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

Mukherjee, Krishnendu and Sarkar, Bijon and Bhattacharyya, Ardhendu

Department of Mechanical Engineering,Budge Budge Institute of Technology, Department of Production Engineering, Jadavpur University, Department of Mechanical Engineering, JIS College of Engineering

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Krishnendu Mukherjee*

Department of Mechanical Engineering,
Budge Budge Institute of Technology,
Kolkata-700137, India
E-mail: gopal.mech2010@gmail.com
*Corresponding author

Bijon Sarkar

Department of Production Engineering,
Jadavpur University,
Kolkata-700032, India
E-mail: bijon_sarkar@email.com

Ardhendu Bhattacharyya

Department of Mechanical Engineering,
JIS College of Engineering,
Kalyani, Nadia, West Bengal-741235, India
E-mail: dharam2004@gmail.com

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 emphasises 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.

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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 had 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 *IJPR*, *EJOR* and *IE*(*I*). His fields of interests include tribology, reliability engineering, AI, soft-computing applications and decision engineering.

Ardhendu Bhattacharyya is former Professor and Head of Mechanical Engineering Department, Jadavpur University, Kolkata, India. His 40 years of experience includes under graduate 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 (VlseKriterijumska 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.

Figure 1 Different supplier selection methods

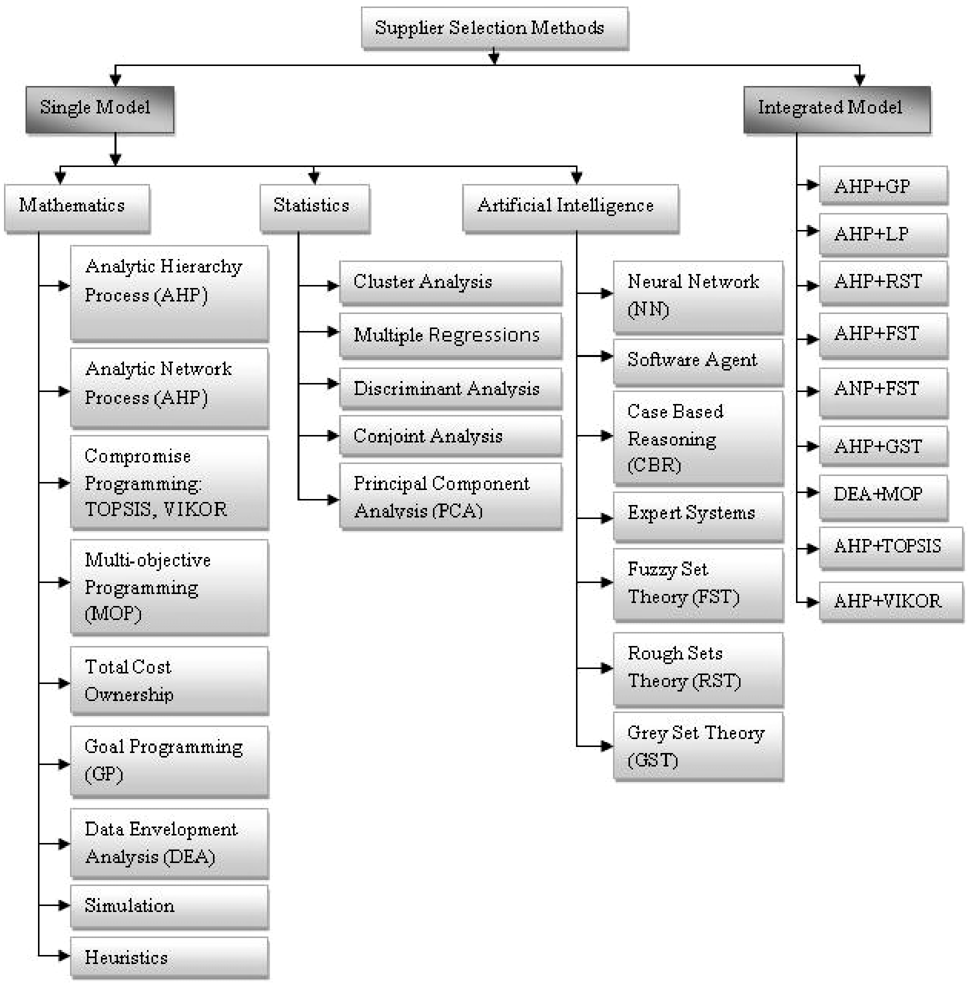


Table 1 A partial list of supplier selection methods and criteria

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

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

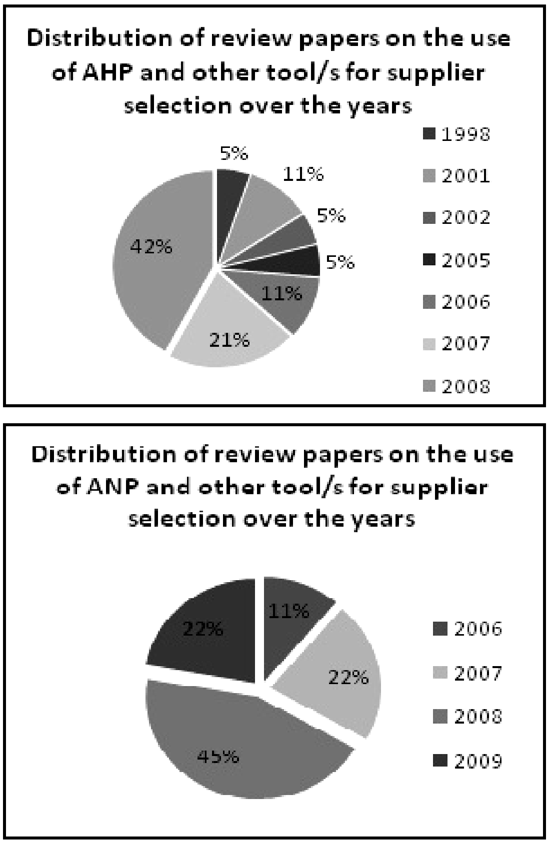


Figure 3 Use of AHP, ANP and their integrated approach

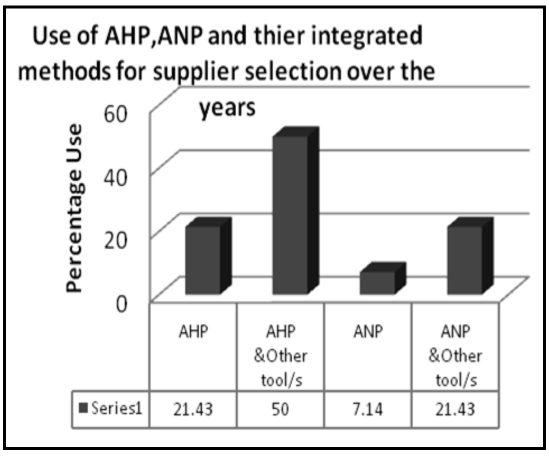
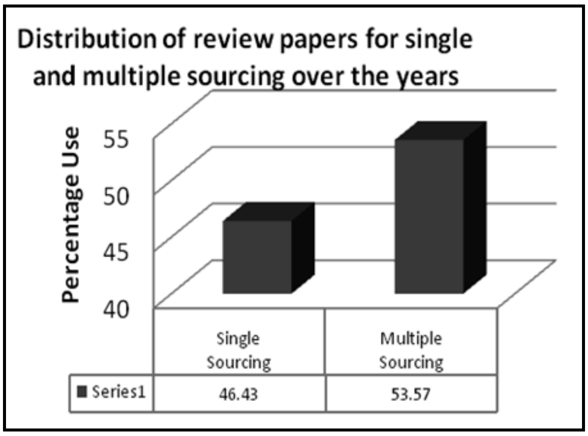


Figure 4 Distribution of review papers for single and multiple sourcing



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).

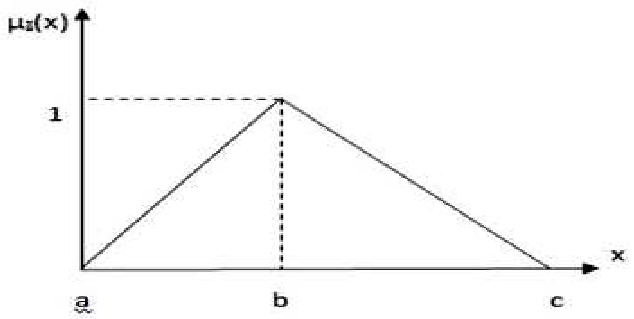
Definition 5: A positive triangular fuzzy number (TFN) $\tilde{n}$ can be specified by three parameters (a, b, c), shown in Figure 5. The MF $\mu_{\tilde{A}}$ is defined as

$$\mu_{\tilde{A}} = \begin{cases} 0, x \leq a \\ \dfrac{x-a}{b-a}, a \leq x \leq b \\ \dfrac{c-x}{c-b}, b \leq x \leq c \\ 0, c \leq x \end{cases}$$

Definition 6: If $\tilde{o} = (o_1, o_2, o_3)$ and $\tilde{n} = (n_1, n_2, n_3)$ are two TFN then the distance between them calculated by vertex method as

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

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 $M_{g_i}^i$ 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

$$S_i = \sum_{i=1}^{m} M_{g_i}^i \otimes \left[\sum_{i=1}^{n} \sum_{i=1}^{m} M_{g_i}^i\right]^{-1} \quad (1)$$

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

$$\left[\sum_{i=1}^{n} \sum_{i=1}^{m} M_{g_i}^i\right]^{-1} = \left\{\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right\} \quad (2)$$

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

where

$$V(M_2 \geq M_1) = \begin{cases} 1, & \text{if } m_2 \geq m_1 \\ 0, & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - u_1)}, & \text{otherwise} \end{cases} \quad (3)$$

As shown in Figure 6, d is the highest intersection point μ_{M_1} and μ_{M_2}.

$$d(A_i) = \min V(S_i \geq S_k)$$
for $k = 1, 2, 3, 4, 5 \ldots\ldots n$; $k \neq i$

The weight vector

$$W^* = (d(A_1), d(A_2), d(A_3) \ldots d(A_n))^T$$

The normalised weight vector

$$W = \frac{W^*}{\sum_{I=1}^{n} d(A_i)} \quad (4)$$

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

Figure 6 Intersection of two MFs

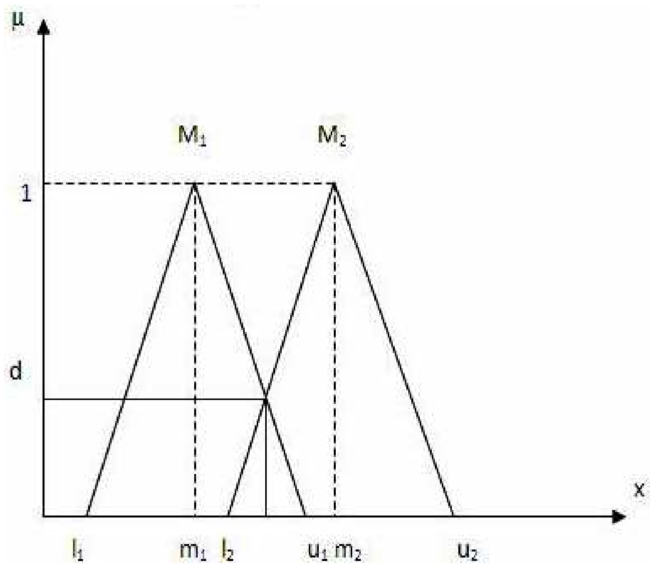


Table 2 Fuzzy TFN values

Linguistic values	*Fuzzy numbers*
Equal	(1, 1, 1)
Weak	(2/3, 1, 3/2)
Fairly strong	(3/2, 2, 5/2)
Very strong	(5/2, 3, 7/2)
Absolute	(7/2, 4, 9/2)

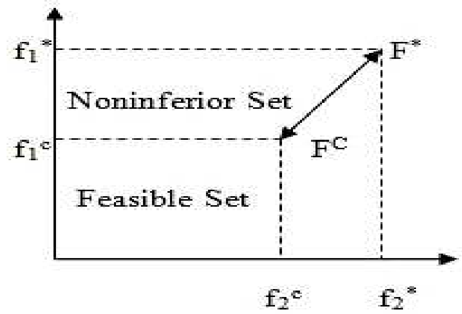
2.3 *VIKOR method*

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

$$L_{pi} = \left\{\sum_{j=1}^{n}\left[w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-)\right]^p\right\}^{1/p}$$
$1 \leq p \leq +\infty;\ i = 1, 2, \ldots m$

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^c is the feasible solution that is closest to ideal F and it is the result of compromise between two criteria. Here compromise volumes are $\Delta f_1 = f_1^* - f_1^c$ and $\Delta f_2 = f_2^* - f_2^c$.

Figure 7 Ideal and compromise solution



Source: Opricovic and Tzeng (2004)

Steps for selecting suppliers by VIKOR

1 Construction of original data evaluation matrix

$$X = \begin{matrix} & C_1 & C_2 & & C_i \\ A_{11} & x_{11} & x_{12} & \cdots \cdots & x_{1j} \\ A_{22} & x_{21} & x_{22} & \cdots \cdots & x_{2j} \\ \vdots & \vdots & \vdots & \vdots \quad \vdots & \vdots \\ A_m & x_{m1} & x_{m2} & \cdots \cdots & x_{mj} \end{matrix}$$

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

$$f_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}^2} \tag{5}$$

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

$$F = \begin{matrix} & C_1 & C_2 & & C_i \\ A_{11} & f_{11} & f_{12} & \cdots \cdots & f_{1j} \\ A_{22} & f_{21} & f_{22} & \cdots \cdots & f_{2j} \\ \vdots & \vdots & \vdots & \vdots \quad \vdots & \vdots \\ A_m & f_{m1} & f_{m2} & \cdots \cdots & f_{mj} \end{matrix}$$

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

$$f_i^* = \max f_{ij} \quad f_j^- = \min f_{ij} \tag{6}$$

Calculate utility measure and regret measure.

$$S_i = \sum_{j=1}^{n} w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right) \tag{7}$$

$$R_i = \max\left[w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right)\right] \tag{8}$$

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

$$Q_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1 - v)\left[\frac{R_i - R^*}{R^- - R^*}\right] \tag{9}$$

where Q_i, represents the i^{th} alternative VIKOR value, $i = 1, 2, \ldots, m$; $S^* = \text{Min}(S_i)$; $S^- = \text{Max}(S_i)$; $R^* = \text{Min}(R_i)$; $R^- = \text{Max}(R_i)$ and v is the weight of the maximum group utility(usually it is to be set to 0.5). The alternative having smallest VIKOR value is determined to be the best solution.

Rank alternatives by Q_i values.

S_i is the distance rate of i^{th} alternative to the positive ideal solution and lower S_i value refers better solution. Hence, we are taking complement of S_i (i.e., $1 - S_i$) to prepare linear weighted model for order allocation to selected suppliers.

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:

$$\begin{aligned} &\text{Min or Max } V(x) = \left[v_1(x),\ v_2(x) \ldots v_n(x)\right] \\ &\text{s.t.} \\ &C_i(x) = 0;\ i = 1,\ 2,\ 3 \ldots k; \\ &C_i(x) \le 0;\ i = k+1, \ldots, m;\ l \le x \le u;\ x \in R^n \end{aligned}$$

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

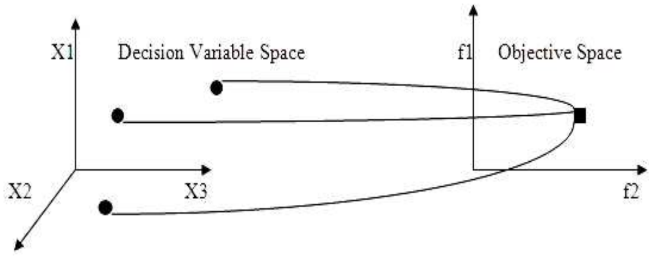


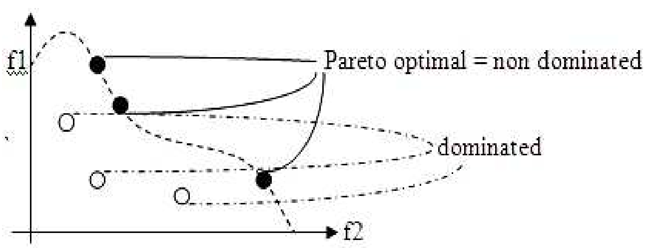
Table 3 MATLAB GA functions

Type	*Function name*	*Remark, if any*
Population type	Bitstring, double vector and custom function	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.
Population size	20 (default)	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.
Selection function	@selectionreaminder, @selectionuniform, @selectionstochunif(default) @selectionroulette @selectiontournament	It chooses parents based on their scaled values from fitness scaling function.
Crossover function	@crossoverheuristic, @crossoversinglepoint, @crossovertwopoint, @crossoverarithmatic, @crossoverintermediate @crossoverscattered(default)	Crossover functions are used to produce offspring from two parents.
Elite count	2 (default)	It guarantees the number of individual to survive to the next generation.
Mutation function	@mutationguassian(default), @mutationadaptfeasible, @mutationuniform, @custom	@mutationadaptfeasible is commonly used as it satisfies linear as well as non-linear constraints.

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 favour 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*): *N* number of solutions $x^{(i)}$, where i = 1, 2, 3, ... *N* dominate the other M number of solutions $x^{(j)}$, where j = 1, 2, 3........ *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



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.

C_i purchase cost of per ton of coal from i^{th} supplier

TC_i transportation cost of per ton of coal from i^{th} supplier

$CC_i = 1 - S_i$ complement of utility measure of i^{th} supplier obtained from fuzzy VIKOR

α_i reliability of i^{th} supplier

X_i order quantity to i^{th} supplier

LD_i percentage of late delivery from i^{th} supplier

β_i percentage of coal contains 15% to 18% of ash in per ton received from i^{th} supplier

γ_i percentage of coal contains 15% to 16% of moisture in per ton received from i^{th} supplier

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 ashcontent :
$$\sum_{i=1}^{n} (1-\beta_i) X_i$$

Minimise amount of rejected lot based onmoisture 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 : $X_i \le V_i$ for $i = 1, 2, 3 \ldots\ldots\ldots n$

Demand constraint :
$$\sum_{i=1}^{n} X_i = D$$

Cost constraint :
$$\sum_{i=1}^{n} C_i X_i \le B$$

Non-negativity constraint : $X_i \ge 0$ for $i = 1, 2, 3 \ldots\ldots\ldots n$

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

This integrated model consists of three stages. Stage-1and 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.

Figure 10 Integrated model of fuzzy-AHP-VIKOR-MOGA for supplier selection

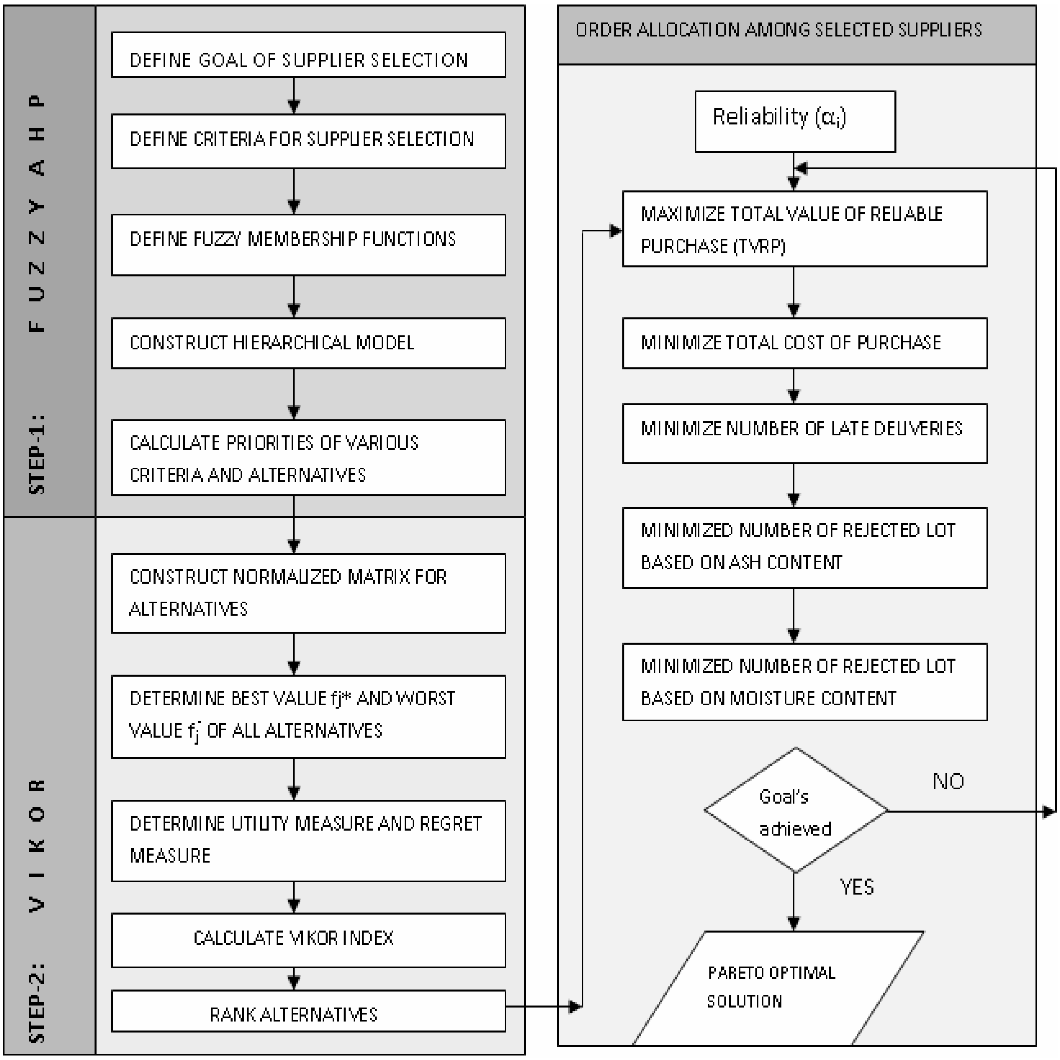
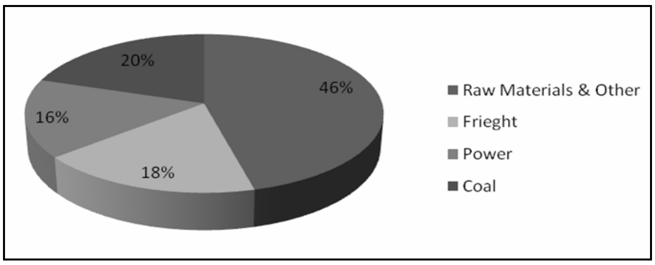


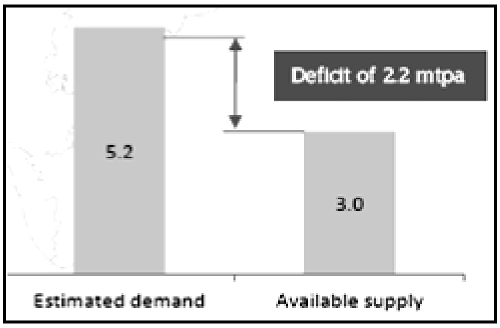
Figure 11 Components of cost of producing cement



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 fulfil 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.

Figure 12 North East India: cement demand supply-gap



Source: http://www.ibef.org

4.1 Calculation

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

Figure 13 Hierarchical model of supplier selection (see online version for colours)

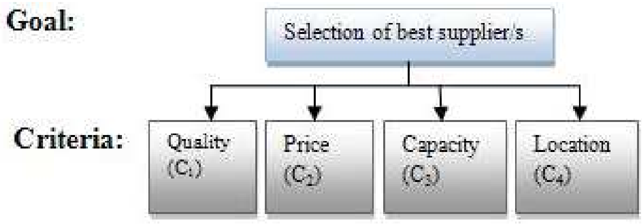


Table 4 Fuzzy pair wise comparison matrix for criteria

	Quality (C_1)	*Price (C_2)*	*Capacity (C_3)*	*Location (C_4)*	*Priority*
Quality	(1, 1, 1)	(2/3, 1, 3/2)	(3/2, 2, 5/2)	(3/2, 2, 5/2)	0.4362
Price	(2/3, 1, 3/2)	(1, 1, 1)	(5/2, 3, 7/2)	(3/2, 2, 5/2)	0.5288
Capacity	(2/5, 1/2, 2/3)	(2/7, 1/3, 2/5)	(1, 1, 1)	(2/3, 1, 3/2)	0
Location	(2/5, 1/2, 2/3)	(2/5, 1/2, 2/3)	(2/3, 1, 3/2)	(1, 1, 1)	0.0349

Table 5 Linguistic values and fuzzy numbers for alternatives

Linguistic values	*Fuzzy numbers*
Very low (VL)	(0, 0, 0.2)
Low (L)	(0, 0.2, 0.4)
Medium (M)	(0.2, 0.4, 0.6)
High (H)	(0.4, 0.6, 0.8)
Very high (VH)	(0.6, 0.8, 1)
Excellent	(0.8, 1, 1)

Table 6 Fuzzy evaluation matrix for alternatives

A_i	C_1	C_2	C_3	C_4
A_1	(0.4, 0.6, 0.8)	(0, 0.2, 0.4)	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)
A_2	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)	(0.4, 0.6, 0.8)	(0, 0, 0.2)
A_3	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.4, 0.6, 0.8)	(0.8, 1,1)

The defuzzified value of a TFN $\tilde{R} = (l, m, u)$ can be determined by its centroid (Wang and Parkan, 2006), Figure 14, which is $z^* = \frac{1(l+m+u)}{3}$. After defuzzification, elements are normalised by equation (5) to prepare normalised matrix, shown in Table 7.

Figure 14 Defuzzification of TFN by centroid method

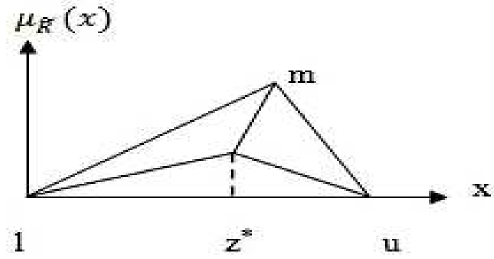


Table 7 Normalised matrix for alternatives

A_i	C_1	C_2	C_3	C_4
A_1	0.707	0.2357	0.4714	0.4714
A_2	0.4834	0.4834	0.7252	0.08
A_3	0.5787	0.1446	0.4341	0.6750

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

A_i	S_i	R_i	Q_i	*Rank*
A_1	0.3985	0.3866	0	1
A_2	0.4711	0.4362	0.2694	2
A_3	0.779	0.5288	1	3

4.1.1 Multi-objective functions for supplier selection

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

$$\text{Minimise TCP}: \; 3{,}859\,x1 + 3{,}850\,x2 + 3{,}851\,x3$$

$$\text{Maximise TVRP}: \; 0.5654\,x1 + .5024\,x2 + 0.2033\,x3$$

$$\text{Minimise number of late deliveries}: 0.1\,x1 + 0.15\,x2 + 0.2\,x3$$

Table 9 Supplier performance data sheet

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

Quality:

1 minimise amount of rejected lot based on ash content: $0.2\,x1 + 0.25\,x2 + 0.3\,x3$

2 minimise amount of rejected lot based on moisture content: $0.15\,x1 + 0.2\,x2 + 0.2\,x3$.

Subject to

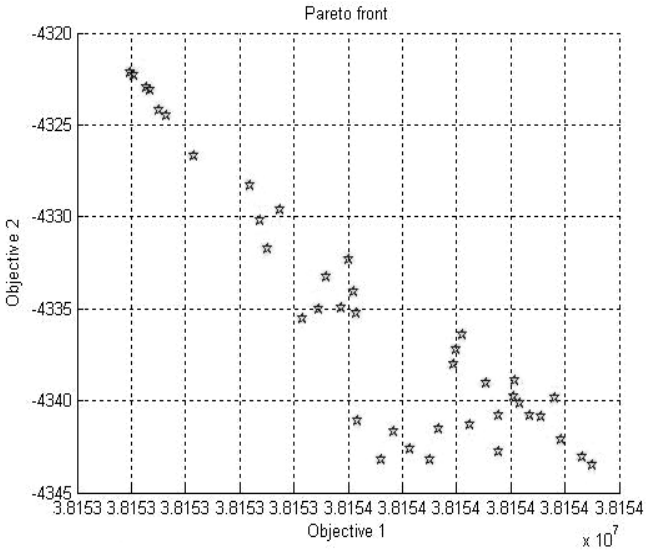
$$\text{Demand constraint}: x1 + x2 + x3 = 9{,}900$$

$$\text{Capacity constraint}: x1 \le 4{,}000;\ x2 \le 3{,}000;\ x3 \le 3{,}000$$

$$\text{Cost constraint}: 2{,}760\,x1 + 2{,}750\,x2 + 2{,}749\,x3 \le 28{,}000{,}000$$

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.

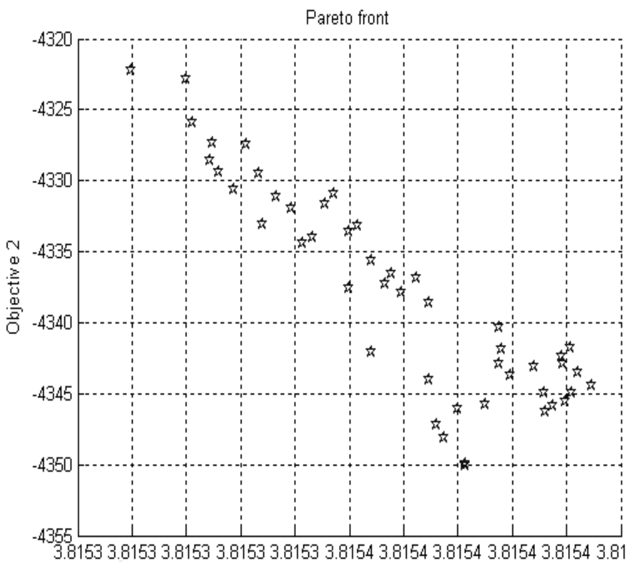
Figure 15 Obtained Pareto-front from non-hybrid GA solver



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 $(3{,}900,\ 3{,}000,\ 3{,}000)^T$.

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

3 it can be used for both single sourcing and multiple sourcing supplier selection

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

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

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