A Fuzzy Group Decision Making Approach for Agility Evaluation in Aviation Industry

Mehtap Dursun, Nazli Goker, and Osman Ogunclu

Abstract—**The problem of dealing with unpredictable and uncertainty emerges the agility concept which denotes the capability of firms for responding immediately to environmental changes. To obtain supply chain agility, agile supplier selection becomes a crucial managerial problem due to its multi-objective framework with conflicting criteria. This study introduces a fuzzy group decision making approach for agile supplier evaluation. A case study conducted to determine the most appropriate fuel supplier in aviation industry is introduced to illustrate the application of the decision methodology.**

Index Terms—**Agility, fuzzy decision making, fuzzy multiple objective programming, supplier selection.**

I. Introduction

AGILITY for businesses, which is emerged from the need of dealing with unpredictable changes and uncertainty, denotes the capability of a company to give immediate response successfully to change [1]. Agility concept refers to the ability of surviving by replying instantaneously and effectively to market changes, the competence of an institution to grow in an unpredictable and changing business environment. Over the manufacturing perspective, the idea of agility introduced in related area and became popular in 1991 by researchers at the Iaccoca Institute of Lehigh University. The idea emerged through the perception of industry authorities whose objective was to achieve a significant contribution in the manufacturing perspective to focus on revolutions in the global market which was hardly competitive.

The term agile manufacturing is defined as an exceptionally capable manufacturing system within competence including technologies and human resources with trained management, information. Moreover, agile manufacturing system responses quickly to the changes in demand, therefore flexibility and responsiveness are the main conceptual components of an agile production system [1]. Through the supply chain perspective; objective of the agility concept is similar with the manufacturing perspective, which is adaptation for rapid changes in the global environment to keep competitive ability. Since supplier selection is one of the most crucial decision problem of supply chain management, companies should collaborate with agile suppliers in order to construct an agile supply chain for being able to give quick responses to the changes.

Since gaining competitive power is crucial for the firms and agility becomes one of the most efficient concepts, agile manufacturing catches great deal of attention. In this point, achieving manufacturing agility is not adequate by itself, yet it should be supported by supply chain agility as well. In order to achieve supply chain agility, agile supplier selection with relevant evaluation methodology and criteria becomes the considerably important problem to be questioned in this work.

Over the last decade, researchers have contributed to the agile supplier selection problem by proposing several decision approaches. Chu and Varma [2] compared fuzzy technique for order preference by similarity to ideal solution (TOPSIS) and Fuzzy-MOORA in the context of supplier selection in agile supply chain. Viswanadham and Samvedi [3] determined the most suitable agile supplier alternative by developing a fuzzy MCDM framework. Lee et al. [4] constructed a decision framework which is based on Pareto frontier. They weighted agile supplier selection criteria with fuzzy AHP method, and selected the most appropriate agile supplier alternative by implementing fuzzy TOPSIS approach. Felice et al. [5] evaluated agile supplier alternatives with AHP method. Abdollahi et al. [6] evaluated agile suppliers based on the properties that are corresponding to product and organizational characteristics of them for obtaining competitive advantage in business environment and improving the level of flexibility against possible fluctuations in supply and demand. ANP was applied to indicate each criterion weight, data envelopment analysis (DEA) was implemented for ranking process. A fuzzy decision making trial and evaluation laboratory (DEMATEL) is used in order to resolve the interdependency. Beikkhakhian et al [7] weighted agile supplier selection criteria by using fuzzy analytic hierarchy process (AHP) approach, determined the most appropriate agile supplier alternative by employing fuzzy technique for order preference by similarity to ideal solution (TOPSIS) methodology. Matawale et al. [8] proposed a research with an application of fuzzy multi-level multi-criteria decision approach for agile supplier selection.

This paper proposes a group decision making approach based on fuzzy multiple objective programming for agile

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supplier evaluation. Linguistic variables and triangular fuzzy numbers are employed to quantify the impreciseness inherent in supplier selection criteria.

The rest of the paper is organized as follows. Section II presents the fuzzy multiple objective decision making procedure. The application of the decision approach to a real-world agile supplier evaluation problem is delineated in section III. Conclusion and future research directions are provided in the final section.

II. Fuzzy Multiple Objective Decision Making Procedure

Let X be the set of alternatives and C be the set of objectives that has to be satisfied by X. The objectives to be maximized and the ones to be minimized are denoted by Z_k and W_p, respectively. Considering these definitions, the model formulation is as [9]

$$\text{Max } \tilde{Z}(\mathbf{x}) = (\tilde{\mathbf{c}}_1\mathbf{x}, \tilde{\mathbf{c}}_2\mathbf{x}, \ldots, \tilde{\mathbf{c}}_l\mathbf{x}) \tag{1}$$

$$\text{Min } \tilde{W}(\mathbf{x}) = (\tilde{\mathbf{c}}'_1\mathbf{x},\ \tilde{\mathbf{c}}'_2\mathbf{x}, \ldots, \tilde{\mathbf{c}}'_r\mathbf{x})$$

subject to

$$\mathbf{x} \in X = \left\{ \mathbf{x} \geq \mathbf{0} \,\middle|\, \tilde{\mathbf{A}}\mathbf{x} * \tilde{\mathbf{b}} \right\},$$

where l is the number of objectives to be maximized, r is the number of objectives to be minimized, $\tilde{\mathbf{c}}_\mathbf{k}$ (k =1, …, l) and $\tilde{\mathbf{c}}'_\mathbf{p}$ (p = 1, …, r) are n-dimensional vectors, $\tilde{\mathbf{b}}$ is an m-dimensional vector, $\tilde{\mathbf{A}}$ is an m x n matrix, $\tilde{\mathbf{c}}_\mathbf{k}$, $\tilde{\mathbf{c}}'_\mathbf{p}$, $\tilde{\mathbf{A}}$ and $\tilde{\mathbf{b}}$'s elements are fuzzy numbers, and "*" indicates "≤", "≥" and "=" operators. The formulation given above is a multiple objective linear programming model. Here, the coefficients of the constraints and the objective functions are triangular fuzzy numbers, which are useful means in quantifying the uncertainty in decision making due to their intuitive appeal and computational-efficient representation [10]. The membership function of triangular fuzzy number coefficients represented by $\tilde{Q} = (q_1, q_2, q_3)$ is given as

$$\mu_{\tilde{Q}}(x) = \begin{cases} 0 & , \quad x < q_1 \\ (x - q_1)/(q_2 - q_1) , & q_1 \leq x \leq q_2 \\ (q_3 - x)/(q_3 - q_2) , & q_2 \leq x \leq q_3 \\ 0 & , \quad x > q_3. \end{cases} \tag{2}$$

The importance degree of each objective can be included in the formulation using fuzzy priorities [11]. The general representation for the membership function corresponding to the importance degrees can be given as

$$\mu_I(x) = \begin{cases} 0 & , \quad x < i_1 \\ (x - i_1)/(i_2 - i_1) & , i_1 \leq x \leq i_2 \\ 1 & , \quad x > i_2. \end{cases} \tag{3}$$

For a given value of α, using the maxmin approach, the formulation that incorporates fuzzy priorities of the objectives is stated as a deterministic linear problem with multiple objectives as follows:

$$\text{Max } \beta \tag{4}$$

subject to

$$\beta \leq \mu_I \circ \mu_k^{\alpha}(Z_k)$$
$$\beta \leq \mu_I \circ \mu_p^{\alpha}(W_p)$$
$$\beta \in [0,1]$$
$$x \in X_\alpha$$
$$x_j \geq 0, \quad j = 1, \ldots, n$$

where "$\circ$" is the composition operator, β is the grade of compromise to which the solution satisfies all of the fuzzy objectives while the coefficients are at a feasible level α, and X_α denotes the set of system constraints.

The "min" operator is non-compensatory, and thus, the results obtained by the "min" operator indicate the worst situation and cannot be compensated by other members that may be very good. A dominated solution can be obtained due to the non-compensatory nature of the "min" operator. This problem can be overcome by applying a two-phase approach employing the arithmetic mean operator in the second phase to assure a nondominated solution [12].

Lee and Li [12] proposed a two-phase approach, where in the first phase they solve the problem parametrically for a given value of α, and in the second phase, they obtain a nondominated solution using the value of α determined in the first phase. In this study, a modified version of the algorithm proposed by Lee and Li [12] is employed as given below.

A. First Phase

Define λ = step length, τ = accuracy of tolerance, k = multiple of step length, c = iteration counter. Set k:=0, c:=0. Set $\alpha_c := 1 - k\lambda$.

Solve the problem for α_c to obtain β_c and x_c. If $\alpha_c - \beta_c > \tau$ then $c := c + 1$, $k := k + 1$, set $\alpha_c := 1 - k\lambda$. If $\alpha_c - \beta_c < -\tau$ then $\lambda := \lambda/2$, $k := 2k - 1$, set $\alpha_c := 1 - k\lambda$. If $|\alpha_c - \beta_c| \leq \tau$ then output α_c, β_c, and x_c.

B. Second Phase

After computing the values of α and β according to the procedure given in the first phase, we can solve the following problem in order to obtain a nondominated solution for the situation where the solution is not unique.

$$\text{Max}\ \frac{1}{l+r}\left(\sum_{k=1}^{l}\beta_k + \sum_{p=1}^{r}\beta_p'\right) \quad (5)$$

subject to

$$\beta \le \beta_k = \frac{\left[\sum_{j=1}^{n}\left[c_{kj_3} - (c_{kj_3} - c_{kj_2})\alpha\right]x_j - (\tilde{Z}_k)_\alpha^- - i_{k1}((\tilde{Z}_k)_\alpha^* - (\tilde{Z}_k)_\alpha^-)\right]}{\left[((\tilde{Z}_k)_\alpha^* - (\tilde{Z}_k)_\alpha^-)(i_{k2} - i_{k1})\right]},$$

$k = 1, \ldots, l$

$$\beta \le \beta_p' = \frac{\left[(\tilde{W}_p)_\alpha^- - \sum_{j=1}^{n}\left[c'_{pj_1} + (c'_{pj_2} - c'_{pj_1})\alpha\right]x_j - i_{p1}((\tilde{W}_p)_\alpha^- - (\tilde{W}_p)_\alpha^*)\right]}{\left[((\tilde{W}_p)_\alpha^- - (\tilde{W}_p)_\alpha^*)(i_{p2} - i_{p1})\right]},$$

$p = 1,\ldots, r$

$$\beta_k, \beta_p' \in [0,1],\ k = 1, \ldots, l;\ p = 1,\ldots, r$$

$$x \in X_\alpha$$

$$x_j \ge 0, \qquad j = 1, \ldots, n$$

where $(\tilde{Z}_k)_\alpha^*$, $(\tilde{W}_p)_\alpha^*$ are the ideal solutions and $(\tilde{Z}_k)_\alpha^-$, $(\tilde{W}_p)_\alpha^-$ are the anti-ideal solutions, respectively, which can be obtained by solving formulation (2) for each objective separately subject to the constraints.

III. Case Study

Recently, agile supplier selection becomes a crucial managerial decision problem in supply chain management because of the rapid changes in competitive environment. In order to illustrate the application of the decision making approach to agile supplier selection problem, a case study conducted to determine the most appropriate fuel supplier in aviation industry is introduced. Three decision-makers indicated seven supplier alternatives while criteria are determined by both decision makers' opinions and literature survey. Four criteria for agile supplier selection problem are defined as

C_1: Management and organization
C_2: Agile customer responsiveness
C_3: Transportation cost
C_4: Unit production cost

The fuzzy multiple objective decision making framework presented in this paper determines the most appropriate supplier by maximizing *management and organization*, *customer relationship*, *production capacity*, *quality*, and *agile customer responsiveness*; while minimizing *transportation cost and unit production cost*. The importance degree of the objectives which are denoted by linguistic variables such as 'low', 'moderate', and 'high' are given in Table I.

TABLE I
IMPORTANCE DEGREE OF THE OBJECTIVES

Objective	Type	Importance degree	Importance degree
C_1	Max	Moderate (M)	(0.2, 0.5, 0.5)
C_5	Max	Very High (VH)	(0.7, 1, 1)
C_6	Min	High (H)	(0.5, 0.7, 0.7)
C_7	Min	High (H)	(0.5, 0.7, 0.7)

Considering the evaluation data of each supplier alternative given in Table II, formulation (4) is employed. The step length (λ) and the accuracy of tolerance (τ) are set to be 0.05 and 0.005, respectively, as in [13]. The ratings of 7 supplier alternatives with respect to supplier selection criteria are considered as linguistic variables 'very low (VL)', 'low (L)', 'medium (M)', 'high (H)', and 'very high (VH)', which possess membership functions depicted in Fig. 1.

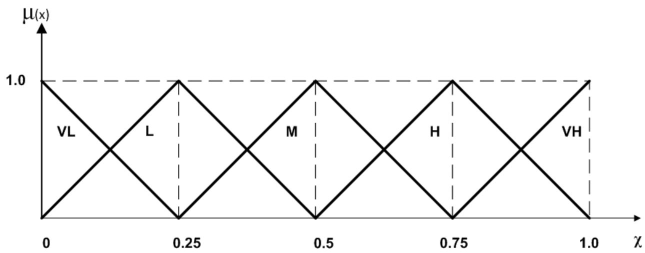

Fig. 1. A linguistic term set where VL: (0, 0, 0.25), L: (0, 0.25, 0.5), M: (0.25, 0.5, 0.75), H: (0.5, 0.75, 1), VH: (0.75, 1, 1).

The fuzzy multi-objective algorithm presented in section 2 gives the results shown in Table III. In order to ensure an undominated solution, formulation (5) is solved using the α value determined at the end of the first phase and the arithmetic mean operator. According to the results given in Table IV, supplier 7 is the selected alternative, and the grade of compromise obtained by the arithmetic mean operator is 0.92075.

TABLE II
RATING OF SUPPLIERS WITH RESPECT TO CRITERIA

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
C_1	(H, H, VH)	(H, H, VH)	(H, M, VH)	(H, H, VH)	(M, H, M)	(M, H, VH)	(M, H , H)
C_2	(M, M, VH)	(M, VH, VH)	(VH, H, VH)	(H, VH, VH)	(M, M, M)	(VH, VH, VH)	(VH, H, VH)
C_3 ($/ton)	25.6	49.4	35.6	64.1	49.5	113.1	42
C_4 ($/ton)	478.1	472.7	505.7	489.8	455.9	523.8	455.2

TABLE III
RESULTS OF THE FIRST PHASE

α_c	β_c	α_c-β_C
1	0,4667	0,5333
0,95	0,5057	0,4443
0,9	0,5429	0,3571
0,85	0,5783	0,2717
0,8	0,6121	0,1879
0,75	0,6444	0,1056
0,7	0,6753	0,0247
0,65	0,705	-0,055
0,675	0,6903	-0,0153
0,6875	0,6828	0,0047

TABLE IV
NONDOMINATED SOLUTION FOR THE FUZZY MULTIPLE OBJECTIVE PROGRAMMING MODEL

α	β	$\lvert\alpha$-$\beta\rvert$	$\overline{\beta}$	Selected alternative
0.6875	0.6828	0.0047	0.92075	7

IV. CONCLUSIONS

In today's highly competitive and changing environment, supply chain agility is an important necessity of the firms. In this regard, global companies have started to invest in agile supply chain. This study presents a fuzzy multiple objective programming decision making framework for agile supplier selection problem. Fuzzy multiple objective programming framework enables to incorporate conflicting supply chain management objectives with imprecise data into the supplier decision model. Consideration of the information provided by multiple decision-makers is more appropriate in decision making problems. Thus, the methodology employed in this paper is a group decision-making approach. Future research will focus on applying the decision framework presented in here to real-world group decision making problems.

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