An Integrated Fuzzy DEA and Fuzzy Goal Programming Approach for Selecting Suppliers

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Abstract: - Supplier evaluation and selection is a critical decision process for companies in order to gain competitive advantage. Decision models focusing on risk minimization have recently received increasing attention in supplier selection literature. In this paper, risk factors, which incorporate qualitative as well as quantitative data, are employed in fuzzy data envelopment analysis for obtaining efficient supplier alternatives. Linguistic variables are used to quantify the impreciseness inherent in risk criteria. A fuzzy goal programming model is formulated to determine order quantities allocated to the appropriate suppliers determined by fuzzy data envelopment analysis. Decision makers' desired achievement degrees for fuzzy purchasing goals are aggregated using the average operator. A supplier selection problem is presented to illustrate the application of the proposed fuzzy group decision making approach based on fuzzy data envelopment analysis and fuzzy goal programming.

Key-Words: Fuzzy data envelopment analysis, fuzzy goal programming, risk, supplier selection

1 Introduction

Purchasing decisions are crucial for a successful supply chain. Although managers' primary concern is the reduction of costs, various aspects must be considered in buying processes. These decisions include the selection of suppliers and the determination of order quantities allocated to the selected suppliers [1]. When no one supplier can satisfy the buyer's total requirements, some part of the demand needs to be purchased from one supplier and the rest from the others [2].

This research investigates the supplier selection problem when the buyer's demand for one product cannot be satisfied completely by one supplier due to capacity constraints of possible alternatives.

In this paper, firstly, fuzzy data envelopment analysis (DEA) is employed to evaluate supplier alternatives in presence of quantitative and qualitative criteria. Then, a fuzzy goal programming model is built in order to find how much purchased from each of selected alternatives.

The rest of the paper is organized as follows. The following section presents the fuzzy DEA methodology. Section 3 outlines the fuzzy goal programming method. The proposed fuzzy approach is given in Section 4. The application of the decision framework to an illustrative supplier selection problem is delineated in Section 5. Finally, Section 6 presents concluding remarks and directions for further research.

2 Fuzzy Data Envelopment Analysis

Data Envelopment Analysis (DEA), first proposed by Charnes et al. [3] is a non-parametric linear programming-based decision making technique which measure the efficiency of decision making units (DMUs) calculated for each DMU as the ratio of its total weighted outputs to weighted inputs [4].

In real world problems, input and output data are sometimes imprecise. Since the pioneer work of Sengupta [5] fuzzy methods are used in DEA models. Hatami-Marbini et al. [6] present a review and a taxonomy of the fuzzy DEA methods published in the literature.

In this paper fuzzy DEA model proposed by Saati et al. [7] is employed due to the need to consider qualitative as well as quantitative data. The model presented in (1), is based on the concept of α-cut.

This model is equivalent to a parametric programming model with parameter α. For each value of α, the decision maker has an optimal solution.

$$\max E = \bar{y}_p \tag{1}$$

subject to

$$\bar{x}_p = 1$$
$$\bar{y}_j - \bar{x}_j \le 0$$
$$v(\alpha x_j^m + (1-\alpha)x_j^l) \le \bar{x}_j \le v(\alpha x_j^m + (1-\alpha)x_j^u) \quad \forall j,$$
$$u\ (\alpha y_j^m + (1-\alpha)y_j^l) \le \bar{y}_j \le u(\alpha y_j^m + (1-\alpha)y_j^u) \quad \forall j,$$
$$u, v \ \ge 0$$

3 Fuzzy Goal Programming

Goal programming (GP), first employed by Charnes et al. [8], is a multi-objective optimization tool which deals simultaneously with conflicting objective measures for multiple criteria decision making (MCDM) problems. In a fuzzy environment, to specify imprecise aspiration levels of the goals, Narasimhan [9] had initially proposed fuzzy goal programming by using membership functions.

Some goals are usually have a higher priority than the others under system constraints. In the fuzzy goal programming model proposed by Chen and Tsai [10], decision-makers can specify an achievement degree for each fuzzy goal based incorporate the preemptive priority structure. The desirable minimum achievement degrees are added to the formulation (2) based on linear membership functions presented by Zimmerman [11], as constraints.

$$Max \qquad f(\mu) = \sum_{k=1}^{n} \mu_k \tag{2}$$

$$\text{subject to} \qquad \mu_{\mathrm{i}} = \frac{G_i(x) - L_i}{g_i - L_i} \quad \text{for some } i,$$
$$\mu_{\mathrm{j}} = \frac{U_i - G_i(x)}{U_i - g_i} \quad \text{for some } j, \quad j \ne i,$$
$$\mathrm{Ax} \le b,$$
$$\mu_i, \mu_j \le 1,$$
$$x, \mu_i, \mu_j \ge 0; \qquad i, j \in \{1, \ldots, n\},$$

where L_i is the lower tolerance limit, U_i is the upper tolerance limit for the i^{th} fuzzy goal and g_i is the aspiration level.

4 Integrated Decision Approach

In this paper, firstly, the performance of candidate suppliers is measured by using fuzzy DEA methodology. Risk criteria are employed as input and output of fuzzy DEA model. Uncertainties on decision making of supplier selection lead the firms to consider risk criteria in related process. Generally, firms collaborate with suppliers by taking into consideration only profit maximization obtained by suppliers, risk minimization is a relatively novel objective of supplier selection process.

Once the efficient supplier alternatives depending risk criteria are identified by fuzzy DEA, in order to find best order quantities, a fuzzy preemptive goal programming model is formulated.

The factors that affect the risk of suppliers are determined by examining the literature. In this study four criteria related to risk are selected from a number of criteria collected from the literature. These criteria are rejected items (poor product quality) [12, 13, 14, 15]; late delivery [12, 13, 14, 15, 16], financial status [12, 13, 15, 16, 17, 18], and technological capability to respond changes in product design [12]. The number of rejected items per 1000 products and late delivery are considered as inputs; supplier's financial status and technological capability are considered as outputs. Late delivery and technological capability criteria are evaluated by the related department's managers using linguistic variables.

Multi-objective programming combined with DEA methodology has been used [19, 20] in the literature on supplier evaluation and selection, and Talluri et al. [21] presented a chance-constrained data envelopment analysis approach considering risk factors (price as the input, quality and delivery as the outputs) to measure vendor performance. Kumar et al. [22, 23] employed fuzzy goal programming in order to solve supplier selection problems.

In this paper fuzzy goal programming is used to find best order quantities from supplier alternatives determined by fuzzy DEA methodology. The total purchasing cost [22, 23], the number of rejected items [22, 23], and order quantities are considered as goals for fuzzy programming approach. Experts' desired achievement degrees for fuzzy goals are aggregated using the average operator.

5 Illustrative Problem

The supplier selection problem considered in this paper uses hypothetical data for 6 supplier alternatives. The assessment matrix for risk related criteria; namely rejected items (input 1), late delivery (input 2), financial status (output 1) and technological capability (output 2), are given in Table 1.

Table 1. Risk data for supplier alternatives

	input 1	input 2	output 1	output 2
Supplier1	7	VH	6	H
Supplier2	12	M	9	M
Supplier3	3	H	5	DH
Supplier4	8	DL	7	H
Supplier5	10	L	8	VH
Supplier6	15	M	5	DH

The fuzzy scale for the linguistic term set is considered as DL: (0, 0, 0.16), VL: (0, 0.16, 0.33), L: (0.16, 0.33, 0.50), M: (0.33, 0.50, 0.66), H: (0.50, 0.66, 0.83), VH: (0.66, 0.83, 1), DH: (0.83, 1, 1). Efficiency scores for different values of α calculated using fuzzy DEA model (1) are shown in Table 2. For α = 0.1, 0.3, 0.5, 0.7 supplier alternatives 3, 4, and 5 are efficient.

Table 2. Efficiency scores for different values of α

	0.1	0.3	0.5	0.7	1
Supplier1	0.878	0.748	0.717	0.694	0.658
Supplier2	0.825	0.805	0.784	0.763	0.732
Supplier3	1	1	1	1	1
Supplier4	1	1	1	1	1
Supplier5	1	1	1	1	0.858
Supplier6	0.967	0.844	0.743	0.658	0.553

In order to find best order quantities from these three suppliers, a fuzzy goal programming model including five objectives (the total purchasing cost, the number of rejected items, and order quantities from three suppliers) subject to system constraints (total demand of the buyer and the capacity constraints of the suppliers) is formulated.

Fuzzy goals:
Goal 1: $8 x_3 + 8 x_4 + 7 x_5 \leq 205000$
Goal 2: $0.003 x_3 + 0.008 x_4 + 0.01 x_5 \leq 175$
Goal 3: $x_3 \geq 16000$
Goal 4: $x_4 \geq 6000$
Goal 5: $x_5 \geq 5000$

subject to
$x_3 + x_4 + x_5 \geq 25000$
$x_3 \leq 20000$
$x_4 \leq 10000$
$x_5 \leq 10000$
$x_3, x_4, x_5 \geq 0$.

where x_i (i=3, 4, 5) correspond to the quantities ordered from supplier i.

The tolerance limits of the five fuzzy goals are (210000, 195, 14000, 5000, 4000). The desirable achievement degrees of fuzzy goals are determined by calculating the average of priority degrees given by two experts, which are shown in Table 3. Consequently, the desirable achievement degrees of the five fuzzy goals are (0.9, 0.9, 0.6, 0.6, 0.6).

Table 3. The desirable achievement degrees for fuzzy goals

	Decision maker 1	Decision maker 2
Goal 1	0.9	0.9
Goal 2	0.9	0.9
Goal 3	0.4	0.8
Goal 4	0.5	0.7
Goal 5	0.6	0.6

The resulting achievement degree is 1.0 for the first, second, fourth and fifth fuzzy goals and the achievement degree is equal to 0.625 for the third goal. 15250 items can be purchased from supplier alternative 3, 6000 items from supplier alternative 4, and finally 5000 items can be ordered from supplier 5.

6 Conclusion

This research investigates the supplier selection problem when no one supplier can satisfy the buyer's total demand for one product. To solve this problem a fuzzy approach integrating fuzzy DEA and fuzzy goal programming is proposed. Risk criteria are employed in fuzzy DEA as inputs and outputs for obtaining efficient supplier alternatives. A goal programming model with fuzzy goals is formulated to find order quantities.

Future research will focus on the use of the 2-tuple linguistic representation model to define the importance of the fuzzy goals. The fuzzy 2-tuple linguistic approach allows making computations with linguistic values and rectifies the problem of loss of information. Future works will address the application of the decision framework presented in here to real-world group decision making problems.

Acknowledgement:
This research has been financially supported by Galatasaray University Research Fund Project 16.402.017.

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