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# A Fuzzy Decision Making Approach for Supplier Selection in Healthcare Industry

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***Abstract*****—**Supplier evaluation and selection is one of the most important components of an effective supply chain management system. Due to the expanding competition in healthcare, selecting the right medical device suppliers offers great potential for increasing quality while decreasing costs. This paper proposes a fuzzy decision making approach for medical supplier selection. A real-world medical device supplier selection problem is presented to illustrate the application of the proposed decision methodology.

***Keywords*****—**Fuzzy decision making, fuzzy multiple objective programming, medical supply chain, supplier selection.

## I. Introduction

IN recent years, with the rapid growth of medical device use, the number of reported problems related to lack of quality has increased dramatically. The healthcare industry has been troubled by serious adverse event cases and product recalls [1].

Selecting the best medical device supplier among multiple alternatives has become crucial in order to achieve customer satisfaction. Due to the expanding competition in healthcare, effective medical device supplier decision offers great potential for increasing quality while decreasing costs.

Since the pioneer work of Dickson [2], several studies have been focused on identifying the criteria used to select suppliers [3]-[5]. With its need to trade-off multiple criteria, supplier selection is a highly important multi-criteria decision making (MCDM) problem. There are various methods which have been developed for supplier selection in the literature. The interested reader may refer to the recent study reviewing the literature regarding supplier evaluation and selection models presented by Ho et al. [6].

This paper proposes a decision making approach based on fuzzy multiple objective programming for medical supplier selection. Linguistic variables and triangular fuzzy numbers are employed to quantify the impreciseness inherent in supplier selection criteria. The importance level of each decision criterion considered as an objective to be maximized or minimized is obtained using decision making trial and evaluation laboratory (DEMATEL) method.

The rest of the paper is organized as follows. Section II outlines the DEMATEL method. In Section III, the fuzzy multiple objective decision making procedure is presented. The application of the proposed decision approach to a real-world medical supplier selection problem is presented in Section IV. Conclusion and directions for further research are given in the final section.

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## II. DEMATEL Method

The decision making trial and evaluation laboratory (DEMATEL) method [7] is developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976 [8]. The DEMATEL method enables the decision maker to visualize influences between criteria and it computes their importance weights. The steps of the method can be summarized as follows [8]-[10]:

Compute the average matrix $\boldsymbol{A}$. Respondents are asked to indicate the direct influence that they believe each factor $i$ exerts on each factor $j$ of the others, as indicated by $a_{ij}$, using an integer scale [8].

Calculate the normalized initial direct influence matrix $\boldsymbol{D}$. The normalized initial direct influence matrix can be obtained by normalizing the average matrix $\boldsymbol{A}$ which is also called the initial direct influence matrix in the following way [8]-[10]:

$\boldsymbol{D}=s.\boldsymbol{A}$, where

$$s = \min\left[\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n}\left|a_{ij}\right|}, \frac{1}{\max_{1\le i\le n}\sum_{i=1}^{n}\left|a_{ij}\right|}\right] \tag{1}$$

Calculate the total relation matrix. The total relation matrix $\boldsymbol{T}$ is defined as $T = D(I - D)^{-1}$, where $\boldsymbol{I}$ is the identity matrix.

Define $r$ and $c$ be $n$ x 1 and 1 x $n$ vectors representing the sum of rows and sum of columns of the total relation matrix $\boldsymbol{T}$, respectively. Suppose $r_i$ be the sum of $i$th row in matrix $T$, then $r_i$ shows both direct and indirect effects given by factor $i$ to the other factors. If $c_j$ denotes the sum of $j$th column in matrix $T$, then $c_j$ shows both direct and indirect effects by factor $j$ from the other factors [10].

When $j = i$, the sum $(r_i + c_j)$ shows the degree of importance for factor $i$ in the entire system. In addition, the difference $(r_i - c_j)$ represents the net effect that factor $i$ contributes to the system. Specifically, if $(r_i - c_j)$ is positive, factor $i$ is a net causer, and when $(r_i - c_j)$ is negative, factor $i$ is a net receiver [10].

Set up a threshold value to obtain the network relationship map which explains the structural relations among criteria [10].

## III. 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 [11]

$$\text{Max } \tilde{Z}(\mathbf{x}) = (\tilde{\mathbf{c}}_1\mathbf{x}, \tilde{\mathbf{c}}_2\mathbf{x}, \ldots, \tilde{\mathbf{c}}_l\mathbf{x}) \tag{2}$$

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

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 [12]. The membership function of triangular fuzzy number coefficients represented by $\tilde{Q} = (q_1, q_2, q_3)$ is given as

$$\mu_{\tilde{Q}}(x) = \begin{cases} 0, & x < q_1 \\ (x - q_1)/(q_2 - q_1), & q_1 \leq x \leq q_2 \\ (q_3 - x)/(q_3 - q_2), & q_2 \leq x \leq q_3 \\ 0, & x > q_3. \end{cases} \tag{3}$$

The importance degree of each objective can be included in the formulation using fuzzy priorities [13]. The general representation for the membership function corresponding to the importance degrees can be given as

$$\mu_I(x) = \begin{cases} 0, & x < i_1 \\ (x - i_1)/(i_2 - i_1), & i_1 \leq x \leq i_2 \\ 1, & x > i_2. \end{cases} \tag{4}$$

For a given value of $\alpha$, using the max min approach, the formulation that incorporates fuzzy priorities of the objectives is stated as a deterministic linear problem with multiple objectives as follows:

$$\text{Max } \beta \tag{5}$$

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, $\beta$ is the grade of compromise to which the solution satisfies all of the fuzzy objectives while the coefficients are at a feasible level $\alpha$, and $X_\alpha$ 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 an undominated solution [14].

Lee and Li [14] proposed a two-phase approach, where in the first phase they solve the problem parametrically for a given value of $\alpha$, and in the second phase, they obtain an undominated solution using the value of $\alpha$ determined in the first phase. In this study, a modified version of the algorithm proposed by Lee and Li [14] is employed as given below.

### A. First Phase

Define $\lambda$ = step length, $\tau$ = 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 $\alpha_c$ to obtain $\beta_c$ 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, $k$ := 2$k$ - 1, set $\alpha_c := 1 - k\lambda$. If $|\alpha_c - \beta_c| \leq \tau$ then output $\alpha_c$, $\beta_c$, and $x_c$.

### B. Second Phase

After computing the values of $\alpha$ and $\beta$ according to the procedure given in the first phase, we can solve the following problem in order to obtain an undominated solution for the situation where the solution is not unique.

$$\text{Max } \frac{1}{l + r}\left(\sum_{k=1}^{l} \beta_k + \sum_{p=1}^{r} \beta_p{}'\right) \tag{6}$$

subject to

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

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

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

$$x \in X_\alpha$$

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

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.

## IV. Medical Device Supplier Selection Using the Proposed Decision Framework

This section presents the application of the proposed decision making method to a real-world medical device supplier selection problem which is conducted in a private hospital.

The nine supplier selection criteria identified by the supplier evaluation team created in the purchasing department are *Product Volume* (C1), *Delivery Time* (C2), *Payment Method* (C3), *Supply Variety* (C4), *Reliability* (C5), *Experience in the Sector* (C6), *Earlier Business Relationship* (C7), *Management* (C8), and *Geographical Location* (C9).

In order to find the most important criteria in selecting medical suppliers, the DEMATEL method is employed. The importance weights of criteria are calculated by using the data collected from pairwise comparisons made by the team. A seven point scale ranging from 0 to 7 is used to identify the degree of relative importance between two criteria. The importance weights obtained by DEMATEL method are given in Table I.

TABLE I
Importance Weights of Supplier Selection Criteria

| Supplier selection criterion | Importance weight |
|---|---|
| Product volume | 0.081407 |
| Delivery time | 0.110049 |
| Payment method | 0.092310 |
| Supply variety | 0.100551 |
| Reliability | 0.120702 |
| Experience in the sector | 0.142790 |
| Earlier business relationship | 0.124756 |
| Management | 0.151093 |
| Geographical location | 0.076342 |

Reducing the number of criteria taken into account in the decision process enables the team to focus more on the key criteria which improves supply chain performance. Based on a threshold value of 0.100000, the team identified 6 decision criteria (*delivery time*, *supply variety*, *reliability*, *experience in the sector*, *earlier business relationship*, and *management*) which are considered as objectives employed to evaluate supplier alternatives.

The fuzzy multiple objective decision making framework presented in this paper determines the most appropriate supplier by maximizing *supply variety*, *reliability*, *experience in the sector*, *earlier business relationship*, and *management*; while minimizing *delivery time*. The importance degree of the objectives which are denoted by linguistic variables such as 'moderate', 'high', and 'very high' are given in Table II.

TABLE II
Importance Degree of the Objectives

| Objective | Type | Importance degree | Membership function |
|---|---|---|---|
| Delivery time (DT) | Min | Medium (M) | (0.2, 0.5, 0.5) |
| Supply variety (SV) | Max | Medium (M) | (0.2, 0.5, 0.5) |
| Reliability (R) | Max | High (H) | (0.5, 0.7, 0.7) |
| Experience in the sector (ES) | Max | Very high (VH) | (0.7, 1, 1) |
| Earlier business relationship (EBR) | Max | High (H) | (0.5, 0.7, 0.7) |
| Management (M) | Max | Very high (VH) | (0.7, 1, 1) |

Using the evaluation data of each supplier alternative given in Table III, (5) is employed. The step length ($\lambda$) and the accuracy of tolerance ($\tau$) are set to be 0.05 and 0.005, respectively, as in [15].

The ratings of 12 supplier alternatives with respect to supplier selection criteria are considered as linguistic variables 'definitely low (DL)', 'very low (VL)', 'low (L)', 'medium (M)', 'high (H)', 'very high (VH)', and 'definitely high (DH)' which possess membership functions depicted in Fig. 1.

TABLE III
Ratings of Supplier Alternatives with Respect to Decision Criteria

| | DT | SV | R | ES | EBR | M |
|---|---|---|---|---|---|---|
| Supplier 1 | VL | VH | VH | VH | M | DH |
| Supplier 2 | L | H | VH | DH | H | VH |
| … | … | … | … | … | | … |
| Supplier 11 | VL | VH | L | H | M | H |
| Supplier 12 | DL | VL | H | M | L | M |

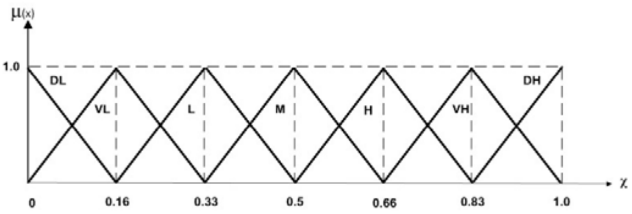


Fig. 1 Membership functions for linguistic variables regarding technical difficulty of engineering characteristics (DL: (0, 0, 0.16), VL: (0, 0.16, 0.33), L: (0.16, 0.33, 0.50), M: (0.33, 0.50, 0.66), H: (0.50, 0.66, 0.83), VH: (0.66, 0.83, 1), DH: (0.83, 1, 1)).

The algorithm presented in section 3 yields the results given in Table IV. In order to ensure an undominated solution, (6) is solved using the $\alpha$ value determined at the end of the first phase and the arithmetic mean operator. According to the results given in Table V, supplier 2 is the selected medical supplier alternative, and the grade of compromise obtained by the arithmetic mean operator is 0.983646.

TABLE IV
RESULT OF THE FIRST PHASE

| $\alpha_c$ | $\beta_c$ | $\alpha_c$-$\beta_c$ |
|---|---|---|
| 1.00 | 0.800000 | 0.200000 |
| 0.95 | 0.855900 | 0.094100 |
| 0.90 | 0.908240 | 0.008240 |
| 0.925 | 0.882493 | 0.042507 |
| 0.9125 | 0.895470 | 0.017030 |
| 0.90625 | 0.901876 | 0.004374 |

TABLE V
UNDOMINATED SOLUTION FOR THE FUZZY MULTIPLE OBJECTIVE PROGRAMMING MODEL

| $\alpha$ | $\beta$ | $\lvert\alpha-\beta\rvert$ | $\overline{\beta}$ | Selected alternative |
|---|---|---|---|---|
| 0.90625 | 0.901876 | 0.004374 | 0.983646 | Supplier 2 |

## V. CONCLUSION

In medical supply chain, one of the most critical decisions is to select the most appropriate medical device supplier among multiple alternatives. In this study, a fuzzy multiple objective programming based decision framework is presented for medical supplier selection. Fuzzy multiple objective programming model enables to incorporate conflicting supply chain management objectives with imprecise data into the supplier decision model.

Considering opinions of multiple decision-makers rather than a single decision-maker is more appropriate in making decisions in supplier selection process which may involve information provided by many people. Thus, future research will focus on applying the decision framework presented in here to real-world group decision making problems.

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