Selection of Calibration Supplier under Fuzzy Environment

Nihal Erginel, Ayse Gecer

***Abstract*— Companies measure several quality characteristics of row metarial and/or semi product and/or product for both incoming quality control and the manufacturing process according to quality control plans. Behind the measurement devices and capabilities of operators, calibration of measurement devices is crucially important for measurement system, especially for ISO 9001 Quality System Management Standard. So, selection of calibration supplier is coming into prominence.**

This paper presents a methodology for selection among calibration supplier. Firstly, the selection criteria of a calibration supplier and their weights are determined with a questionnaire. Then, multi-objective linear programming (MOLP) model is used to assign the devices to the calibration supplier in fuzzy environment. Two objectives are considered in this model: maximizing the weights of criterions and minimizing calibration cost under the constraints. Two phase approach is used for this model.

***Index Terms*—, calibration supplier selection, fuzzy approach, fuzzy multi-objective linear programming, supplier selection, two phase approach**

I. Introduction

Selection of calibration supplier is a supplier selection problem actually. But most known supplier selection problems are on the buying row material or component part suppliers. Nowadays, selection of calibration supplier has become more popular topic because of the raising number of calibration suppliers.

Although two main topics on the supplier selection problems that are to determine the criteria of supplier and to select the supplier are important, most of papers in this area are on choosing the right supplier with several qualitative and quantitative techniques.

Firstly Dickson [1] made comprehensive study on supplier selection criteria. 23 criteria that include quality, delivery, performance history, warranties, price, technical capability and financial position are identified. A great number of techniques on the supplier selection take place in the literature like, linear weighted methods [2-6], analytic hierarchy process [7-13], analytical network process [14-16], mathematical programming [17-19], goal programming [20], multi-objective programming [21-22], and fuzzy set theory [23-24].

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Nihal Erginel is with Anadolu University, Eskisehir, Turkey. (corresponding author to provide phone:: +90-222-335 05 80/6434; fax: +90-222-323 95 01; e-mail: nerginel@anadolu.edu.tr).

Ayse Gecer is with Anadolu University, Eskisehir, Turkey. (e-mail: aygecr@gmail.com).

Integrated approaches on supplier selection are presented in literature: AHP is used for evaluating the supplier performance with several criteria and goal programming is studied to determine the best supplier [25-28]. AHP and multi-objective mixed integer programming model for supplier selection is presented [29]. ANP and multi-objective mixed integer linear programming is integrated to determine the optimal order allocation [30]. ANP and goal programming is collaborating with three objective functions [31].

Also, fuzzy approach is integrated to supplier selection process in literature: Decision makers' comparisons are examined with fuzzy AHP when the weights of criteria are linguistic variable [32-33]. Fuzzy multi-objective linear programming model is used to determine the optimum order quantity for each supplier with three objective functions [34].

Although many papers are handled to select the suppliers that are for buying raw material and/or component parts, there is no any manuscript on the calibration supplier selection.

In this paper, the methodology is presented to select the calibration suppliers in fuzzy environment. Weights of criteria for selecting the calibration suppliers are determined with questionnaire by using 5-scale Likert on 103 companies in Turkey [35]. Questionnaires were sent to about 200 companies and turn rate of questionnaire is 51.5%. This percentage is higher than general questionnaire turn over since many questionnaires were applied by getting an appointment with companies. Many interviews for questionnaire were made face to face. After determining the weight of criteria on calibration supplier selection, important criteria were used in multi-objective linear programming model with two objectives: maximizing the weights of criteria and minimizing the total calibration cost under constraints. Two phase fuzzy approach is used for solving multi-objective linear programming model.

II. MOLP Problems and Solution with Two Phase Approach

In general, multi-objective linear programming problems can be formulated as follows [36]:

$$\begin{aligned} &\max Z = [c_1 x,..., \ c_N x]^T = [Z_1(x),..., Z_N(x)]^T \\ &subject \ to \\ &x \in X, \ \ X = \{ x \in R^n : Ax \le b, \ x \ge 0 \} \end{aligned} \qquad (1)$$

where $A = (a_{ij})_{mxn}$; $c_i \in R^n$; $i = 1,2,..., \ N \ and \ b \in R^m$.

In the multi-objective linear programming problems, all objective functions can take optimal values at

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the same time under problems constraints. Zimmerman proposed a fuzzy approach the name of which is "max-min operator to solve multi-objective linear programming problems". He defines "the satisfaction levels" or "membership degree" that represents the approximation ratio of each objective function to its optimal value.

$$\begin{aligned} &\max \lambda \\ &\textit{subject to}; \\ &\lambda \le \mu_k(x), \quad k = 1,\dots,N. \\ &\lambda \in [0,1], \qquad x \in X \end{aligned} \tag{2}$$

where; $\mu_k(x)$ is the membership function of objective function that were described in (5) and (6) for maximizing objective functions and for minimizing objective functions, respectively. Z^* is the ideal solution of each objective and Z^- is the anti-ideal solution of each objective, individually.

$$Z^* = [Z_1^*,\dots,Z_N^*] = [\max(Z_1(x)),\dots, \max(Z_N(x))] \tag{3}$$

$$Z^- = [Z_1^-,\dots,Z_N^-] = [\min(Z_1(x)),\dots, \min(Z_N(x))] \tag{4}$$

$$\mu_k(x) = \begin{cases} 1, & Z_k(x) > Z_k^*, \\ 1 - \dfrac{Z_k(x) - Z_k^-}{Z_k^* - Z_k^-} & Z_k^- \le Z_k(x) \le Z_k^*, \\ 0 & Z_k(x) < Z_k^-, \end{cases} \tag{5}$$
$k = 1,\dots,N.$

$$\mu_k(x) = \begin{cases} 1, & Z_k(x) < Z_k^*, \\ 1 - \dfrac{Z_k^* - Z_k(x)}{Z_k^* - Z_k^-} & Z_k^* \le Z_k(x) \le Z_k^-, \\ 0 & Z_k(x) \ge Z_k^*, \end{cases} \tag{6}$$
$k = 1,\dots,N.$

Two-Phase Approach

After obtaining the optimal solution by max-min operator approach, the satisfaction level of each objective can be improved by applying second phase as follows [37]:

$$\begin{aligned} &\max \sum_{i=1}^{N} w_k \lambda_k \\ &\textit{subject to} \\ &\lambda_k^* \le \lambda_k \le \mu_k(x) \quad k = 1,2,\dots,N \\ &\lambda_k \in [0,1] \\ &x \in X \end{aligned} \tag{7}$$

III. MOLP MODEL FOR SELECTION CALIBRATION SUPPLIER

Selection calibration supplier has some differences from raw material or component supplier. These differences are handling with constraints. In the following, constraints, objectives, parameters and decision variables, and their explanations are given.

A. Constraints

Time: Companies desire minimum calibration time because they want to use their measurement device as long as possible. In this application, it is determined in not more than two weeks of calibration time. At the same time, calibration firms have the number of certified expert on calibration with related measurement device. Time is calculated by multiplying the number of desired week, the number of certified expert and their work hours in a week. This constraint also represents the capability of calibration firms and is given in equation (10).

The number of certified expert: Calibration firms should have at least one certified expert for selecting. It is used in equation (10) and (11).

Calibration capability: Calibration firms should have certificate with ISO/IEC17025:2005: General requirements stand for the competence of testing and calibration laboratories standard. Also, calibration supplier can get technical capability for measurement device. It is given in equation (12).

Demand: Each measurement device should be assigned to one calibration firm. So, the demand of calibration should be satisfied. It is given in equation (13).

B. Objectives

Maximizing criteria weights: Criteria's weights come from the averages of related questions and respondent answer. Criteria weights multiply calibration firms' performance degree for each criterion. It is desired that the total criteria weights are maximum. It is provided with equation (8).

Minimizing calibration costs: The total calibration cost minimizes with this objective. It is written in equation (9).

C. Parameters

C_{ij} : price for *i*th measurement device type from *j*th calibration firms

S_{ij} : operation time of *i*th measurement device and jth calibration supplier

$$D_{ij} = \begin{cases} 1 & \text{; calibration capability of } i\text{th calibration firms for } j\text{th measurement device} \\ 0 & \text{; other wise} \end{cases}$$

U_j : the number of certified expert

t_i : the number of measurement device for *i*th device type

m : the number of device type

n : the number of calibration supplier

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h: the number of criteria

W_k : weights of kth criteria

P_{kj}: performance score of kth criteria for jth calibration supplier

D. Decision variable

$$X_{ij} = \begin{cases} 1 & \text{; if the } j\text{th calibration supplier is selected for } i\text{th measurement device} \\ 0 & \text{; other wise} \end{cases}$$

E. Determining the criteria and their weights

Criteria and their weights are determined with questionnaire. Two criteria are the prerequisite for becoming the calibration supplier that are “Competence of documentation” and “Technical capability”. In MOLP model, if one supplier doesn’t have ISO/IEC17025:2005 certificate, it cannot be a calibration supplier. Also if one supplier doesn’t have the technical capability for each measurement device, it cannot calibrate the related measurement device. So, these two criteria aren’t considered in the maximizing criteria weights objective. But the technical capability is handled in the third constraint.

“Warranties and complaint policy”, "Communication”, “Service features”, “Quality” and “Performance history” are defined as the importance criteria. The weights (4.48; 4.4; 4.36; 4.24; 4.15 respectively) of them are considered in the maximizing criteria weights objective.

In addition, the performance scale of calibration supplier for each criteria and the number of certified expert for each calibration supplier are given in Table 1 and 2.

F. Model

$$Z_1 = Max\sum_{j=1}^{n}\left[\left(\sum_{k=1}^{h} W_k * P_{kj}\right) * \left(\sum_{i=1}^{m} X_{ij}\right)\right] \quad (8)$$

$$Z_2 = Min\sum_{j=1}^{n}\left(\sum_{i=1}^{m} t_i * C_{ij} * X_{ij}\right) \quad (9)$$

subject to

$$\sum_{i=1}^{m} T_i * S_{ij} * X_{ij} \le 2(week) * 45(hours/week) * U_j \quad (10)$$

$$U_j * X_{ij} + U_j * (1 - X_{ij}) \ge 1 \quad (11)$$

$$D_{ij} * X_{ij} + D_{ij}(1 - X_{ij}) \ge X_{ij} \quad (12)$$

$$\sum_{j=1}^{n} X_{ij} = 1 \quad (13)$$

$$X_{ij} = 0 \text{ or } 1 \quad (14)$$

$i = 1,2,3,....,20$ and $j = 1,2,3,4$

TABLE 1
PERFORMANCE SCALE OF CALIBRATION SUPPLIER FOR EACH CRITERIA

Criteria / Suppliers	**A**	**B**	**C**	**D**
Warranties and complaint policy	4	3	4	2
Communication	5	4	5	4
Service features	4	5	4	4
Quality	5	4	4	3
Performance history	5	3	4	3

TABLE 2
THE NUMBER OF CERTIFIED EXPERT FOR EACH CALIBRATION SUPPLIER

Suppliers	A	B	C	D
The number of certified expert	6	2	3	1

Model for the first phase

$$MaxZ = \lambda$$

subject to

$$\lambda \le \left(\frac{1}{Z_1^* - Z_1^-}\right) * \left(\sum_{j=1}^{n}\left[\left(\sum_{k=1}^{h} W_k * P_{kj}\right) * \left(\sum_{i=1}^{m} X_{ij}\right)\right] - Z_1^-\right) \quad (15)$$

$$\lambda \le \left(\frac{1}{Z_2^- - Z_2^*}\right) * \left(Z_2^- - \left(\sum_{j=1}^{n}\left(\sum_{i=1}^{m} t_i * C_{ij} * X_{ij}\right)\right)\right) \quad (16)$$

$$x \in X \quad (17)$$

$$X_{ij} = 0 \text{ or } 1 \quad (18)$$

$$\lambda_k \in [0,1] \quad (19)$$

Results for the first phase

Model for the first phase is solved by LINGO 12.0 software and Z is found as 0.8245. It shows that both two objectives were achieved by 82.45%. It is a good ratio.

Model for the second phase

$$MaxZ = (1/2)(\lambda_1 + \lambda_2) \quad (20)$$

subject to

$$0{,}8245 \le \lambda_1 \le \left(\frac{1}{Z_1^* - Z_1^-}\right) * \left(\sum_{j=1}^{n}\left[\left(\sum_{k=1}^{h} W_k * P_{kj}\right) * \left(\sum_{i=1}^{m} X_{ij}\right)\right] - Z_1^-\right) \quad (21)$$

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$$0,8245 \le \lambda_2 \le \left(\frac{1}{Z_2^- - Z_2^*}\right) * \left(Z_2^- - \left(\sum_{j=1}^{n}\left(\sum_{i=1}^{m} t_i * C_{ij} * X_{ij}\right)\right)\right)$$

$$x \in X \tag{22}$$

$$X_{ij} = 0 \text{ or } 1 \tag{23}$$

$$\lambda_k \in [0,1] \tag{24}$$

Results for the second phase

Model is solved also by/ in LINGO 12.0 software where Z=0.8320 ; λ_1=0.8395 and λ_2=0.8245 are found. λ_1 and λ_2 represent the achievement level of first and second objectives, respectively. Z presents the average of two achievement levels of objective functions. It is seen that, the achievement level of first objective (83.95%) improves more than in the first phase (82.45%). The achievement level of second objective is the same.The following decision variables show the selected calibration supplier.

$$X_{1,1} = X_{2,3} = X_{3,3} = X_{4,2} = X_{5,1} = X_{6,1} = X_{7,3} = X_{8,1}$$
$$= X_{9,3} = X_{10,1} = X_{11,1} = X_{12,3} = X_{13,1} = X_{14,1} = X_{15,1}$$
$$= X_{16,1} = X_{17,1} = X_{18,3} = X_{19,2} = X_{20,4} = 1$$

IV. Conclusion

This study is the first on the selection of calibration supplier. This study shortly presents the criteria on calibration supplier. Here, there are some differences between raw material/ component suppliers and calibration supplier criteria. The weights of these criteria are determined with questionnaire. Then, MOLP model to select the calibration suppliers is conducted and the example is solved for a firm in health sector with 20 measurement device types and 4 calibration suppliers. The MOLP model to select the calibration suppliers can be handled with fuzzy parameters in a further research.

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