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A material supplier selection model for property developers using Fuzzy Principal Component Analysis

Ka-Chi Lam *, Ran Tao, Mike Chun-Kit Lam

Department of Building & Construction, City University of Hong Kong, Hong Kong SAR, China

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ABSTRACT

Nowadays, the participants in construction industry are facing pressure to meet the higher customer expectations under a tighter budget. On the other hand, an effective and efficient material supplier selection system has a significant effect in the business success of property developers. The aim of this study is to investigate a selection model based on Fuzzy Principal Component Analysis (PCA) for solving the material supplier selection problem from the perspective of property developers. First, the Triangular Fuzzy Numbers is used to quantify the decision makers' subjective judgments. Second, PCA is employed to compress the data of the selection criteria and eliminating the multicollinearity among them. Third, the linear combined score of PCA ($SCORE_{PCA}$) is used to rank the suppliers. Four material purchases are used to validate the proposed selection model. The results show that the proposed model can be adopted in construction material supplier selection by the property developers.

1. Introduction

Owing to the construction material market in Mainland China that is not yet well developed, the quality and the price of the materials are varied among suppliers. For this reason, most of the Chinese property developers will purchase the construction materials directly from the material suppliers they selected in order to ensure the building quality and cost control. On the other hand, under the environment of keen bidding and higher customer expectations, Chinese property developers devote more time and resources on business process improvement.

The cost of the construction project could be broadly divided into three major groups, namely: materials, labor and overhead. The materials can typically account for around 40% to 45% of the total cost in construction industry [1]. In addition, the labor cost in construction industry is generally governed by the availability of workers within the proximity, only the construction materials can provide the greatest flexibility in seeking the lower cost for the construction companies [2]. Therefore, an effective and efficient material supplier selection model which can help the developers to select the "best" suppliers at the right cost, in the right quantity, with the right quality at the right time has a significant effect in the business success of property developers [3].

The research of the supplier selection has a historical record. It is basically a multiple criteria decision making (MCDM) problem, which consists of three major stages: evaluation, prioritization and selection of alternatives [4]. There are two major approaches for researching supplier selection. The first approach focuses on which criteria are more effective, e.g. Dickson [5] identified 23 criteria for supplier selection based on the survey of 273 purchasing managers. The second approach concerns the selection methods for supplier selection and many methods were proposed to select suppliers in accordance with different selection criteria. However, there are some deficiencies of those methods which are affecting the quality of the result. First, the published methods do not deal with the inter-correlations, which will cause the problem of multicollinearity and add complexity to the evaluation process, among the supplier selection criteria. As a result, trade-offs and repetitive errors, which affect the final selection outcomes, are generated. Second, most of the criteria weighting allocation depend on the subjective judgments, which is not precisely made by the decision makers (DM) and the subjective errors shall affect the final selection outcomes. Third, during the selection process, most of the methods involve a large amount of selection criteria, which are not easy to implement in reality as they require high computational requirements and are time consuming.

This study aims to provide a user-friendly supplier selection model for the property developers to select their best material suppliers effectively and efficiently while mitigating the problems identified above.

2. Literature review

The major supplier selection methods can be broadly categorized into: categorical methods, analytic hierarchy process (AHP), analytic network process (ANP), data envelopment analysis (DEA) and

* Corresponding author. Tel.: +852 2788 7238; fax: +852 2788 7612.
E-mail address: bckclam@cityu.edu.hk (K.C. Lam).

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Table 1
The comparison of the selection methods' features.

Method / Features	Categorical methods	Analytic hierarchy process (AHP)	Analytic network process (ANP)	Data envelopment analysis (DEA)	Multiple attribute utility theory (MAUT)
1 Eliminate the multicollinearity among the selection criteria	×	×	×	×	✓
2 Automatically assign weights to each criterion	×	×	×	✓	×
3 Reduce the dimensionality of the selection data without much loss of information	×	×	×	×	×
4 User-friendly	✓	✓	×	×	✓
5 Handle both quantitative and qualitative criteria	×	✓	✓	×	✓
6 Ability to deal with large size alternatives	×	×	×	✓	✓
7 Reduce subjective error	×	×	✓	✓	×

multiple attribute utility theory (MAUT). The categorical methods are one of the most commonly used traditional methods for candidates' evaluation. They are qualitative methods based on historical data, with assigning good (+), neutral (0) or unsatisfactory (−) to each defined criteria for candidate suppliers [6]. AHP is a commonly used method to break down a complex problem into different levels and find out the interrelationships among them using pair-wise comparison [7]. By the help of AHP, the DMs can just make simple pair-wise judgments, typically with redundancy throughout the hierarchy, to arrive at overall priorities for the alternatives [8]. However, it is hard for the DMs to make accurate expression of relative preferences on the selection criteria due to the limitations of the 9-value scale of AHP [9]. ANP is used for catching the effects of the same level criteria on themselves and the effects for the alternatives on the criteria [10]. In addition, ANP can also reduce judgmental forecast error through reliability of information processing and is widely used for the selection process [11,12]. DEA is a linear programming method that can handle both multiple inputs and outputs. DEA can be regarded as a black-box method that can automatically derive optimal weights of criteria with the performance scores of the suppliers [13]. Castro-Lacouture et al. [14] applied the DEA as a supply chain optimization

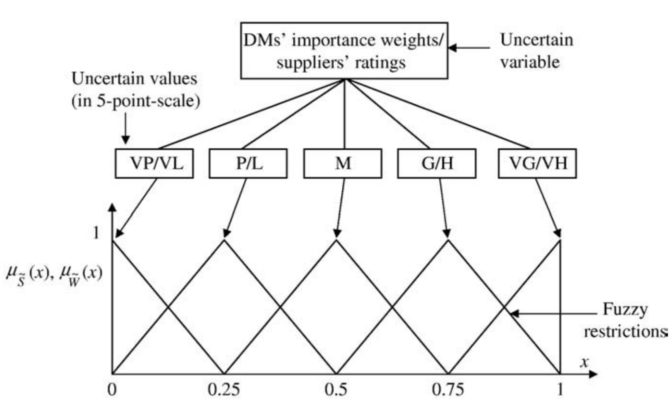

Fig. 1. Membership functions of DMs' importance weights and suppliers' ratings (modified from [27]).

tool for the construction material (rebar) supplier selection. There were also some other applications such as technology selection [15] and vender performance [16] of DEA to solve the supplier selection problem. MAUT is a well-established analytical method for complex decision making problem such as selection with the ability to deal with both deterministic and stochastic decision environments [17]. It can also help to break down a complex problem into simply hierarchy manner and evaluate a large number of quantitative and qualitative factors in the presence of risk and uncertainty [18].

Literature reviews show that an optimal supplier selection method should include the capabilities of: first, eliminate the multicollinearity among the selection criteria; second, automatically assign weights to each criterion; third, reduce the dimensionality of the selection data without much loss of information [19]; fourth, user-friendly [8]; fifth, handle both quantitative and qualitative criteria [17]; sixth, ability to deal with large size alternatives; last but not least, reduce subjective error [13]. Based on these seven capabilities or features of an optimal supplier selection method, the above methods are compared and summarized in Table 1.

Although each of the above mentioned methods does have its own features to solve specific supplier selection problem, no single method can provide all features. Therefore, an optimal method which could have these seven features is needed to aid the DMs to solve the supplier selection problem.

3. Methodology

3.1. Triangular Fuzzy Numbers (TFN)

Practically for the property developers, a supplier selection process involves indistinct needs and vague preferences such as reputation, relationship, etc. [20]. Such subjective, imprecise and uncertain information need to be translated into quantitative data for decision making. Fuzzy sets, which were first introduced by Zadeh [21], are one of the widely used methods to solve this kind of problem. It is specially designed to mathematically represent uncertainty and vagueness and provides formalized tools for dealing with the imprecise and intrinsic factors to many decision problems [22]. In this study, one of the most widely used fuzzy set i.e. triangular fuzzy set is employed to quantify the qualitative information. As a result, all the fuzzy variables are represented as Triangular Fuzzy Numbers $\tilde{A}$. The reason of using TFN method is because of its intuitive, easy to use, computational simplicity, useful in promoting representation and information processing in a fuzzy environment [23,24]. According to Lam et al. [25], the membership function (μ) of $\tilde{A}$ can be defined as below:

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{(x-a)}{(b-a)}, & a \le x \le b, \\ \dfrac{(c-x)}{(c-b)}, & b \le x \le c, \\ 0 & \text{Otherwise.} \end{cases} \tag{1}$$

with $-\infty < a \le b \le c < \infty$.
where a is the lower bound of variable x; b is the strongest grade of membership; c is the upper bound of variable x.

In this study, all the qualitative information i.e. the important weights of DMs ($\tilde{W}$) and the ratings assigning to the candidates by DMs in accordance with the subjective criteria ($\tilde{S}$) should be firstly decided. In addition, according to the "seven plus or minus two" principle [26], the scale of five (see Fig. 1) is adopted in this study. It brings the convenience to the DMs to make the subjective judgments. For the $\tilde{W}$, the five-point-scale can be defined as: Very Low (VL), Low (L), Medium (M), High (H), Very High (VH). For the $\tilde{S}$, the five-point-scale can be defined as: Very Poor (VP), Poor (P), Medium (M), Good (G), Very Good (VG). Therefore, the $\tilde{W}$ and $\tilde{S}$ can be represented by the TFN and their μ are shown in the Fig. 1.