,0,089)^T
\]

(3) Calculate the weight of each BOCR and the weight of each sub-criterion

Similar procedures are carried out to calculate the weight of merits with respect to each control criterion and the sub-criteria weights with respect to each merit. The results are shown in Table 4 and Table 5.

### Table 3. Fuzzy pairwise comparison of control criteria

<table>
<thead>
<tr>
<th>Component quality</th>
<th>Production capacity</th>
<th>Component costs</th>
<th>Technology R&amp;D ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1,1,1)</td>
<td>(1,000,2,080,4,217)</td>
<td>(1,442,2,466,4,718)</td>
<td>(1,442,3,557,5,593)</td>
</tr>
<tr>
<td>(0,189,0,342,0,481)</td>
<td>(1,1,1)</td>
<td>(0,523,0,843,1,71)</td>
<td>(2,08,2,924,5,278)</td>
</tr>
<tr>
<td>(0,143,0,200,0,333)</td>
<td>(0,585,1,186,1,912)</td>
<td>(1,1,1)</td>
<td>(0,754,1,442,2,268)</td>
</tr>
<tr>
<td>(0,143,0,200,0,333)</td>
<td>(0,189,0,342,0,481)</td>
<td>(0,441,0,693,1,326)</td>
<td>(1,1,1)</td>
</tr>
</tbody>
</table>

### Table 4. BOCR’s weights

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Component quality(0,406)</th>
<th>Production capacity(0,293)</th>
<th>Component costs(0,211)</th>
<th>Technology R&amp;D ability(0,089)</th>
<th>Normalized weights</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0,411</td>
<td>0,388</td>
<td>0,435</td>
<td>0,152</td>
<td>0,386</td>
</tr>
<tr>
<td>Opportunities</td>
<td>0,141</td>
<td>0,196</td>
<td>0,185</td>
<td>0,306</td>
<td>0,181</td>
</tr>
<tr>
<td>Costs</td>
<td>0,395</td>
<td>0,311</td>
<td>0,307</td>
<td>0,322</td>
<td>0,345</td>
</tr>
<tr>
<td>Risks</td>
<td>0,053</td>
<td>0,105</td>
<td>0,073</td>
<td>0,222</td>
<td>0,087</td>
</tr>
</tbody>
</table>
(4) Calculate the evaluation value of each candidate partner
The three expert groups give the evaluation values of three partners. The Eq. (23) is applied to standardize the evaluation matrix.

\[ a_{ij} = \min_k \{ a_{ik} \}, \quad b_{ij} = \frac{1}{k} \sum_{k=1}^{k} b_{ik}, \quad c_{ij} = \max_k \{ c_{ik} \} \]  

(23)

(5) Synthesize the evaluation values of candidates and sort them by using the five methods of BOCR
It can use Eq. (24) to calculate the evaluation values of each candidate and standardize them. In order to generate alternative ranking, the alternative data should be processed beforehand for obtaining 1/C and 1/R(normalized)and 1-C and 1-R values for all the sub-criteria.

\[ x = \frac{a + 4b + c}{6} \]  

(24)

Table 5. sub-criteria weights

<table>
<thead>
<tr>
<th>Merits</th>
<th>sub-criteria weights</th>
<th>Global priorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits(0.38)</td>
<td>H1-Quality control(0.36)</td>
<td>0.139</td>
</tr>
<tr>
<td></td>
<td>H2-Duration matching(0.14)</td>
<td>0.054</td>
</tr>
<tr>
<td></td>
<td>H3-Deliver on time(0.20)</td>
<td>0.077</td>
</tr>
<tr>
<td></td>
<td>H4-Supply capacity(0.13)</td>
<td>0.050</td>
</tr>
<tr>
<td></td>
<td>H5-Service capability(0.17)</td>
<td>0.066</td>
</tr>
<tr>
<td>Opportunities(0.181)</td>
<td>H6-Quick market response ability(0.42)</td>
<td>0.076</td>
</tr>
<tr>
<td></td>
<td>H7-Comprehensive strength of innovation(0.20)</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>H8-Professional organization and management level(0.20)</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>H9-Stable cooperation relationship(0.18)</td>
<td>0.033</td>
</tr>
<tr>
<td>Costs(0.345)</td>
<td>H10-Production and transportation costs(0.45)</td>
<td>0.155</td>
</tr>
<tr>
<td></td>
<td>H11-Construction cost(0.27)</td>
<td>0.093</td>
</tr>
<tr>
<td></td>
<td>H12-Repair cost(0.18)</td>
<td>0.062</td>
</tr>
<tr>
<td></td>
<td>H13-Relationship cost(0.10)</td>
<td>0.035</td>
</tr>
<tr>
<td>Risks(0.087)</td>
<td>H14-Production technology unreliability(0.44)</td>
<td>0.038</td>
</tr>
<tr>
<td></td>
<td>H15-Supply capability instability(0.38)</td>
<td>0.070</td>
</tr>
<tr>
<td></td>
<td>H16-Conflict of management mode and organizational culture(0.18)</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Using Eqs. (9)–(13), final alternative rankings are showed in Table 6. It can be seen that for all the five methods, alternative S3 has emerged as the winner.

Table 6. BOCR scores and ranking for candidates

<table>
<thead>
<tr>
<th>Scoring method</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additive</td>
<td>0.365</td>
<td>0.294</td>
<td>0.377</td>
<td>S3&gt;S1&gt;S2</td>
</tr>
<tr>
<td>Probabilistic Additive</td>
<td>0.522</td>
<td>0.446</td>
<td>0.537</td>
<td>S3&gt;S1&gt;S2</td>
</tr>
<tr>
<td>Subtractive</td>
<td>0.053</td>
<td>-0.023</td>
<td>0.068</td>
<td>S3&gt;S1&gt;S2</td>
</tr>
<tr>
<td>Multiplicative priority powers</td>
<td>0.336</td>
<td>0.279</td>
<td>0.374</td>
<td>S3&gt;S1&gt;S2</td>
</tr>
<tr>
<td>Multiplicative</td>
<td>0.214</td>
<td>0.012</td>
<td>0.561</td>
<td>S3&gt;S1&gt;S2</td>
</tr>
</tbody>
</table>

(6) Calculate the comprehensive evaluation of the candidates and sort them by using the TOPSIS method
For sub-criteria weights and the evaluation of the alternatives, Using Eqs. (14)–(18), it can calculate the evaluation value of each candidate.

Using Eq. (19), It can calculate the relative closeness of each candidate’s score and the ideal solution, and sort them in Table 7.

Table 7. The relative closeness of each candidate’s score and the ideal solution

<table>
<thead>
<tr>
<th>Candidates</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>d^+</td>
<td>0.016</td>
<td>0.039</td>
<td>0.011</td>
</tr>
<tr>
<td>d^-</td>
<td>0.035</td>
<td>0.008</td>
<td>0.034</td>
</tr>
<tr>
<td>C</td>
<td>0.686</td>
<td>0.170</td>
<td>0.756</td>
</tr>
<tr>
<td>Ranking</td>
<td>S3&gt;S1&gt;S2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(7) Compare the calculation results of the two methods for BOCR and TOPSIS and select the most suitable candidate.
According to the comparison of the calculation results in Table 6 and Table 7, we can select the most likely ranking of the six methods and the sorting of appropriate supplier partners is S3>S1>S2.

4.3 Sensitivity analysis

The purpose of sensitivity analysis is to determine the influence of model parameters on the selected results or to verify the results. Here in order to assess the impact of weights on the candidate's choice it will change the weight values through the ten set of experiments. Details are as follows:

In the first set of experiments, we set the same weight of each sub-index (H1-H16=0.063).

In the second set of experiments, we set the weight of each Benefit criterion to the same, and the other criteria weights being set equal to 0 (H1=0.200, H6=H16=0).

In the third set of experiments, we set the weight of each Opportunity criterion to the same, and the other criteria weights being set equal to 0 (H1-H5=0, H6=H9=0.250, H10-H16=0).

In the fourth set of experiments, we set the weight of each Cost criterion to the same, and the other criteria weights being set equal to 0 (H1-H9=0, H10-H13=0.250, H14-H16=0).

In the fifth set of experiments, we set the weight of each Risk criterion to the same, and the other criteria weights being set equal to 0 (H1-H13=0, H14-H16=0.333).

In the sixth set of experiments, we set the weight of each Benefit and each Opportunity criterion to the same, and the other criteria weights being set equal to 0 (H1-H9=0.111, H10-H16=0).

In the seventh set of experiments, we set the weight of each Cost and each Risk criterion to the same, and the other criteria weights being set equal to 0 (H1-H9=0.200, H10-H16=0.125).

In the eighth set of experiments, we set the weight of each Benefit and each Cost criterion to the same, and the other criteria weights being set equal to 0 (H1-H5=0.111, H10-H13=0.111, H6-H9=0.111, H14-H16=0).

In the ninth set of experiments, we set the weight of each Opportunity and each Risk criterion to the same, and the other criteria weights being set equal to 0 (H1-H5=0, H10-H13=0, H6-H9=0.143, H14-H16=0.143).

In the tenth set of experiments, we set the weight of each Benefit, Opportunity and Risk criterion to the same, and the other criteria weights being set equal to 0 (H1-H13=0.077, H14-H16=0).

According to the weights of the set, the ranking results are in Table 8 by the TOPSIS methods.

Table 8. Ranking of TOPSIS method by sensitivity analysis

<table>
<thead>
<tr>
<th>No.</th>
<th>TOPSIS method</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1</td>
<td>S2</td>
</tr>
<tr>
<td>1</td>
<td>0.576</td>
<td>0.253</td>
</tr>
<tr>
<td>2</td>
<td>0.658</td>
<td>0.224</td>
</tr>
<tr>
<td>3</td>
<td>0.266</td>
<td>0.379</td>
</tr>
<tr>
<td>4</td>
<td>0.822</td>
<td>0.007</td>
</tr>
<tr>
<td>5</td>
<td>0.855</td>
<td>0.144</td>
</tr>
<tr>
<td>6</td>
<td>0.352</td>
<td>0.357</td>
</tr>
<tr>
<td>7</td>
<td>0.823</td>
<td>0.068</td>
</tr>
<tr>
<td>8</td>
<td>0.827</td>
<td>0.468</td>
</tr>
<tr>
<td>9</td>
<td>0.400</td>
<td>0.355</td>
</tr>
<tr>
<td>10</td>
<td>0.569</td>
<td>0.269</td>
</tr>
</tbody>
</table>

The sensitivity analysis diagram of the TOPSIS method is shown in Fig. 2. The probability of S3 in the first place is 60%, followed by S1, whose probability of the first place is 40%. The sensitivity analysis diagram of BOCR methods for additive, probabilistic additive, subtractive and multiplicative priority powers are shown in Fig. 3-6. Multiplicative method is not affected by the weight, here the analysis is no longer carried out. As shown in the figures, the probability of S3 in the all four methods is 60%, and probability of S1 in the first place is 40%. It can be concluded that the weight of each criterion is not sensitive to the ranking of candidates, and it also shows that the evaluation method is feasible.
5. CONCLUSION

The choice of supplier partner of construction industrialization project is a new and important research field in China. The component production and construction pattern of traditional cast-in-place is different from the one of factory and standardized precast concrete production and construction. It’s essential to improve the comprehensive competitiveness that choosing the strong supplier of prefabricated components. This paper firstly adopts the BOCR evaluation index classification method which it considers not only the positive factors (profit & opportunity) but also the negative factors (cost & risk), and which it also considers the physical factors (such as cost, etc.) and intangible factors (such as relative risk, etc.). Then it uses the scoring method of the triangular fuzzy number for the paired comparison to quantify the weight value of each index by a group of experts based on control criteria and evaluation index. Five comprehensive evaluation method of BOCR and MTOPSIS method are used to sort the candidate partners respectively, and then the comparative analysis method is used to...
select the most suitable partner from the six kinds of sorting scheme. Finally sensitivity analysis is applied to determine the effect of index weights and scoring method for sorting the results.

Based on six comprehensive score methods this paper puts forward the supplier partners selection method for industrialization construction project, which eliminates the deviation of assessment result of the single evaluation method. This method has strong practicability and applicability.

References


Luo F.Z., Han Y.H., Li S.T.. Large-scale Complicated Project Strategic Alliance Partner Selection-Based on the Combination of Empowerment Grey Correlation Evaluation. Research on technology economy and management. 2013,(4) ,pp. 8-11.


