Supplier selection by F-compromise method: a case study of cement industry of NE India

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Supplier selection by F-compromise method: a case study of cement industry of NE India

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Abstract: In this paper, we initially conducted a brief review of supplier selection methods to find most cited multi-criteria decision making method, present trend of supplier selection and most cited criteria for supplier selection. Our study reveals that irrespective of several limitations of analytic hierarchy process (AHP), AHP and its integrated model is most preferred supplier selection method. Present research trend of supplier selection gives more emphasis on multiple sourcing instead of single sourcing. Based on our initial study, a suitable integrated model is proposed. In this integrated model, fuzzy analytic hierarchy process (FAHP) and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje; in Serbian) is used to select suppliers from a predefined supplier base. Multi-objective genetic algorithm (MOGA) is used further to allocate order among suppliers. Finally, a case study is discussed to use proposed method.

Keywords: supplier selection; fuzzy AHP; VIKOR; multi-objective genetic algorithm; MOGA; India.


Biographical notes: Krishnendu Mukherjee received his first class Bachelor of Engineering degree in Mechanical Engineering in 1998 from Jadavpur University and a Masters degree in Mechanical Engineering in 2002 from Birla Institute of Science and Technology, Pilani, India. He is pursuing his PhD from Jadavpur University, Kolkata, India. He has ten years teaching experience in India and abroad. He also worked as a reviewer of Journal of Operational Research Society, UK, Palgrave Macmillan publication. Currently, he is an Assistant Professor with the Department of Mechanical Engineering, Budge Budge Institute of Technology, West Bengal, India. He has published papers in Computers and Industrial Engineering, Elsevier, International Journal of Applied Engineering Research, IEEE, etc. His main research areas include supplier selection, green supply chain, decision engineering and mass customisation.

Bijon Sarkar is Professor and former Head of Production Engineering Department, Jadavpur University, Kolkata, India. He has received Outstanding Paper Award at Emerald Literati Network for Excellences 2006, UK. He has also received the Best Paper Awards from ‘Indian Institute of Industrial Engineering (IIIE), Mumbai’ in 2002 and 2003. He was also awarded certificates of merit by the ‘Institution of Engineers India’ during 2001–2002 and 2002–2003. He is the co-author of the book on Production Management published by AICTE, CEP, New Delhi. He has published more than 150 papers in the national/international journals and proceedings. He is the reviewer of LIPR, EJOR and IE(I). His fields of interest include tribology, reliability engineering, AI, soft-computing applications and decision engineering.
Supplier selection by F-compromise method

Ardhendu Bhattacharyya is former Professor and Head of Mechanical Engineering Department, Jadavpur University, Kolkata, India. His 40 years of experience includes undergraduate and post graduate teaching, research and consultation on many academic and industrial projects at Indian Institute of Technology, Kharagpur and Jadavpur University, Kolkata, India. He has published 59 papers in the national/international journals and proceedings. Currently, he is working as the Dean in JIS College of Engineering, Kalyani, Nadia, West Bengal, India.

1 Introduction

In most industries the cost of raw materials and component parts constitutes the main cost of a product, such that in some cases it can account for up to 60%. In such cases the procurement department can play an important role in cost reduction, and supplier selection is one of the most important functions of procurement department. Moreover, judicious selection of supplier could reduce various upstream supply chain risks and thereby develop a resilient supply chain. Among various approaches, multi-criteria decision making (MCDM) approach is one of the most discussed aids in conflict management situation and widely used for single as well as multiple sourcing process to trade-off tangible and intangible criteria. In this paper, we initially conducted a brief review to select most cited MCDM processes and their integrated approach. Our study further tries to reveal the present trend of supplier selection. Based on our initial study, we proposed a suitable MCDM method. Rest of the paper is organised as follows – first it discusses about fuzzy VIKOR (ViseKriterijumska Optimizacija I Kompromisno Resenje; in Serbian) method for supplier selection. Second it gives a brief introduction to multi-objective optimisation by MATLAB. Third it depicts multi-objective optimisation and the integrated model of fuzzy VIKOR and multi-objective genetic algorithm (MOGA). Finally, the proposed model is further explained with the case study of cement industry of NE India.

![Different supplier selection methods](image-url)
Table 1  A partial list of supplier selection methods and criteria

<table>
<thead>
<tr>
<th>Year</th>
<th>Author/s</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>S.H. Ghodsypour and C. O’Brien</td>
<td>Cost, quality, service</td>
</tr>
<tr>
<td>2001</td>
<td>Eon-Kyung Lee, Sungdo Ha and Sheung-Kown Kim</td>
<td>Quality, cost, delivery, service</td>
</tr>
<tr>
<td>2001</td>
<td>Maggie C.Y. Tam and V.M. Rao Tummala</td>
<td>Cost, quality</td>
</tr>
<tr>
<td>2002</td>
<td>Robert Handfield, Steven V. Walton, Robert</td>
<td>Environmental issues</td>
</tr>
<tr>
<td></td>
<td>Stroufe and Steven A. Melnyk</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>Ozden Bayazit and Birsen Karpak</td>
<td>Logistical performance, commercial structure, production</td>
</tr>
<tr>
<td>2006</td>
<td>Huan-Jyh Shyur and Hsu-Shih Shih</td>
<td>On-time delivery, product quality, price/cost, facility and technology,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>responsiveness to customer needs, professionalism of salesperson,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>quality of relationship with vendor</td>
</tr>
<tr>
<td>2007</td>
<td>Fu Yao and Liu Hongli</td>
<td>Cost, quality, project, certification and delivery performance</td>
</tr>
<tr>
<td>2007</td>
<td>Felix T.S. Chan and Niraj Kumar</td>
<td>Overall cost of the product, quality of the product, service performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of supplier, supplier’s profile, risk factor</td>
</tr>
<tr>
<td>2007</td>
<td>Weijun Xia and Zhiming Wu</td>
<td>Price, quality, service</td>
</tr>
<tr>
<td>2007</td>
<td>Min Wu</td>
<td>Quality, price, delivery, service, management and culture, technology,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>financial situation, etc.</td>
</tr>
<tr>
<td>2007</td>
<td>Sanjay Jharkharia and Ravi Shankar</td>
<td>Compatibility, cost, reputation, quality</td>
</tr>
<tr>
<td>2007</td>
<td>Cevriye Gencer and Didem Gürpinar</td>
<td>Business structure, manufacturing capability, quality system</td>
</tr>
<tr>
<td>2007</td>
<td>Ezgi Aktar Demirtas and Ozden Ustun</td>
<td>Cost, quality, service, customer complaint, order delay, inability to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>meet further requirement, consistency, support to design process,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mutual trust and ease of communication</td>
</tr>
<tr>
<td>2008</td>
<td>Ali Kokangul and Zeynep Susuz</td>
<td>Price performance, delivery performance, collaboration and developing</td>
</tr>
<tr>
<td>2008</td>
<td>Reuven R. Levary</td>
<td>Supplier reliability; country risk; transportation reliability; reliability of the supplier’s suppliers</td>
</tr>
<tr>
<td>2008</td>
<td>Jing-Rung Yu and Chao-Chia Tsai</td>
<td>Cost, quality, delivery, service, environment</td>
</tr>
<tr>
<td>2008</td>
<td>Ozan Cakir and Mustafa S. Canbolat</td>
<td>Cost, annual demand, blockade effect, availability, lead time, common</td>
</tr>
<tr>
<td>2008</td>
<td>Sung Ho Ha and Ramayya Krishnan</td>
<td>Product facilities, quality management intention, organisational control,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>business plans, and customer communication</td>
</tr>
<tr>
<td>2008</td>
<td>Eleonora Bottani and Antonio Rizzi</td>
<td>Customer satisfaction, technical and organisational capabilities, supplier willingness, firm’s interest</td>
</tr>
<tr>
<td>2008</td>
<td>Ozden Ustun and Ezgi Aktar Demirtas</td>
<td>Cost, quality, service, customer complaint, order delay, inability to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>meet further requirement, consistency, support to design process, mutual</td>
</tr>
<tr>
<td></td>
<td></td>
<td>trust and ease of communication</td>
</tr>
<tr>
<td>2009</td>
<td>Amy H.I. Lee</td>
<td>Delivery, cost, quality, flexibility, product/process technology</td>
</tr>
<tr>
<td>2009</td>
<td>Semih Önüt, Selin Soner Kara and Elif İskik</td>
<td>Cost, quality, delivery time, execution time, etc.</td>
</tr>
<tr>
<td>2009</td>
<td>Jia-Wen Wang, Ching-Hsue Cheng and Huang</td>
<td>Cost, quality, service</td>
</tr>
<tr>
<td></td>
<td>Kun-Cheng</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>Rong-Ho Lin</td>
<td>Quality, technique, price, delivery</td>
</tr>
<tr>
<td>2009</td>
<td>Wann-Yih Wu et al.</td>
<td>Quality, cost</td>
</tr>
<tr>
<td>2009</td>
<td>Chia-Wei Hsu and Allen H. Hu</td>
<td>Procurement, R&amp;D, process, incoming quality, management system</td>
</tr>
</tbody>
</table>

1.1 Supplier selection methods revisited

In today’s highly competitive environment, an effective supplier selection process is very important to the success of any manufacturing organisation. In this context, supplier selection represents one of the most important functions to be performed by the purchasing department. Supplier selection is a multi-criterion problem which includes both qualitative and quantitative factors (criteria). A trade-off between these tangible and intangible factors is essential in selecting the best supplier. A number of models and techniques have been developed to deal with the selection and evaluation of suppliers. In this paper, a brief review is conducted to identify different selection methods concerning supplier selection. In this regard, 30 papers are randomly selected from reputed peer reviewed journal from 1998–2009 to find recent trend of supplier selection. Figure 1 shows a partial list of existing methods for both single sourcing as well as multiple sourcing supplier selection.
However, our study reveals that out of all methods-analytic hierarchy process (AHP), ANP and their integrated model is mostly used by various researchers. Figures 2 to 4 clearly indicate that. Irrespective of several limitations, AHP and the integrated method of AHP and other tools is most cited method for supplier selection. Moreover, our study reveals that present research trend on supplier selection gives more emphasises on multiple suppliers selection instead of single supplier selection. It is shown in Figure 4. We further extended our study to find different criteria used for supplier selection methods. This can be seen from Table 1.

**Figure 2** Distribution of review papers on the use of AHP, ANP and their integrated approach

![Distribution of review papers on the use of AHP, ANP and their integrated approach](image)

**Figure 3** Use of AHP, ANP and their integrated approach

![Use of AHP, ANP and their integrated methods for supplier selection over the years](image)

**Figure 4** Distribution of review papers for single and multiple sourcing

![Distribution of review papers for single and multiple sourcing](image)

Among several criteria-cost, quality and service are mostly cited by various researchers. However, different researchers used same criterion with different terminology, ex. delivery time, on-time delivery, delivery reliability, etc.

## 2 Fuzzy numbers and linguistic variables

In this section, some basic definition of fuzzy sets, fuzzy numbers and linguistic variables are given. Throughout this paper these basic definitions and notations will be used until otherwise stated.

**Definition 1:** A fuzzy set $\tilde{A}$ in universe of discourse $X$ is defined as the set of ordered pairs: $\tilde{A} = \{(x, \mu(x)) \mid x \in X\}$ where $\mu(x)$ is called the membership function (MF). MF maps each element of $X$ in the interval $[0, 1]$ (Jang et al., 2004).

**Definition 2:** The core of a fuzzy set $\tilde{A}$ is the set of all points in $X$ such that $\mu(x) = 1$. A fuzzy set is normal if its core is non-empty (Jang et al., 2004).

**Definition 3:** A fuzzy set $\tilde{A}$ is convex if and only if for any $x_1$ and $x_2 \in X$ and any $\lambda \in [0, 1]$, $\mu, \tilde{A}(\lambda x_1 + (1 - \lambda) x_2) \geq \min \{\mu, \tilde{A}(x_1), \mu, \tilde{A}(x_2)\}$.

**Definition 4:** A fuzzy number $\tilde{n}$ is a fuzzy subset in the universe of discourse $X$ that is both convex and normal. A matrix is called fuzzy matrix if at least one of its member is fuzzy number (Chen et al., 2006).

**Definition 5:** A positive triangular fuzzy number (TFN) $\tilde{n}$ can be specified by three parameters ($a$, $b$, $c$), shown in Figure 5. The MF $\mu, \tilde{n}$ is defined as

$$
\mu, \tilde{n} = \begin{cases} 
0, & x \leq a \\
\frac{x-a}{b-a}, & a \leq x \leq b \\
\frac{c-x}{b-c}, & b \leq x \leq c \\
0, & c \leq x
\end{cases}
$$
**Definition 6:** If \( \hat{o} = (o_1, o_2, o_3) \) and \( \hat{n} = (n_1, n_2, n_3) \) are two TFN then the distance between them calculated by vertex method as

\[
d(\hat{o}, \hat{n}) = \frac{1}{2} \left[ (o_1 - n_1)^2 + (o_2 - n_2)^2 + (o_3 - n_3)^2 \right]
\]

**Figure 5** Triangular fuzzy number

2.1 **Reason for selecting TFN for supplier selection problem**

Either trapezoidal fuzzy number or TFN could be used for supplier selection, however TFN is chosen as it is easy to understand and it used most often for representing fuzzy number (Dağdeviren et al., 2009).

2.2 **Extent fuzzy AHP**

Chang’s (1996) extent analysis is based on the following steps

1. If \( M^i_{g_i} \) are the TFNs where \( g_i \) is the goal set \((i = 1, 2, 3 \ldots m)\)

   The fuzzy extent value \( S_i \) with respect to the \( i^{th} \) criterion is defined as

   \[
   S_i = \left[ \sum_{i=1}^{m} M^i_{g_i} \otimes \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{g_i} \right] \right]^{-1}
   \]

   where \( M^i_{g_i} = (\sum_{i=1}^{m} l \cdot \sum_{i=1}^{m} m \cdot \sum_{i=1}^{m} u) \). \( l \) is the lower limit value, \( m \) is the most promising value and \( u \) is the upper limit value.

   \[
   \left[ \sum_{i=1}^{m} \sum_{j=1}^{m} M^i_{g_i} \right]^{-1} = \left\{ \frac{1}{\sum_{i=1}^{m} u_i}, \frac{1}{\sum_{i=1}^{m} m_i}, \frac{1}{\sum_{i=1}^{m} l_i} \right\}
   \]

2. The degree of possibility of \( M_2 \geq M_1 \) is given by \( V(M_2 \geq M_1) \)

   \[
   V(M_2 \geq M_1) = \begin{cases} 
   1, & \text{if } m_2 \geq m_1 \\
   0, & \text{if } l_1 \geq u_2 \\
   \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - u_1)}, & \text{otherwise}
   \end{cases}
   \]

   As shown in Figure 6, \( d \) is the highest intersection point \( \mu_{M_1} \) and \( \mu_{M_2} \).

   \[
   d(A_k) = \min V(S_k \geq S_i) \\
   \text{for } k = 1, 2, 3, 4, 5 \ldots n; k \neq i
   \]

   The weight vector

   \[
   W^* = \left( d(A_1), d(A_2), d(A_3) \ldots d(A_n) \right)^T
   \]

   The normalised weight vector

   \[
   W = \frac{W^*}{\sum_{i=1}^{n} d(A_i)}
   \]

For fuzzy comparison matrix, fuzzy TFN value has been selected as shown in Table 2.

**Figure 6** Intersection of two MFs

<table>
<thead>
<tr>
<th>Linguistic values</th>
<th>Fuzzy numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal</td>
<td>(1, 1, 1)</td>
</tr>
<tr>
<td>Weak</td>
<td>(2/3, 1, 3/2)</td>
</tr>
<tr>
<td>Fairly strong</td>
<td>(3/2, 2, 5/2)</td>
</tr>
<tr>
<td>Very strong</td>
<td>(5/2, 3, 7/2)</td>
</tr>
<tr>
<td>Absolute</td>
<td>(7/2, 4, 9/2)</td>
</tr>
</tbody>
</table>

2.3 **VIKOR method**

The VIKOR method is a compromise MADM method, developed by Opricovic and Tzeng (2004) started from the form of \( L^p \)-metric:

\[
L^p = \left\{ \sum_{j=1}^{n} w_j \left( \frac{f_{j'} - f_{j}}{f_{j'} - f_{j}} \right)^p \right\}^{1/p}
\]

\( 1 \leq p \leq +\infty, \ i = 1, 2, \ldots m\)
Supplier selection by F-compromise method

The compromise solution is the feasible solution closest to ideal solution, and a compromise means an agreement established between positive ideal solution and negative ideal solution by mutual concessions (Opricovic and Tzeng, 2004). As shown in Figure 7, $F^*$ is the feasible solution that is closest to ideal $F$ and it is the result of compromise between two criteria. Here compromise volumes are $\Delta f_1 = f_1^* - f_1^*$ and $\Delta f_2 = f_2^* - f_2^*$.

**Figure 7** Ideal and compromise solution


Steps for selecting suppliers by VIKOR

1. **Construction of original data evaluation matrix**

   \[
   X = \begin{bmatrix}
   C_1 & C_2 & C_i \\
   A_{i1} & x_{i1} & x_{i2} & \ldots & \ldots & x_{ij} \\
   \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\
   A_{in} & x_{in1} & x_{in2} & \ldots & \ldots & x_{nj} \\
   \end{bmatrix}
   \]

2. **Assuming that there are m alternatives, and j attributes.** Normalisation is used to make all criteria dimensionless. In VIKOR, linear normalisation method is used. It could be represented as follows

   \[
   f_y = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}^2}
   \]

   where $i = 1, 2, 3, \ldots m$; and $x_{ij}$ is the performance of alternative $A_i$ with respect to the $j^{th}$ criterion.

   Normalised matrix $F$ could be written as

   \[
   F = \begin{bmatrix}
   C_1 & C_2 & C_i \\
   A_{i1} & f_{i1} & f_{i2} & \ldots & \ldots & f_{ij} \\
   \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\
   A_{in} & f_{in1} & f_{in2} & \ldots & \ldots & f_{nj} \\
   \end{bmatrix}
   \]

   Determine the best value of $f_j^*$ and worst value of $f_j^-$ for all attribute

   \[
   f_j^* = \max f_{ij}, \quad f_j^- = \min f_{ij}
   \]

Calculate utility measure and regret measure.

\[
S_i = \sum_{j=1}^{n} w_j \left( f_j^* - f_{ij} \right) / \left( f_j^* - f_j^- \right)
\]

\[
R_i = \max \left[ w_j \left( f_j^* - f_{ij} \right) / \left( f_j^* - f_j^- \right) \right]
\]

where $S_i$ and $R_i$ represent utility measure and the regret measure, respectively, and $w_j$ is the weight of $j^{th}$ criterion.

Calculate VIKOR index

\[
Q_i = v \left( \frac{S_i - S}{S - S^*} \right) + (1 - v) \left( \frac{R_i - R}{R - R^*} \right)
\]

3 **Multi-objective optimisation by MATLAB**

Genetic algorithms (GA) are stochastic search algorithms based on the Darwinian principle of ‘survival of the fittest’. The basic concept of GA was introduced by Holland. Later several approaches were developed to solve single objective as well as multi-objective by GA. Multi-objective optimisations deals with minimisation or maximisation of a vector objectives $V(x)$ that can be subject to number of constraints:

\[
\text{Min or Max } V(x) = [v_1(x), v_2(x), \ldots, v_n(x)]
\]

s.t.

\[
C_i(x) = 0; \quad i = 1, 2, \ldots, k; \quad C_i(x) \leq 0; \quad i = k + 1, \ldots, m; \quad 1 \leq x \leq u; \quad x \in R^n
\]

There is no unique solution of multi-objective optimisation as improvement of any objective degrades another objective function. Any multi-objective optimisation is associated with two search spaces-decision variable space and objective space. Figure 8 shows graphical representation of multi-objective optimisation.

**Figure 8** Decision variable space and objective space
Evolutionary algorithms for multi-objective optimisation can be categorised as Pareto-based and non-Pareto approaches. Non-dominated sorting genetic algorithm (NSGA) (Srinivas and Deb, 1994) is an example of Pareto-based approach. MATLAB R2009a GA solver uses a controlled elitist GA, a new variant of NSGA-II. An elitist GA always favours individual with better fitness value. However, controlled elitist GA always favours individual that can help to increase diversity even if they have a lower fitness value. Initially, GA solver generates population by random number between [0, 1]. The default size of population is 15 times the number of variables. The next generation of population is computed using non-dominated rank and distance measure of individuals in current generation. Non-dominated rank is assigned to each individual by using the relative fitness. Individual ‘A’ dominates B’ if ‘A’ is strictly better than ‘B’ in at least one objective and ‘A’ is no inferior than ‘B’ in all objectives. If ‘A’ and ‘B’ have same rank then distance measure is used to compare them. As proposed by Deb (2001), two most important issues of multi-objective optimisation are to find a set of solution as close as possible to the Pareto-optimal front; and to find a set of solutions as diverse as possible. MATLAB GA solver uses ‘ParetoFraction’ and ‘DistanceFcn’ functions to control the elitism. Pareto fraction function limits the number of individual on Pareto front and distance function helps to maintain diversity on front. MATLAB R2009a GA solver consists several in-built functions, a partial list is shown in Table 3. Interested readers can refer MATLAB R 2009a help file in this regard for further information.

**Definition 1 (Pareto domination):** Let \( N \) number of solutions \( x^{(i)} \), where \( i = 1, 2, 3, \ldots N \) dominate the other \( M \) number of solutions \( x^{(j)} \), where \( j = 1, 2, 3, \ldots M \), if solutions \( x^{(i)} \) are no worse than \( x^{(j)} \) in all objectives and solutions \( x^{(i)} \) are strictly better than solutions \( x^{(j)} \) in at least one objective. If solutions \( x^{(i)} \) are strictly better than solutions \( x^{(j)} \) in all objectives, then solutions \( x^{(i)} \) strongly dominate solutions \( x^{(j)} \). A solution is said to be Pareto-optimal if it is not dominated by another solution in the solution space. Figure 9 gives graphical representation of Pareto-optimality. The set of all possible non-dominated solutions are referred as Pareto-optimal set. For a given Pareto-optimal set, corresponding objective function values in objective space are called Pareto front.

![Figure 9 Illustration of the concept of Pareto optimality](image)

**Table 3 MATLAB GA functions**

<table>
<thead>
<tr>
<th>Type</th>
<th>Function name</th>
<th>Remark, if any</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population type</td>
<td>Bitstring, double vector and custom function</td>
<td>It describes population data type. User can prepare custom function for population type. Double vector population type is suitable for linear or non-linear constraints.</td>
</tr>
<tr>
<td>Population size</td>
<td>20 (default)</td>
<td>User can change the population size as per the requirement of optimisation problem. Large population reduces the chance of getting local optima but runs very slowly.</td>
</tr>
<tr>
<td>Selection function</td>
<td>@selectionreaminder, @selectionuniform, @selectionstochunif(default), @selectionroulette, @selectiontournament</td>
<td>It chooses parents based on their scaled values from fitness scaling function.</td>
</tr>
<tr>
<td>Crossover function</td>
<td>@crossoverheuristic, @crossoversinglepoint, @crossovertwo point, @crossoverarithmetic, @crossoverintermediate, @crossoverscattered(default)</td>
<td>Crossover functions are used to produce offspring from two parents.</td>
</tr>
<tr>
<td>Elite count</td>
<td>2 (default)</td>
<td>It guarantees the number of individual to survive to the next generation.</td>
</tr>
<tr>
<td>Mutation function</td>
<td>@mutationguassian(default), @mutationadaptfeasible, @mutationuniform, @custom</td>
<td>@mutationadaptfeasible is commonly used as it satisfies linear as well as non-linear constraints.</td>
</tr>
</tbody>
</table>
3.1 Forming multi-objective model for supplier selection

In single objective function equal priority is given to all constraints (Ghodsypour and O’Brien, 2001). However this is rarely happened in real life. Moreover single objective may give suboptimal solution (Desheng and Olson, 2008).

Total five objective functions and three constraints are considered in this paper. The following assumptions are considered to prepare objective functions for supplier selection.

Assumptions

1. only one item is purchased from all suppliers
2. quantity discounts are not taken into consideration
3. no shortage of item is allowed for any supplier
4. demand of item is constant and known with certainty.
5. $C_i$: purchase cost of per ton of coal from $i^{th}$ supplier
6. $TC_i$: transportation cost of per ton of coal from $i^{th}$ supplier
7. $CC_i = 1 – S_i$: complement of utility measure of $i^{th}$ supplier obtained from fuzzy VIKOR
8. $\alpha_i$: reliability of $i^{th}$ supplier
9. $X_i$: order quantity to $i^{th}$ supplier
10. $LD_i$: percentage of late delivery from $i^{th}$ supplier
11. $\beta_i$: percentage of coal contains 15% to 18% of ash in per ton received from $i^{th}$ supplier
12. $\gamma_i$: percentage of coal contains 15% to 16% of moisture in per ton received from $i^{th}$ supplier
13. $H$: handling cost per ton.

3.1.1 Objective function

The purpose of the first objective function is to minimise total cost of purchase (TCP). TCP consists of purchase, transportation, order/setup, and holding cost. Although we are using multiple suppliers, order/setup cost is neglected as per the information obtained from the company which is mentioned in the case study. Similarly for holding cost only handling cost is considered.

Minimise TCP:

$$\sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} TC_i X_i + H \sum_{i=1}^{n} X_i$$

Our second model is similar to Ghodsypour and O’Brien (1998). Here supplier’s weight (i.e., complement of $S_i$) are used as coefficients of objective function along with reliability of supply of each supplier to allocate order quantities among suppliers such that the total value of reliable purchase (TVRP) becomes a maximum. Reliability of supply of each supplier is calculated from past performance data of supplier.

Minimise TVRP:

$$\sum_{i=1}^{n} \alpha_i CC_i X_i$$

Our third objective function is to minimise number of late deliveries. Since lot is accepted based on two quality parameters-ash content and surface moisture content, fourth and fifth objective functions are considered to maintain quality in supply.

Minimise number of late deliveries:

$$\sum_{i=1}^{n} LD_i X_i$$

Minimise amount of rejected lot based on ash content:

$$\sum_{i=1}^{n} (1 – \beta_i) X_i$$

Minimise amount of rejected lot based on moisture content:

$$\sum_{i=1}^{n} (1 – \gamma_i) X_i$$

3.1.2 Constraints for supplier selection

The most important constraints for any supplier selection problems are supplier capacity, minimum order quantity to fulfil demand, and cost or budgetary limitations (Kumar et al., 2004; Ghodsypour and O’Brien, 1998). The following constraints are considered to optimise above five objective functions

- Capacity constraint: $X_i \leq V_i$ for $i = 1, 2, 3, ..., n$
- Demand constraint: $\sum_{i=1}^{n} X_i = D$
- Cost constraint: $\sum_{i=1}^{n} C_i X_i \leq B$
- Non-negativity constraint: $X_i \geq 0$ for $i = 1, 2, 3, ..., n$

3.2 Integrated model of f-AHP-VIKOR and MOGA for supplier selection

This integrated model consists of three stages. Stage-1 and 2 consists of fuzzy AHP and VIKOR to rank suppliers. Stage-3 is basically a multi-objective optimisation process to allocate order among selected suppliers. The proposed integrated model is shown in Figure 10.

4 Case study

India is a second largest producer of cement in the world. Total installed capacity for production of cement is around 231 MT (as on September 2009). Cement is a high bulk and low value localised commodity. The location of limestone reserves and proximity of coal deposits are two important factors for selecting a cement manufacturing plant in India. As shown in Figure 11, total 20% of total cost is spent for procuring coal to produce cement.
North East (NE) India has consistently been a cement deficit area region over several years. At present this deficit is about 2.2 MTPA.

To fulfill the deficit, an ISO 9001:2000 certified company of NE India is in need to select supplier of raw material to increase its production. The capacity of the company is 460 ton per day (TPD). Company is using Dry Process Rotary Kiln Technology with four stages Suspension Pre Heater Technology to produce various grades of cement like Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC). Two critical materials for cement are limestone as raw material and coal as fuel. Gypsum is essential for OPC and fly ash is essential for PPC. Company is in need for supplier of coal. Daily consumption of coal is 110 ton. Company will accept coal if its ash content is 15% to 18% and surface moisture content is 15% to 16%. Moreover company can wait maximum three days to get supply. Material handling cost comes to Rs. 350 per ton. However order/set up cost and other holding cost is negligible. Company is working for seven days a week. Company initially got response from ten suppliers. Based on lead time criteria of the company three suppliers are selected to form supply base. People from various departments like purchase, technical and finance are taken to form decision maker (DM) team. Based on the decision DMs four criteria-quality, price, capacity and location of the supplier have been chosen as criteria for supplier selection.
Supplier selection by F-compromise method

4.1 Calculation

The weights of the criteria are calculated by f-AHP. The fuzzy comparison matrix can be seen from Table 4.

Table 4 Fuzzy pair wise comparison matrix for criteria

<table>
<thead>
<tr>
<th></th>
<th>Quality (C₁)</th>
<th>Price (C₂)</th>
<th>Capacity (C₃)</th>
<th>Location (C₄)</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>0.4362</td>
</tr>
<tr>
<td>Price</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(5/2, 3, 7/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>0.5288</td>
</tr>
<tr>
<td>Capacity</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/7, 1/3, 2/5)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>0</td>
</tr>
<tr>
<td>Location</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>0.0349</td>
</tr>
</tbody>
</table>

Table 5 Linguistic values and fuzzy numbers for alternatives

<table>
<thead>
<tr>
<th>Linguistic values</th>
<th>Fuzzy numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low (VL)</td>
<td>(0, 0, 0.2)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>(0, 0.2, 0.4)</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>(0.2, 0.4, 0.6)</td>
</tr>
<tr>
<td>High (H)</td>
<td>(0.4, 0.6, 0.8)</td>
</tr>
<tr>
<td>Very high (VH)</td>
<td>(0.6, 0.8, 1)</td>
</tr>
<tr>
<td>Excellent</td>
<td>(0.8, 1, 1)</td>
</tr>
</tbody>
</table>

The defuzzified value of a TFN \( \hat{R} = (l, m, u) \) can be determined by its centroid (Wang and Parkan, 2006), Figure 14, which is \( z^* = \frac{l + m + u}{3} \). After defuzzification, elements are normalised by equation (5) to prepare normalised matrix, shown in Table 7.

Table 7 Normalised matrix for alternatives

<table>
<thead>
<tr>
<th></th>
<th>( C_1 )</th>
<th>( C_2 )</th>
<th>( C_3 )</th>
<th>( C_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_1 )</td>
<td>0.707</td>
<td>0.2357</td>
<td>0.4714</td>
<td>0.4714</td>
</tr>
<tr>
<td>( A_2 )</td>
<td>0.4834</td>
<td>0.4834</td>
<td>0.7252</td>
<td>0.08</td>
</tr>
<tr>
<td>( A_3 )</td>
<td>0.5787</td>
<td>0.1446</td>
<td>0.4341</td>
<td>0.6750</td>
</tr>
</tbody>
</table>

Finally, utility measure, regret measure, and VIKOR index are calculated by equation (7) to (9). This can be seen from Table 8.

Table 8 Final evaluation of the alternatives

<table>
<thead>
<tr>
<th></th>
<th>( S_i )</th>
<th>( R_i )</th>
<th>( Q_i )</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_1 )</td>
<td>0.3985</td>
<td>0.3866</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>( A_2 )</td>
<td>0.4711</td>
<td>0.4362</td>
<td>0.2694</td>
<td>2</td>
</tr>
<tr>
<td>( A_3 )</td>
<td>0.779</td>
<td>0.5288</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

4.1.1 Multi-objective functions for supplier selection

Based on supplier performance data sheet, shown in Table 9, following objective functions are prepared

\[
\begin{align*}
\text{Minimise} & \; \text{TCP} : & 3,859 x_1 + 3,850 x_2 + 3,851 x_3 \\
\text{Maximise} & \; \text{TVRP} : & 0.5654 x_1 + 0.5024 x_2 + 0.2033 x_3 \\
\text{Minimise} & \; \text{number of late deliveries} : & 0.1 x_1 + 0.15 x_2 + 0.2 x_3
\end{align*}
\]
Table 9  Supplier performance data sheet

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>% Failure rate of supply (f)</th>
<th>Reliability ( (\alpha = 1 - f) )</th>
<th>Capacity (ton)</th>
<th>Purchase cost (Rs/ton)</th>
<th>Transportation cost</th>
<th>Quality</th>
<th>% of coal contains 15% to 18% ash in per ton</th>
<th>% of coal contains 15% to 16% moisture in per ton</th>
<th>% Late delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>0.94</td>
<td>4,000</td>
<td>2,760</td>
<td>749</td>
<td>0.8</td>
<td>0.85</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>0.95</td>
<td>3,000</td>
<td>2,750</td>
<td>750</td>
<td>0.75</td>
<td>0.8</td>
<td>0.8</td>
<td>0.15</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>0.92</td>
<td>3,000</td>
<td>2,749</td>
<td>752</td>
<td>0.7</td>
<td>0.8</td>
<td>0.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Quality:

1. minimise amount of rejected lot based on ash content: 
   \[ 0.2x_1 + 0.25x_2 + 0.3x_3 \]

2. minimise amount of rejected lot based on moisture content: 
   \[ 0.15x_1 + 0.2x_2 + 0.2x_3 \]

Subject to

Demand constraint: \( x_1 + x_2 + x_3 = 9,900 \)

Capacity constraint: \( x_1 \leq 4,000; \ x_2 \leq 3,000; \ x_3 \leq 3,000 \)

Cost constraint: \( 2,760x_1 + 2,750x_2 + 2,749x_3 \leq 28,000,000 \)

The proposed model is solved by using MATLAB 2009a and run it on a personal computer Intel(R) Core(TM) 2 Duo 2.00 GHz. Various values of crossover rate and population size are taken by trial and error to improve Pareto front. Finally, 0.85 was taken as crossover rate and population size was fixed at 80.

Figure 15  Obtained Pareto-front from non-hybrid GA solver

4.2 Post optimal solution

Obtained Pareto-front is discontinuous in nature as it displays two conflicting objectives, shown in Figures 15 and 16. Usually smaller average distance on Pareto-front indicates that solutions are evenly distributed. However, it is not applicable for discontinuous Pareto-front. Number of points obtained on Pareto-front was 40, average distance measure was 0.00043703 and spread measure was 0.0438135. In MATLAB 2009a, GA solver contains hybrid function ‘fgoalattain’ to improve Pareto front. By using hybrid function number of points on Pareto-front became 49, average distance measure became 0.000639913 and spread measure became 0.0518684. A slight improved average distance measure and spread measure is obtained for hybrid function. Hence, no hybrid function is opted for GA solver. Obtained order quantities are (3,900, 3,000, 3,000).  

Figure 16  Obtained Pareto-front from hybrid GA solver

5 Conclusions

Selection of supplier is an indispensible part of any business. Judicious selection of supplier could reduce procurement cost, inbound risks and enhance reliability of on-time delivery and responsiveness of upstream supply chain. The proposed model has following advantages

1. it can consider multiple criteria such as cost, quality, location, etc., in supplier selection
2. proposed model is very simple and easy to apply by purchasing management
it can be used for both single sourcing and multiple sourcing supplier selection

a schedule for delivery can be prepared to tell the buyer how much to procure from each supplier

along with TCP, total cost of reliable purchase (TVRP) is considered in this model to reduce the procurement risk.

References


