A Decision Framework to Select Suppliers Considering Risk Criteria

Zeynep Sener, Michele Cedolin, Nazli Goker, and Mehtap Dursun

Abstract—**The primary objective of supplier selection is usually to maximize buyer's profit. Risk minimization is an emerging concept in this decision-making process which has conflicting criteria and requires qualitative assessment. Hence, a fuzzy multiple criteria decision making approach should be employed for solving the problem. This paper presents a fuzzy group decision-making framework based on regression analysis and fuzzy linear programming in order to identify the most appropriate supplier alternative by introducing risk into the supplier evaluation process.**

Index Terms—**Supplier selection, risk, fuzzy regression, fuzzy linear programming**

I. Introduction

Supply chain operations become major elements rather than support elements for the companies in global markets. Growing market competition enables firms to establish more successful and sustainable relationships with their suppliers. However, supply chain operations have been undergone different kinds of risks as a result of globalization [1]. Besides, increasing dependency on suppliers makes companies more encountered to supply risks [2]. Investing in partnerships with suppliers can improve company performance [3], thus it is very crucial to analyze risks of long-term suppliers.

Supplier selection process possesses strategic importance in all operations related to supply chain management; however, researchers have not commonly focused on incorporating risk concept into the supplier selection problem. In general, 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.

Uncertainties on decision making of supplier selection lead the firms to consider risk criteria in related process. Supplier selection criteria can be classified as the quality risk of the product, service risk, supplier's profile risk and long term cooperation risk [1]. Rejection rate, on-time delivery rate, financial status, performance history, production facility and capacity, rapid response to changes, technological and R&D support, ease of communication are the examples of the supplier's risk criteria employed in the literature [1]. Positive as well as negative aspects of the suppliers should be considered simultaneously for the appropriate and sustainable supplier selection process [4].

Over the last decade, scholars have contributed to supplier selection problem by considering risk concept and introducing risk factors, and they proposed several decision making approaches to identify the most appropriate supplier alternative. Chan and Kumar [5] and Chan et al. [6] used analytic hierarchic process (AHP) for selecting the most suitable supplier. Aghai et al. [7] employed a multi-objective programming approach for solving the same problem. Chatterhee and Kar [8] indicated the best supplier by applying technique for order preference by similarity to ideal solution (TOPSIS) method. Ramkumar [9] employed ANP methodology to identify the most appropriate supplier. Sheikhalishahi and Torabi [10] solved a fuzzy goal programming model to determine the most suitable supplier. Govindan and Jepsen [11] used ELECTRE TRI-C method for sorting suppliers into risk categories. Deng et al. [12] proposed a decision approach by integrating decision making and trial evaluation laboratory (DEMATEL) method to AHP. Lee [4] constructed a benefit, opportunity, cost and risk (BOCR) framework in order to rank supplier alternatives. Nepal and Yadav [13] created a Bayesian network for supplier selection.

This work proposes a group multiple criteria decision making approach incorporating risk factors. The fuzzy regression methodology is used to obtain a descriptive risk equation in a way to relate risk level of suppliers to predetermined risk factors. This approach enables supply chain managers to possess a mathematical expression of risk rather than a subjective evaluation. A fuzzy boolean linear programming model using the obtained risk scores from fuzzy regression methodology, is built in order to select the most suitable supplier alternative.

The rest of the paper is organized as follows. Section II provides a concise treatment of fuzzy linear regression. Section III delineates a fuzzy group decision making framework for supplier evaluation and selection. The application of the proposed model is presented through a supplier selection problem in section IV. Conclusions are given in section V.

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II. FUZZY LINEAR REGRESSION METHODOLOGY

Fuzzy linear regression analysis methodology was first introduced by Tanaka et al. [14]. It provides an alternative approach to classical regression for modeling situations where the relationships are not precisely defined or the assumptions of statistical regression cannot be satisfied by the available data.

Tanaka et al. [14] delineated a fuzzy linear regression function as

$$\tilde{y}_i^* = \tilde{A}_0 + \tilde{A}_1 x_{i1} + \tilde{A}_2 x_{i2} + ... + \tilde{A}_N x_{iN} \quad (1)$$

In (1), $\tilde{A}_j$ denotes a symmetric triangular fuzzy number with center m_j and spread s_j for computational simplicity. The problem in the fuzzy linear regression model is to determine fuzzy parameter estimates $\tilde{A}_j$ ={(m_0, m_1, …, m_n), (s_0, s_1,…, s_n)} such that the membership value of y_i to its fuzzy estimate is at least H. $H \in [0,1]$, which is referred to as a measure of goodness of fit, is selected by the decision-maker [15]. The aim of the fuzzy linear regression analysis is to minimize the total fuzziness of the predicted values for the dependent variables.

Three cases for input-output data, which are crisp input and output, crisp input-fuzzy output, and fuzzy input and output respectively, are considered in fuzzy regression analyses. In this study, fuzzy linear regression model for crisp input-fuzzy output is employed.

The problem with the given fuzzy dependent variable or fuzzy output (y_i, e_i) leads to the following linear programming model [16]:

$$\text{Min} \sum_{j=0}^{N} \left(s_j \sum_{i=1}^{M} \left| x_{ij} \right| \right) \quad (2)$$

subject to

$$\sum_{j=0}^{N} m_j x_{ij} + \left| L^{-1}(H) \right| \sum_{j=0}^{N} s_j \left| x_{ij} \right| \geq y_i + \left| L^{-1}(H) \right| e_i ,$$

$$\sum_{j=0}^{N} m_j x_{ij} - \left| L^{-1}(H) \right| \sum_{j=0}^{N} s_j \left| x_{ij} \right| \leq y_i - \left| L^{-1}(H) \right| e_i ,$$

$$x_{i0} = 1, \; i = 1, 2, ..., M$$

$$s_j \geq 0, \quad j = 0, 1, \ldots, N$$

where L is equal to

$$L(x) = \max(0, 1 - |x|) \rightarrow \left| L^{-1}(H) \right| = (1 - H) \; .$$

III. FUZZY GROUP DECISION MAKING APPROACH FOR SUPPLIER SELECTION

Risk levels of suppliers are generally determined by supply chain managers subjectively, on an ad hoc basis. Thus, these assessments which reflect decision makers' thoughts are not consistent. This paper proposes the use fuzzy regression analysis for obtaining a functional relationship to relate risk level to selected supplier performance criteria. The factors that affect the risk of suppliers are determined by examining the literature. In this study three criteria related to risk are selected from a number of criteria collected from the literature. These criteria are poor product quality [1], [17], [18], and [19]; late delivery [1], [2], [17], [18], and [19]; and financial status [1], [2], [4], [10], [17], and [19].

A fuzzy linear regression model is built in a way to relate risk level, which is used as the dependent variable, to poor quality product rate, delayed products rate and financial status which are independent variables. Predicted risk scores for each supplier alternative are calculated by employing the resulting fuzzy regression equation. Finally, a fuzzy Boolean programming model which aims to minimize the risk score subject to capacity [1], [2], [4] and [17] and cost variability [2], [4], [10], [11], [18], and [19] constraints is solved for selecting the most suitable supplier alternative. This paper uses fuzzy ranking methods to obtain a nonfuzzy objective function with crisp values instead of fuzzy risk scores, as described in Herrera and Verdegay [20].

IV. ILLUSTRATIVE PROBLEM

Supplier evaluation and selection problem considered in here uses hypothetical data for five supplier alternatives. The percentage of poor quality products, the percentage of delayed products and the financial status (scaled from 1 to 10) are given in Table I.

Risk level of supplier alternatives are evaluated by two experts using linguistic variables, which are shown in Table II.

TABLE I
DATA FOR RISK RELATED CRITERIA

Supplier alternative	Poor quality products rate	Delayed products rate	Financial status
1	1.8	8	7
2	1.3	10.4	5
3	0.5	7	8
4	1	9.2	7
5	0.7	7	6

TABLE II
RISK ASSESSMENTS FOR SUPPLIER ALTERNATIVES

Supplier alternative	Risk level (Decision maker 1)	Risk level (Decision maker 2)
1	H	VH
2	VH	VH
3	L	VL
4	M	M
5	L	M

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The linguistic variables are quantified using a linguistic scale as follows [21]: very low VL (0, 1, 2), low L (2, 3, 4), medium M (4, 5, 6), high H (6, 7, 8), very high VH (8, 9, 10). The risk assessments obtained from two experts are aggregated using the fuzzy average operator.

A fuzzy linear regression model is built in a way to relate risk level of supplier alternatives to poor quality products rate, delayed products rate, and financial status. The resulting predicting equation using (2) with H= 0.5 is as follows:

TABLE III
PREDICTED RISK SCORES

Supplier alternative	Center value	Spread value
1	7.754	1.496
2	8.532	1.945
3	1.847	1.309
4	5.362	1.720
5	4.156	1.309

Risk score = (3.472, 0) + (3.614, 0) Poor quality products rate + (0.416, 0.187) Delayed products rate – (0.793, 0) Financial status

TABLE IV
CAPACITY CONSTRAINT

Supplier alternative	Production capacity
1	14000
2	22000
3	18000
4	25000
5	30000

TABLE V
PRICE VARIABILITY

Supplier alternative	Price increase
1	10
2	10
3	10
4	5
5	20

where the first term in the parentheses correspond to center, and the second term correspond to spread of fuzzy numbers.

The predicted risk scores for each alternative are calculating using the fuzzy regression equation. Table III shows the center and spread values for the fuzzy risk scores.

The suppliers' production capacity and the percentage of price increase for short term are given in Table IV and Table V, respectively.

In order to select the most appropriate supplier alternative, a fuzzy boolean programming model which aims minimizing the risk of supplier subject to capacity and price variability constraints, is built.

Min $(7.754, 1.496)x_1 + (8.532, 1.945)x_2 + (1.847, 1.309)x_3 + (5.362, 1.720)x_4 + (4.156, 1.309)x_5$

subject to (3)

$14000x_1 + 22000x_2 + 18000x_3 + 25000x_4 + 30000x_5 \geq 20000$
$0.10x_1 + 0.10x_2 + 0.10x_3 + 0.05x_4 + 0.20x_5 \leq 0.15$

$x_1 + x_2 + x_3 + x_4 + x_5 = 1$
x_1, x_2, x_3, x_4, x_5 {0, 1}

In order to solve (3), fuzzy ranking methods can be used to obtain a non fuzzy objective function [20]. When the first index of Yager [20] is employed as fuzzy ranking method, supplier alternative 4 is selected.

V. Conclusion

In this study, a group multiple criteria decision making methodology incorporating risk factors, is proposed. This approach, which uses fuzzy regression to obtain a descriptive risk equation, enables managers to possess a mathematical expression of risk rather than a subjective evaluation. The most suitable supplier alternative is selected by solving a fuzzy boolean linear programming model. Future research will focus on applying the proposed approach to supplier selection problems using real data. Various supplier selection criteria and constraints can be added to real-world problems.

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