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A weighted additive fuzzy programming approach for multi-criteria supplier selection

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ABSTRACT

In supply chain management, to build strategic and strong relationships, firms should select best suppliers by applying appropriate method and selection criteria. In this paper, to handle ambiguity and fuzziness in supplier selection problem effectively, a new weighted additive fuzzy programming approach is developed. Firstly, linguistic values expressed as trapezoidal fuzzy numbers are used to assess the weights of the factors. By applying the distances of each factor between Fuzzy Positive Ideal Rating and Fuzzy Negative Ideal Rating, weights are obtained. Then applying suppliers' constraints, goals and weights of the factors, a fuzzy multi-objective linear model is developed to overcome the selection problem and assign optimum order quantities to each supplier. The proposed model is explained by a numerical example.

1. Introduction

In today's highly competitive and global markets, a firm should establish long term and strategic relationships with its suppliers to accomplish goals of the supply chain effectively. In order to cope with this strategically important issue and manage purchasing function effectively, firms should select best supplier(s) by applying proper model and criteria.

Within its nature, supplier selection is a Multi-Criteria Decision Making (MCDM) problem that includes several tangible and intangible factors. A study carried out by Dickson (1966) that based on a questionnaire sent to 273 purchasing agents and managers from the United States of America and Canada identified 23 commonly used criteria for the problem. As a result, quality, delivery and performance history were concluded as three most important criteria out of them. In another research, based on academic literature, Weber, Current, and Benton (1991) used Dickson's 23 criteria and reviewed 74 related articles appeared since 1966. They noted that 47 of the 74 articles (64%) discussed more than one criteria and this demonstrates the multi-objective nature of many supplier selection decisions. Also they indicated that net price, delivery and quality were discussed in 80, 59 and 54% of the articles respectively.

Several methods have been appeared in literature for supplier selection problem. Mazurak, Rao, and Scotton (1985) applied a linear weighting model that includes quality, delivery, net price and financial position as selection criteria. Weber (1996) developed a model based on Data Envelopment Analysis (DEA) to evaluate the efficiency of suppliers in a just-in-time environment. Yahya and Kingsman (1999) used Saaty's Analytic Hierarchy Process (AHP) method to provide a systematic way for scoring the performance of suppliers. Also in supplier selection problems, hybrid methods have been developed to complement the weaknesses of each method and construct effective selection systems. Ghodsypour and O'Brien (1998) applied an integration of AHP and LP to consider both tangible and intangible factors in choosing the best supplier(s) and placing the optimum order quantities among them. Ha and Krishnan (2008) proposed a hybrid method that incorporates AHP, DEA and Neural Network (NN) techniques into an evaluation process in order to select competitive suppliers in supply chain. The integrated method enables to solve single sourcing and multiple sourcing problems by calculating Combined Supplier Score (CSS). On the other hand, Ustun and Demirtas (2008) presented a two-stage mathematical model to choose best suppliers and determine the optimum order quantities among selected suppliers. In first stage, four different suppliers that produce the plastic parts of a refrigerator plant are evaluated by using Analytic Network Process (ANP). In second stage, the weights derived from first stage are used as coefficients to build the Multi-Objective Mixed Integer Linear Programming (MOMILP) model of the problem to maximize the total value of purchasing.

The tangible and intangible factors in supplier selection problem cause vagueness and ambiguity in decision-making process. Fuzzy Set Theory (FST) is applied as an efficient tool to handle this uncertainty effectively and convert human judgments into

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meaningful results. Chen, Lin, and Huang (2006) presented an extended version of TOPSIS based on FST to select best supplier in a single sourcing problem. Guneri, Yucel, and Ayyildiz (2009) developed an integrated model based on FST and linear programming. In proposed model, integration with linear programming enabled decision-makers to assign order quantities to each supplier considering the Total Value Purchase (TVP) maximizing objective. Faez, Ghodsypour, and O'Brien (2009) applied a model that adds fuzzy logic concept into Case Based Reasoning (CBR) method and integrates with a mixed integer programming model for supplier selection and order allocation. Chan and Kumar (2007) presented a Fuzzy Extended AHP (FEAHP) approach to select the best global supplier for a manufacturing firm to supply one of its most critical parts used in assembling process and applied triangular fuzzy numbers as a pairwise comparison scale for deriving the priorities of different selection criteria and attributes such as overall cost of the product, rejection rate of the product, response to changes, political stability and geographical location. Erol and Ferrell (2003) used fuzzy QFD to convert qualitative information into quantitative parameters and then combined this data with other quantitative data to parameterize a multi-objective mathematical programming model. The methodology allowed both qualitative and quantitative data to be included by applying fuzzy QFD as a translator for the linguistic inputs. A review of articles that based on fuzzy logic concept for supplier selection problem is presented in Table 1.

This paper focuses on fuzzy multi-objective linear model to deal with the problem. In literature, Zarandi and Saghiri (2003) applied multi-objective programming approach and fuzzy methodology jointly to develop a Fuzzy Multiple Objectives Decision Making (FMODM) model for supplier selection process. In proposed model, firstly a fuzzy supplier selection model with multiple products/suppliers, fuzzy objective functions (goals), fuzzy constraints and fuzzy coefficients is developed and then the developed model is converted to a single objective one step by step. In another article, Kumar, Vrat, and Shankar (2006) presented a "fuzzy Multi-objective Integer Programming Vendor Selection Problem" (f-MIP_VSP) formulation that incorporates cost-minimization, quality-maximization and maximization of on-time delivery goals with the buyers' demand and suppliers' capacity constraints. In these two articles, weights for selection criteria are treated as equal importance and this approach is defined as symmetric approach. On the other hand, for the first time in a fuzzy supplier selection problem Amid, Ghodsypour, and O'Brien (2006) developed an asymmetric fuzzy multi-objective linear model that enables the decision-makers to assign different weights to various criteria in the problem. In addition, Amid, Ghodsypour, and O'Brien (2009) presented a fuzzy weighted additive and mixed integer linear programming method that includes minimizing the net cost, minimizing the net rejected items and minimizing the net late deliveries objective functions with capacity and demand requirement constraints under price breaks in a supply chain. In these two papers, Amid and his colleagues assigned different weights to selection criteria according to decision makers' relative importance without concentrating on the calculation methodology of these weights and in illustrative examples of the presented models weights are taken as assumptions.

In this paper, related to calculation methodology of factors' weights, a new model is developed that complements this weakness and proposes a complete fuzzy multi-objective linear model approach for the supplier selection problem. Firstly, linguistic values expressed as trapezoidal fuzzy numbers are used to assess the weights of the factors. Similar to TOPSIS approach, new terms are presented as Fuzzy Positive Ideal Rating (FPIR) and Fuzzy Negative Ideal Rating (FNIR) to compute weights of factors. Then applying suppliers' constraints, goals and weights of the factors, a fuzzy multi-objective linear model is developed to overcome the supplier selection problem and assign optimum order quantities.

The paper is organized as follows. Section 2 introduces the basic definitions and notations of fuzzy numbers and calculation procedure of weights. In Section 3, we present principles of fuzzy multi-objective linear model and algorithm of the entire developed model. A numerical example of the proposed model is presented in Section 4. Finally, conclusions are drawn in Section 5.

2. Basic definitions and calculation model of factors

Definition 2.1. A positive trapezoidal number $\tilde{n}$ can be defined as (n_1, n_2, n_3, n_4) shown in Fig. 1 and the membership function $\mu_{\tilde{n}}(x)$ is expressed as: (Kaufmann & Gupta, 1991)

$$\mu_{\tilde{n}}x = \begin{cases} 0, & x < n_1, \\ \frac{x-n_1}{n_2-n_1}, & n_1 \leqslant x \leqslant n_2, \\ 1, & n_2 \leqslant x \leqslant n_3, \\ \frac{x-n_4}{n_3-n_4}, & n_3 \leqslant x \leqslant n_4, \\ 0, & x > n_4. \end{cases} \quad (1)$$

For a trapezoidal number if $n_1 = n_2$ then the number is called as triangular fuzzy number.

Definition 2.2. A linguistic variable is a variable whose values are expressed in linguistic terms. For example, if "temperature" is interested as a linguistic variable, then its term set could be "very low", "low", "comfortable", "high" and "very high" (Zimmermann, 1991). In this paper, decision makers use the linguistic values shown in Fig. 2 to assess the weights of the factors in fuzzy multi-objective linear model.

Let $\tilde{m} = (m_1, m_2, m_3, m_4)$ and $\tilde{n} = (n_1, n_2, n_3, n_4)$ be two trapezoidal fuzzy numbers. Then the distance between them can be calculated by using the vertex method as: (Chen, 2000)

$$d_v(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{4}\left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2 + (m_4 - n_4)^2\right]}. \quad (2)$$

Assume that a decision group has K decision makers as $k = 1, 2, \ldots, K$ and considers a set of m criteria as $j = 1, 2, \ldots, m$ for a supplier selection problem. Then the aggregated fuzzy weights $(\tilde{w}_j)$ of each criterion can be calculated as: (Chen et al., 2006)

$$(\tilde{w}_j) = (w_{j1}, w_{j2}, w_{j3}, w_{j4}),$$

where

$$w_{j1} = \min_k\{w_{jk1}\}, \quad w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2},$$
$$w_{j3} = \frac{1}{K}\sum_{k=1}^{K} w_{jk3}, \quad w_{j4} = \max_k\{w_{jk4}\}. \quad (3)$$

Similar to TOPSIS approach and considering the linguistic variables (lv), Fuzzy Positive Ideal Rating (FPIR – $A*$) and fuzzy negative-ideal rating (FNIR – A^-) of a selection criterion can be defined as:

$$A^* = lv^*,$$
$$A^- = lv^-. \quad (4)$$

According to the linguistic variables shown in Fig. 2, FPIR and FNIR of a selection criterion can be expressed as respectively, "very high" (0.8, 0.9, 1.0, 1.0) and "very low" (0.0, 0.0, 0.1, 0.2). The distance between aggregated fuzzy weights $(\tilde{w}_j)$ of each criterion and ideal ratings can be calculated by applying vertex method (2).