Chapter 2
Modeling and Optimization of Traditional Supplier Selection

2.1 Introduction

Judicious selection of supplier can mitigate upstream supply chain risk by supplying right quantity at right place and time.

Supplier selection is a strategic process as it can mitigate upstream supply chain risk partially, if not completely. Better supplier–buyer dyadic relationship can enhance supply chain visibility and capability to cope with high demand volatility. Supplier selection, thus, is an indispensible part of any business. Any disruption in upstream supply may cause tremendous disaster in entire supply chain and compel organization to take risk. Risks in supply chain are broadly classified as **internal risk** that appears in normal operation and **external risk** that come from outside the supply. Selection of right supplier(s) could minimize external risks. Supplier selection could be either **single sourcing** or **multiple sourcing**. In single sourcing, entire supply comes from one supplier. In multiple sourcing, on the other hand, entire supply comes from a group of suppliers. Risk in supply chain could be minimized by internal integration and external integration of supply chain entities. External integration strongly encourages single sourcing by strengthening buyer–supplier relationship. Table 2.1 shows the comparative analysis of single-sourcing and multiple-sourcing strategies.

Research on supplier selection methods has rich collection, as shown in Fig. 2.1. Some researchers combined at least two techniques for supplier selection, for instance, AHP-GP, AHP-LP, DEA-AHP, and DEA-MOP. Supplier selection problem involves vague and imprecise assessments, which are by nature fuzzy. Thus, a group of researchers used fuzzy AHP. Various methods have been used to derive priority vectors from fuzzy pairwise comparison. A partial list is shown in Table 2.2.

Among all techniques, extent fuzzy AHP is used most frequently because of its computational simplicity. In Table 2.3, various techniques are classified based on single-sourcing and multiple-sourcing supplier selection.

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Table 2.1 Single sourcing versus multiple sourcing

Single sourcing	Multiple sourcing
Concept of this strategy comes from **just-in-time (JIT)** philosophy. Uncertainty in supply is very high as buyer deals with single supplier	Multiple sourcing is preferable if reliability of one supplier is very poor. It reduces safety stock without increasing stock-out problem (Kelle and silver 1990). It reduces uncertainty in supply but increases ordering cost (Agrawal and Nahmias 1997)
No competition exists as only one supplier is involved. It gives quantity discount from order consolidation and reduces order lead time and logistical lead time (Hahn et al. 1986; Bozarth et al. 1998)	Reduction in price is achieved through competition between suppliers. It gives better on-time delivery and higher volume flexibility (Ramasesh et al. 1991)
It is applicable where goodwill trust exists between buyer and supplier	Dual sourcing is always effective for low ordering cost and highly variable lead times (Ramasesh et al. 1991)
Low threat to loss of information	Since business data are shared among various suppliers, proper security measures should be taken

2.2 State-of-the-Art Literature Review of Supplier Selection Methods

The abundant work on supplier selection can be broadly classified into eight different categories as follows:

1. selection of supplier for single item or multiple items for deterministic or stochastic demand and supply;
2. selection of supplier for manufacturing industry;
3. selection of supplier for service industry;
4. selection of supplier with price–order quantity discount;
5. comparative analysis of single-sourcing and multiple-sourcing strategies;
6. decision support system (DSS) for supplier selection;
7. supplier selection for green supply chain; and
8. supplier selection for new product development.

In this chapter, literature review is conducted to find the followings:

1. to identify relevant criteria for supplier selection;
2. to identify different methods for supplier selection; and
3. to identify the trend of supplier selection methods.

Research work related to supplier selection is considerably very high. For instance, from www.sciencedirect.com, alone 13, 201 articles were found with the search word ‘supplier selection’ for publication 2009 onwards. About 100 research manuscripts are selected from peer-review journals from 1998 to 2012. Papers are selected based on the reputation of journal and citation of papers to find the most

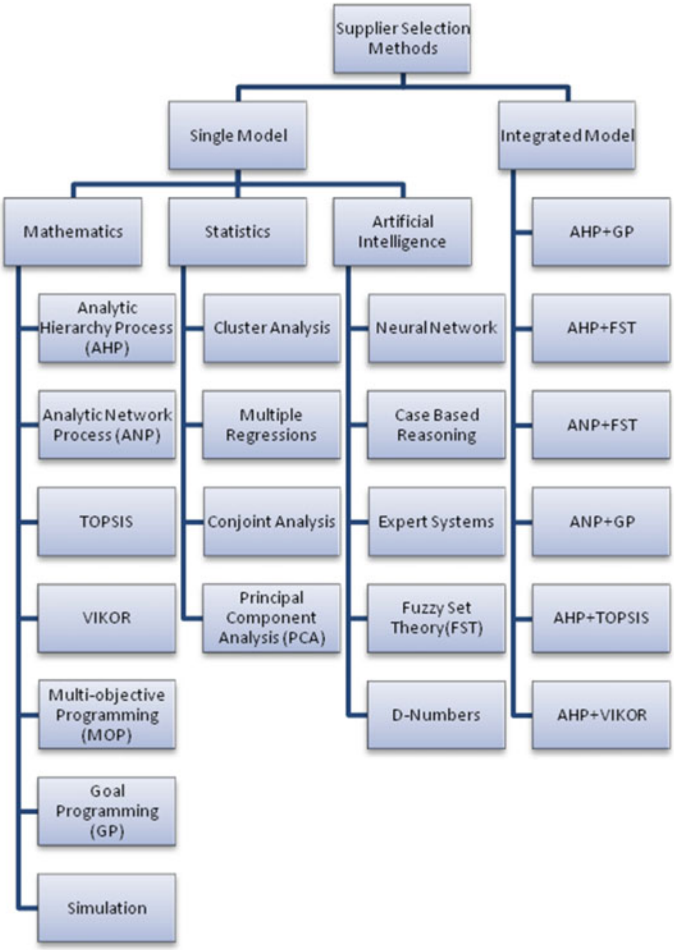


Fig. 2.1 Supplier selection methods

cited method(s) for supplier selection, recent trend of supplier selection, etc. Supplier selection methods are broadly classified into two categories—methods for single model and integrated model, as shown in Fig. 2.1. Single model is further classified into three subcategories—methods based on mathematics, statistics, and artificial intelligence. Integrated models usually combined with **linear program (LP)** or genetic algorithm (GA) or particle swarm optimization (PSO) to allocate order among multiple suppliers. Each method has certain limitations. Therefore, selection of an appropriate method always remains a daunting task for decision makers. AHP, ANP, and their integrated methods are mostly preferred by various researchers because of its simplicity and ability to solve complex problem. Figs. 2.2 and 2.3 clearly indicate such trend. Today, majority of the companies prefer to

Table 2.2 Supplier selection technique—a brief review

Sl. No.	Techniques	Authors
1.	Logarithmic least square method (LLSM) for fuzzy AHP	Van Laarhoven and Pedrycz (1983).
2.	Modified logarithmic least square method (MLLSM)	Wang et al. (2006a, b)
3.	Fuzzy least square priority method	Xu (1996).
4.	Lambda-Max method	Csutora and Buckley (2001)
5.	Eigenvector method	Wang et al. (2008a, b)
6.	Fuzzy preference programming	Mikhailov (2003)
7.	Extent analysis	Chang (1996)

Table 2.3 Various techniques for single-sourcing and multi-sourcing supplier selection

Single sourcing			Multi-sourcing	
Sl. No.	Methods	Remarks	Sl. No.	Methods
1.	Linear weighted point	Depends heavily on human judgments	1.	Mixed integer programming
2.	Categorical method	Depends heavily on human judgments	2.	Goal programming
3.	Cost ratio	Very complicated and needs more financial information	3.	Single- / multi-objective programming
4.	AHP	More accurate than any other method (Ghodsypour and O'Brien 1998)	4.	Multi-attribute utility theory and AHP; AHP-LP; AHP-GA; AHP and multi-objective possibilistic linear programming (AHP-MOPLP) etc

reduce supply base, and because of that, research trend on supplier selection is gradually moving from multiple supplier selection to single supplier selection. However, very less number of research papers has been identified on **supply base reduction** (SBR). Different criteria used for supplier selection methods are shown in Table 2.4. Cost, quality, and service are mostly used for traditional supplier selection process, for example, delivery time, on-time delivery, and delivery reliability. About 78 papers are analyzed thoroughly from 2005 to 2012 to find out the application of supplier selection methods in different industries, as shown in Fig. 2.4 (Table 2.5).

Study reveals that major contribution in research related to supplier selection is obtained from Taiwan, USA, Turkey, Iran, and China. Their cumulative research work related to supplier selection is about 69% of total research work. Both India and UK occupies the same position. This major contribution also inspired researchers to contribute more on supplier selection methods for electronics,

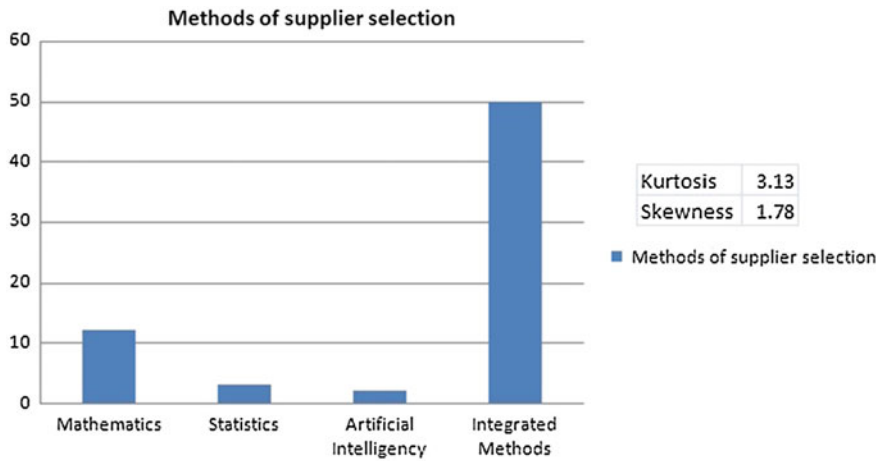
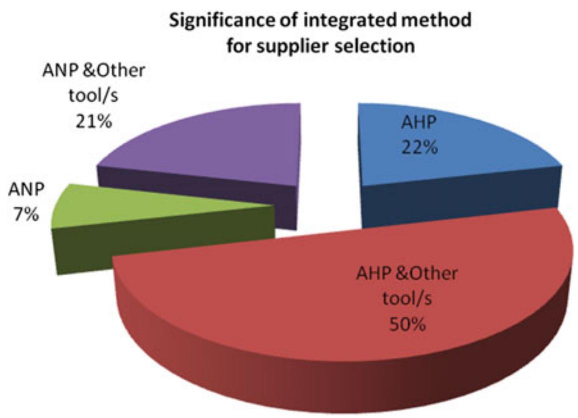


Fig. 2.2 Trend of supplier selection methods

Fig. 2.3 Distribution of research paper for supplier selection



mechanical or manufacturing, and automobile industries, as shown in Fig. 2.4. Unfortunately, supplier selection for construction industries is yet to be explored.

2.3 Pareto Analysis of Supplier Selection Criteria

Dickson (1966) in his seminal work proposed twenty-three criteria for supplier selection. Based on the work of Dickson (1966) and Weber (1991), Pareto analysis is performed to find most cited criterion for supplier selection. Six criteria such as net price, delivery, quality, production facilities and capacity, geographic location, and technical capability are identified as the most cited criteria.

Table 2.4 A partial list of supplier selection criteria

Year	Author/s	Cost	Quality	Service	Delivery	Reputation	Environment	Logistical performance	Commercial structure	Production	Technology	Responsiveness	Supplier's profile	Risk factor	Reliability	Lead time	Flexibility	Supplier's willingness	R&D
1998	Ghodsypour, O'Brien	X	X	X															
2001	Eon-Kyung Lee, Sungdo Ha, and Sheung-Kown Kim,	X	X	X	X														
2001	Maggie C. Y. Tam, Rao Tummala	X	X																
2002	Robert Handfield, Steven V. Walton, Robert Sroufe, and Steven A. Melnyk						X												
2005	Ozden Bayazit and Birsen Karpak							X	X	X									
2006	Huan-Jyh Shyur and Hsu-Shih Shih	X	X		X						X	X							
2007	FU Yao and LIU Hongli	X	X		X														
2007	Felix T.S. Chan and Niraj Kumar	X	X	X									X	X					
2007	Weijun Xia and Zhiming Wu	X	X	X															
2007	Min Wu	X	X	X	X														
2007	Sanjay Jharkharia and Ravi Shankar	X	X			X													
2007	Cevriye Gencer and Didem Gürpinar		X							X									
2007	Ezgi Aktar Demirtas and Ozden Ustun	X	X	X															

(continued)

Table 2.4 (continued)

Year	Author/s	Cost	Quality	Service	Delivery	Reputation	Environment	Logistical performance	Commercial structure	Production	Technology	Responsiveness	Supplier's profile	Risk factor	Reliability	Lead time	Flexibility	Supplier's willingness	R&D
2008	Ali Kokangul and Zeynep Susuz	X			X														
2008	Jia-Wen Wang, Ching-Hsue Cheng, and Huang Kun-Cheng	X	X	X															
2008	Reuven R. Levary													X	X				
2008	Jing-Rung Yu and Chao-Chia Tsai	X	X	X	X		X												
2008	Ozan Cakir and Mustafa S. Canbolat	X																	
2008	Sung Ho Ha and Ramayya Krishnan		X													X			
2008	Amy H.I. Lee	X	X		X						X						X		
2008	Eleonora Bottani and Antonio Rizzi																	X	
2008	Rong-Ho Lin	X	X		X						X								
2008	Semih Önüt, Selin Soner Kara, and Elif Is_ik	X	X		X														
2008	Ozeden Ustun and Ezgi Aktar Demirtas	X	X		X														
2009	Wann-Yih Wu et al.	X	X																
2009	Chia-Wei Hsu, Allen H. Hu		X																X

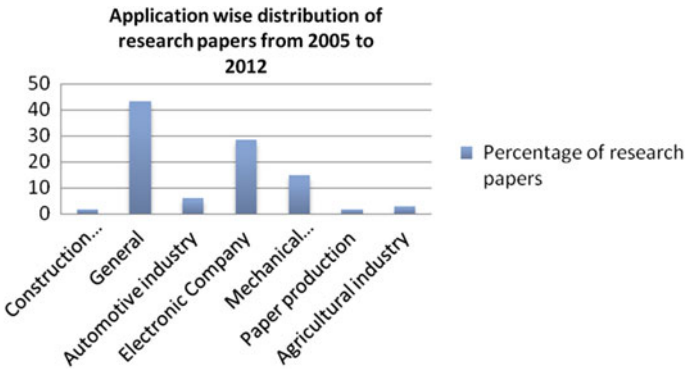


Fig. 2.4 Application of supplier selection methods to different industries

2.4 Stages of Procurement

Supplier selection is the process by which suppliers are reviewed, evaluated, and chosen to become part of the company's supply chain (Sanayei et al. 2010). The overall objective of the supplier selection process is as follows (Chena eta al 2006):

1. to reduce the procurement risk;
2. to maximize the overall value of purchase; and
3. to build the closeness and long-term relationships between buyers and suppliers.

Supplier selection is not a mere clerical issue or a mere optimization problem. Supplier selection is a strategic issue of any business because of the following reasons:

1. Procurement is considered as value addition process to supply chain.
2. Active supplier involvement can enhance efficiency and effectiveness of supply chain.
3. Short product life cycle and rapid product innovation give more emphasizes on integration of material and information flows, both internally and externally.

Supplier selection process consists of four stages—problem definition; formulation of attributes; qualification of potential suppliers; and the final selection of best suppliers (De Boer et al. 2001). A generalized **procurement cycle** can be considered that consists of the following stages:

1. Recognition of need: Identify the demand of product.
2. Specification: Identify part/assembly/raw material specifications.
3. Make or buy decision: It is one of the most crucial stages of procurement cycle to think over about source materials, goods, price, etc. Usually, a company is supposed to take, make, or buy decision for the following reasons:

Table 2.5 Application area wise distribution of research paper from 2005 to 2012

Year	Author(s)	Application areas
2005	Hong et al.	Agricultural industry in Korea
2005	Chen et al.	Electronic components
2005	Bayazit and Karpak	Construction company
2006	Kubat and Yuce	General
2006	Mouli et al.	General
2006	Sarfaraz and Balu	General
2006	Chen et al.	High tech manufacturing
2006	Shyura and Shih	Local Taiwanese company
2007	Gencer and Gu¨rpinar	Electronic company
2007	Demirtas and Ustun	Refrigerator producers
2007	Reza Farzipoor Saen	General
2007	Che et al.	Semiconductor industry
2007	Mehdizadeh and Moghaddam	General
2007	Guo et al.	General
2007	Yao and Hongli	Information & Mgmt Sys outsourcing
2007	Fayez et al.	General
2007	Huang and Keskar	PC manufacturer
2007	Amid et al.	General
2007	Li et al.	General
2007	Chan and Kumar	Manufacturing company
2007	Xia and Wu	General
2007	Min Wu	General
2007	Guan et al.	General
2008	Kokangul and Susuz	Automotive industry
2008	Rong-Ho Lin	General
2008	Moghadam et al.	General
2008a, b	Wang et al.	Lithium-ion battery
2008	Che and Wang	PDA
2008	Hong and Ha	Agricultural industry
2008	Reuven R. Levary	Manufacturing company
2008	Yu and Tsai	Semiconductor industry
2008	Lin and Chang	Manufacturing company
2008	Wan Lung Ng	General
2008	Amin and Razmi	ISP
2008	Wu et al.	TFT-LCD industry
2008	Chou and Chang	IT Industry
2008	Ha and Krishnan	Automobile industry
2008	Lee et al.	TFT-LCD industry
2008	Amy H.I. Lee	TFT-LCD industry
2008	Önüt et al.	Telecommunication industry

(continued)

Table 2.5 (continued)

Year	Author(s)	Application areas
2008	Zhang et al.	General
2008	Bottani and Rizzi	Manufacturing company
2008	Rhee et al.	Manufacturing company
2008	Wu and Olson	General
2008	Yang et al.	Electronic manufacturing company
2008	Ustun and Dem˙ırtas	Refrigerator manufacturing
2009	Amy H.I. Lee	TFT-LCD industry
2009	Wu et al.	Notebook manufacturer
2009	Hsu and Hu	Electronic manufacturing company
2009	Wang et al.	Notebook manufacturer
2010	Wen-Pai Wang	Electronic manufacturing company
2010	Wu et al.	General
2010	Sanayei et al.	Automobile industry
2010	Tadeusz Sawik	General
2011	Bilsel and Ravindran	General
2011	Tadeusz Sawik	General
2011	Amid et al.	General
2011	Selin Soner Kara	Paper production
2012	Erdem and Göçen	White goods manufacturer
2012	Shaw et al.	Garment manufacturing
2012	Mukherjee and Kar	General
2012	Jin Wang	General
2012	Riedl et al.	General
2012	Bruno et al.	General
2012	Choudhary and Shankar	General
2012	Parthiban et al.	Automotive industry

   1. sudden increase in procurement cost;
   2. need for design secrecy;
   3. lack of specific technical competency of suppliers in supply base;
   4. poor services of existing suppliers; and
   5. Unpredictable deterioration of existing supplier's performance, etc.

4. Source Identification: Prepare a supply base as per requirement.
5. Source selection: Organization has to think about single sourcing or optimal number of sourcing as per the goal of organization. Usually, it consists of four stages:

   1. Select criteria to consider palpable and non-palpable issues of supplier selection.
   2. Select appropriate method for supplier selection.

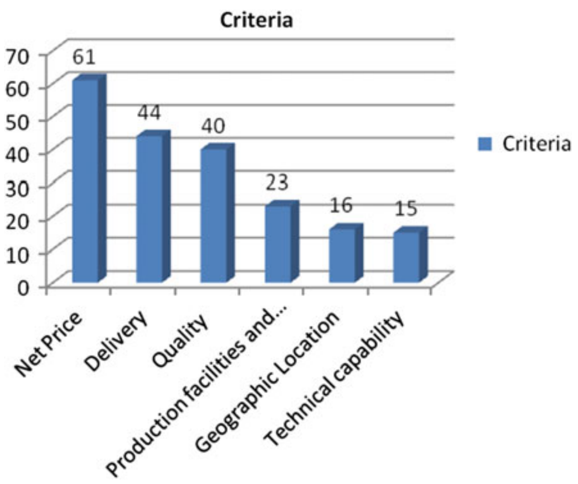


Fig. 2.5 Most cited criteria for supplier selection

3. Select supplier(s) as per the unanimous preference of decision makers.
4. Allocate order to selected suppliers as per mathematical model.

   For single sourcing, last stage is not considered as entire order is allocated to single/best supplier.

6. Contracting: Placed order to selected suppliers.
   In brief, supplier selection procedure can be classified as preselection, selection, and post-selection.
   Preselection and post-selection are highly subjective and varied from company to company as per their goal of procurement process.

2.5 Qualities of Good Supplier

Quality of good supplier is highly subjective as it varied from company to company, product to product, and process to process. It also depends on the type of sourcing decisions. Sourcing decisions are classified as follows:

1. consumable supplies;
2. production materials and components;
3. capital purchases (e.g., machinery);
4. intellectual property (e.g., software);
5. subcontractors; and
6. services.

Based on the above classifications, a generalized list of qualities of good suppliers can be mentioned as follows:

1. on-time delivery;
2. technical capabilities;

3. consistent quality;
4. reasonable low price;
5. good past performance record;
6. ability to maintain volume flexibility to withstand sudden variations in demand;
7. presales and post-sales support;
8. ability to provide his buyers tracking facilities to track the progress of supply. Such tracking process could enhance the reliability of supply;
9. industrial certifications such as ISO and TUV; and
10. proactive to develop a healthy relation with his buyers.

2.6 How to Prepare Supply Base?

A stable supply base could enhance availability of raw material/parts/assembly, increase buyers' bargain power, and increase the possibility to get best supplier(s) to develop a long-term relationship. Preparation of **supply base** is not a much discussed topic in supplier selection literature as major focus is given to selection and evaluation of supplier(s). Often, it is considered as a preprocess of supplier selection. Author strongly suggests that due care should be given to prepare supply base as poor supply base gives low probability of selecting good supplier(s) even if very supplier selection method is used. Following are some of the criteria for preparing supply base:

1. reputation and industrial certification of suppliers;
2. availability of past performances of supplier with authenticated documents;
3. availability of well-documented product catalog. For raw material, a well-documented test report which contains chemical and physical properties should be provided.
4. Ability to provide goods as per delivery due date. Usually, it varies from company to company.
5. For new product, technical know-how of supplier should be verified. At the same time, availability of technical equipments of the supplier should be verified.

2.7 Supplier Selection for Mass Customized System

In Chap. 3, a detailed discussion is given for **customized production system**, **postponement,** and **CODP**. **Mass customization** is a strategy to manufacture customized product from standard product with near mass production efficiency. Mass customization can be broadly classified as ***assembly to order (ATO), build to order (BTO)***, ***engineer to order (ETO),*** *and* ***make to stock (MTS)*** which is commonly used for standard product to reduce customer's waiting time. Literature review reveals ample work on MTS but very few works on ATO/BTO/ETO. In this book, main focus is given to supplier selection methods, development of hybrid model for supplier selection, development of mathematical model for supplier selection for ATO system, and design of decision support system for sustainable supplier selection and strategic sourcing.

2.8 Hybrid Methods for Supplier Selection

In this chapter, three hybrid methods are proposed for supplier evaluation, selection, and order allocation problem. In the first method, modified extent fuzzy AHP is used to consider tangible and intangible criteria for supplier selection, and for **order allocation,** GA is used. In the second method, fuzzy AHP-TOPSIS is used to consider palpable and non-palpable criteria for supplier selection, and order allocation GA is used.

2.8.1 Modified Extent Fuzzy AHP and GA (MEFAHP-GA)

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

1. If $M_{g_i}^i$ are the triangular fuzzy numbers (TFNs) where g_i is the goal set (i = 1, 2, 3…m),
   the fuzzy extent value S_i with respect to the ith criterion is defined as

$$S_i = \sum_{i=1}^{m} M_{g_i}^i \otimes [\sum_{i=1}^{n} \sum_{i=1}^{m} M_{g_i}^i]^{-1} \tag{2.1}$$

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

$$[\sum_{i=1}^{n} \sum_{i=1}^{m} M_{g_i}^i]^{-1} = \left\{ \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right\} \tag{2.2}$$

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

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

If d is the highest intersection point of μ_{M_1} and μ_{M_2} as shown in Fig. 2.6,

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

The weight vector is $W^* = (d(A_1), d(A_2), d(A_3), \ldots., d(A_n))^T$
The normalized weight vector is $W = \frac{W^*}{\sum_{I=1}^{n} d(A_i)}$.

TFNs are used for fuzzy comparisons, as shown in Table 2.6.

Reason behind the popularity of extent fuzzy AHP is its computational simplicity. However, it is unable to find the true weights from fuzzy comparison matrix. Wang et al. (Wang et al. 2008a, b) pointed out that Eq. (2.2) should be modified to find the true fuzzy extent value of ith criteria. This method is known as modified extent fuzzy AHP (MEFAHP).

$$\left[\sum_{i=1}^{n}\sum_{i=1}^{m} M_{g_i}^{i}\right]^{-1} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{j=1}^{n} u_{ij} + \sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n} l_{kj}}\right)$$

where i = 1,2,3…n.

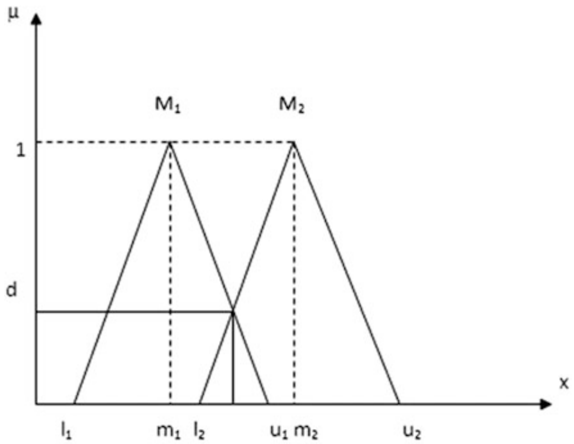


Fig. 2.6 Intersection of two TFNs (from Zhu et al. 1999; with kind permission from Elsevier Limited)

Table 2.6 Fuzzy TFN values (from Tolga et al. 2005; with kind permission from Elsevier Limited)

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)

Wang et al. (2008a, b) further proposed that extent analysis method may be considered as the method for showing how bigger one a decision is than the others in fuzzy comparison and there is chances of loosing of information when it assigns irrational zero to some important criteria or subcriteria. Linear program (LP), integer program (IP), goal program, etc., can be used alone to consider limitations of supplier(s) in supplier selection problem. However, these methods cannot consider qualitative criteria for supplier selection. Therefore, combination of AHP-GA or AHP-LP is a better choice. Extent fuzzy AHP alone is more suitable for single sourcing where best supplier is capable enough to fulfill the entire demand. The following steps are used to combine extent fuzzy AHP with GA.

Step 1. Define goal or objective of the problem.
Step 2. Select criteria for selecting suppliers.
Step 3. Select fuzzy membership function for fuzzy comparison matrix.
Step 4. Find priority of suppliers by extent fuzzy AHP.
Step 5. Form objective function and constraints.
Step 6. Use genetic algorithm to solve single-objective constrained objective function.

Order allocation to selected suppliers with GA is discussed in detail in the next section mentioned below.

2.8.2 *Fuzzy TOPSIS-MOGA*

The following steps are maintained to rank suppliers from a predefined supply base:

Step 1: TFNs, $\tilde{a}_{ij}$, are used to find suitability of each alternatives w.r.t criteria.
Step 2: Since TFNs are already normalized, no need for normalization. Calculate the weighted normalized fuzzy decision matrix, $\tilde{U}$.

$$\widetilde{U} = [\tilde{u}_{ij}]_{n\times j} \quad i = 1, 2, 3\ldots n \quad j = 1, 2, \ldots j$$
$$\tilde{u}_{ij} = \tilde{a}_{ij} \times w_i$$

where w_i is the set of weight of each criterion derived by analytic hierarchy process (AHP).
Step 3: Identify FPIS (fuzzy positive ideal solution) and FNIS (fuzzy negative ideal solution). Calculate the distance of each alternative from FPIS and FNIS.
Step 4: Calculate the closeness coefficient of each alternative, $CC_{i.}$
where $CC_j = \frac{D_j^-}{D_j^+ + D_j^-}$
Step 5: Rank suppliers based on higher value of $CC_{i.}$.

2.8.3 Multi-Objective Model for Supplier Selection

A multi-objective order allocation model is developed with five objective functions and three constraints. The following assumptions are considered to develop order allocation model

Assumptions

1. Selected suppliers will supply only one item.
2. No quantity discount is considered.
3. No shortage of item is allowed for any supplier.
4. Deterministic constant demand is considered.

C_i Procurement cost of per ton of coal from ith supplier
TC_i Transportation cost of per ton of coal from ith supplier
CC_i Closeness coefficient of ith supplier obtained from fuzzy TOPSIS
α_i Reliability of ith supplier
X_i Order quantity to ith supplier
LD_i Percentage of late delivery from ith supplier
β_i Percentage of coal contains 15–18% of ash in per ton received from ith supplier
γ_i Percentage of coal contains 15–16% of moisture in per ton received from ith supplier
H Handling cost per ton

Order allocation model:

Total cost of purchase (TCP) consists of purchase, transportation, order/setup, and holding cost. Order/setup cost is neglected in this mathematical model, and material handling cost is considered as holding cost.

Minimize total cost of purchase (TCP): $\sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} TC_i X_i + H \sum_{i=1}^{n} X_i$

Second objective function in our mathematical model is similar to Ghodsypour and O'Brien (1998). However, their proposed objective function is modified as total value of reliable purchase (TVRP). Reliability of supply of each supplier is calculated from past performance data of supplier.

Maximize total value of reliable purchase (TVRP): $\sum_{i=1}^{n} \alpha_i CC_i X_i$

Third objective function is to mitigate supply risk. Fourth and fifth objective functions are to maintain desired quality level. In any cement company, every lot is accepted based on two quality parameters—ash content and surface moisture content.

Minimize number of late deliveries: $\sum_{i=1}^{n} LD_i X_i$

Minimize amount of rejected lot based on ash content: $\sum_{i=1}^{n} (1 - \beta_i) X_i$

Minimize amount of rejected lot based on moisture content: $\sum_{i=1}^{n} (1 - \gamma_i) X_i$

Constraints for supplier selection:

Supplier capacity constraint, minimum order quantity to fulfill demand constraint, and cost or budgetary constraint are some of the most significant constraints of order allocation model (Kumar et al. 2004; Ghodsypour and O'Brien 1998). The following constraints are considered to optimize above five objective functions:

Capacity constraint: $X_i \leq V_i$ for $i = 1, 2, 3\ldots n$

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 $i = 1, 2, 3\ldots n$

The proposed model is solved by using MATLAB R 2009a and run it on a personal computer intel(R) Core(TM) 2 Duo 2.00 Ghz. This integrated model consists of four stages—preprocessing, supplier selection, order quantity

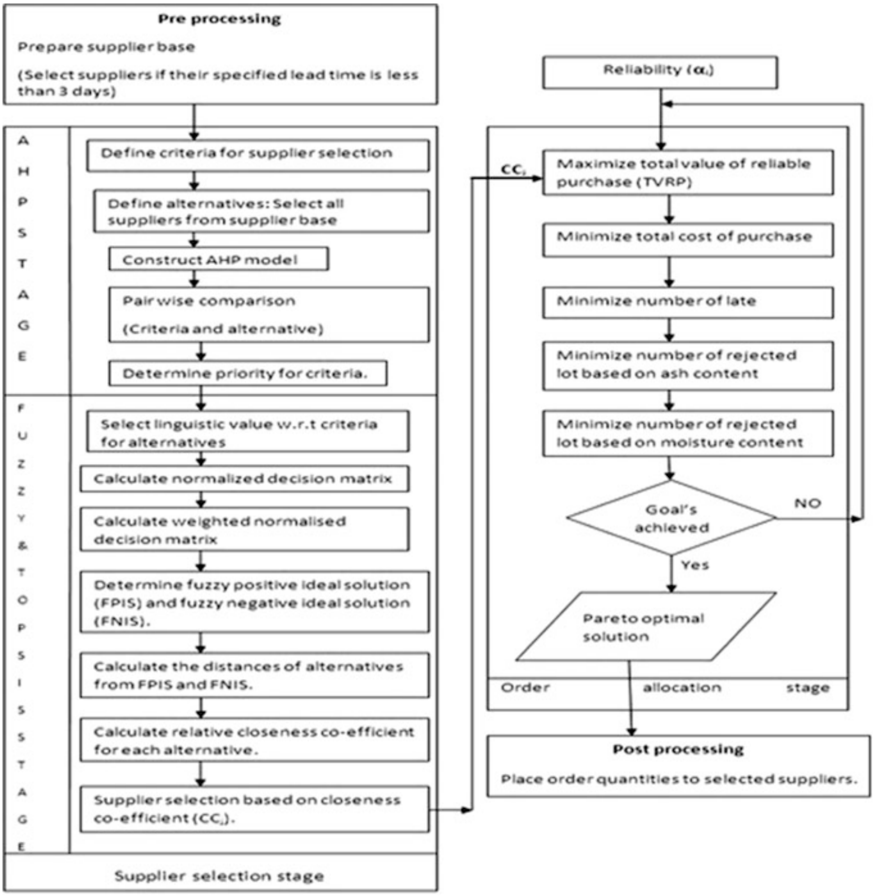


Fig. 2.7 Integrated model of f-TOPSIS-MOGA

calculation, and post-processing. In preprocessing, only preparation of supply base is considered. A supply pool is built initially with predefined supply lead time. In supplier selection stage, suppliers are selected from supply base by combined fuzzy TOPSIS and approval status proposed by Chen et al. (2006). Third stage uses genetic algorithm to optimize multi-objective, and finally, order quantities are selected from Pareto-optimal solutions. In the last stage, orders are placed to selected suppliers. Flowchart of the integrated approach is shown in Fig. 2.7.

2.8.4 Case Study

High initial investment, lack of resources, land acquisition problem for expansion, and long waiting time to get desired return on investment are some of the major barrier for cement industries. Moreover, full capacity utilization of cement plants is highly influenced by demand of realty sector. About 67% of the total production of cement is used in housing sector, 13% is used in commercial construction, 11% is used in infrastructure project, and only 9% is used in industrial construction. India

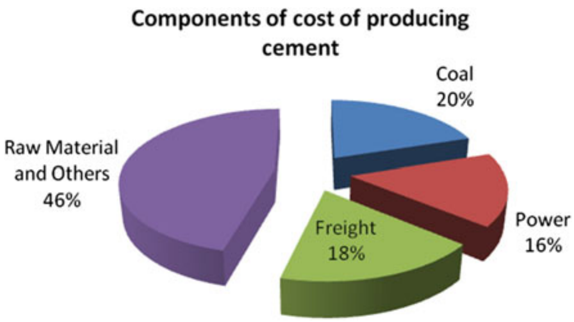


Fig. 2.8 Cost of producing cement

Table 2.7 Priority of supplier selection criteria

Criteria	Priority	Inconsistency
Quality(C_1)	0.3132	0.0935
Price(C_2)	0.0819	
Capacity(C_3)	0.0819	
Location(C_4)	0.5230	

Table 2.8 TFN values

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)

is the second largest producer of cement after China. Indian cement industry is basically oligopolistic in nature with more than 160 companies scattered all over India. Northern, eastern, southern, western, and central are the five main regions responsible for cement production in India. Andhra Pradesh, Tamil Nadu, and Rajasthan are the main contributors to Indian cement industry. Till early 2000, Ordinary Portland Cement (OPC) was the main variety of cement in India. Since 2005, production of Portland Pozzolana Cement (PPC) was increased at the cost of production of OPC. Today, about 61% of total production is PPC. Total 20% of total cost is spent for procuring coal to produce cement, as shown in Fig. 2.8.

An ISO 9001:2000 certified company which is situated in north east is producing various grades of cement such as Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC). Limestone and coal are two important raw materials for cement. Gypsum is essential for OPC, and fly ash is essential for PPC. Company will select supply of coal if its ash content is 15–18% and surface moisture content is 15–16%. Moreover, company can wait maximum three days to get supply. Material handling cost comes to Rs. 350 per ton, and order/setup cost and other holding cost are negligible. Four criteria, namely quality, price, capacity, and location of the supplier, have been chosen to select suppliers as per the consensus of the decision maker's committee which encompasses senior members from finance, marketing, purchase, and sales department of the focal company.

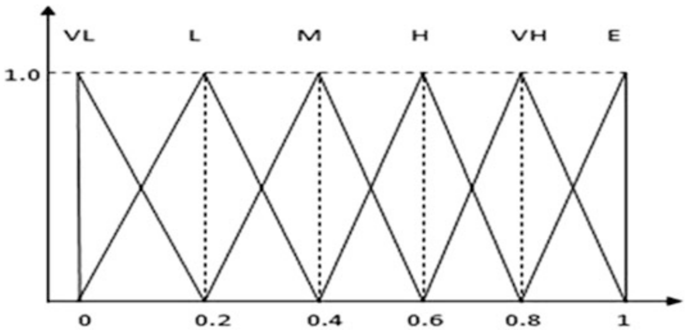


Fig. 2.9 Membership function of linguistic values

Table 2.9 Fuzzy evaluation matrix of alternatives

Alternative	C_1	C_2	C_3	C_4
A_1	High	Low	Medium	Medium
A_2	Medium	Medium	High	Very high
A_3	Very high	Low	High	Excellent
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)
Weight	0.3132	0.0819	0.0819	0.5230

Table 2.10 Weighted evaluation for three suppliers

Alternative	C_1	C_2	C_3	C_4
A_1	(0.125,0.188,0.251)	(0,0.016,0.033)	(0.016,0.033,0.049)	(0.105,0.209,0.314)
A_2	(0.063,0.125,0.188)	(0.016,0.033,0.049)	(0.033,0.049,0.066)	(0,0,0.105)
A_3	(0.188,0.251,0.3132)	(0,0.016,0.033)	(0.033,0.049,0.066)	(0.418,0.523,0.523)
A^+	(1,1,1)	(0,0,0)	(1,1,1)	(0,0,0)
A^-	(0,0,0)	(1,1,1)	(0,0,0)	(1,1,1)

Pairwise comparison value for each criterion is obtained from each decision maker. After that, analytic hierarchy process (AHP) is used to calculate priority of each criterion, as shown in Table 2.6, and linguistic values are shown in Table 2.7 and in Fig. 2.9.

As stated above, detail calculation is shown in Tables 2.8, 2.9, 2.10, and 2.11. Supplier performance data are shown in Table 2.12.

All three suppliers can be accepted with low risk to supply coal.

Multi-objective functions for supplier selection:
In this problem, a linear total cost function (TC(Q)=a + bQ) is considered for all three suppliers for simplicity. As shown below, a **nonlinear integer function** is developed for total cost of purchase which is to be minimized, as shown in Fig. 2.10.

Minimize **total cost of purchase (TCP)**: (3099 + 10 × 1) × 1 + (3100 + 10 × 2) × 2 + (3102 + 10 × 3) × 3

Maximize **total value of reliable purchase (TVRP)**: 0.4674 × 1 + 0.4982 × 2 + 0.4133 × 3

Minimize delay in supply: 0.1 × 1 + 0.15 × 2 + 0.2 × 3

Quality:

1. Minimize defects to maintain permissible ash content in supply: 0.2 × 1 + 0.25 × 2 + 0.3 × 3
2. Minimize defects to maintain permissible moisture content in supply: 0.15 × 1 + 0.2 × 2 + 0.2 × 3

Subject to

Demand constraint: × 1 + × 2 + × 3 = 8000
Production constraint: × 1 ≤ 4000; × 2 ≤ 3000; × 3 ≤ 3000
Budget constraint: (2000 + 10 × 1) × 1 + (2000 + 10 ×2) × 2 + (2000 + 10× 3) × 3 ≤ 30000000

Table 2.11 Fuzzy TOPSIS result

Alternatives	D_i^+	D_i^-	CC_i
A_1	2.0282	2.0092	0.4976
A_2	1.9228	2.1201	0.5244
A_3	2.2134	1.8052	0.4492

Table 2.12 Approval status

Closeness coefficient (CC_i)	Assessment status
CC_i ϵ[0,0.3)	Rejected
CC_i ϵ[0.3,0.5)	Recommended with high risk
CC_i ϵ[0.5,0.7)	Recommended with low risk
CC_i ϵ[0.7,0.9)	Approved
CC_i ϵ[0.9,1.0]	Highly recommended

Table 2.13 Supplier performance data

Sl No.	% failure rate of supply (f)	Reliability ($\alpha = 1 - f$)	Capacity (ton)	Total cost (Rs/ton)	Transportation cost (Rs/ton)	Quality	% late delivery	
						% of coal contains 15–18% ash in per ton	% of coal contains 15–16% moisture in per ton	
1.	6	0.94	4000	2000 + 10*Q	749	0.8	0.85	0.1
2.	5	0.95	3000	2000 + 10*Q	750	0.75	0.8	0.15
3.	8	0.92	3000	2000 + 10*Q	752	0.7	0.8	0.2

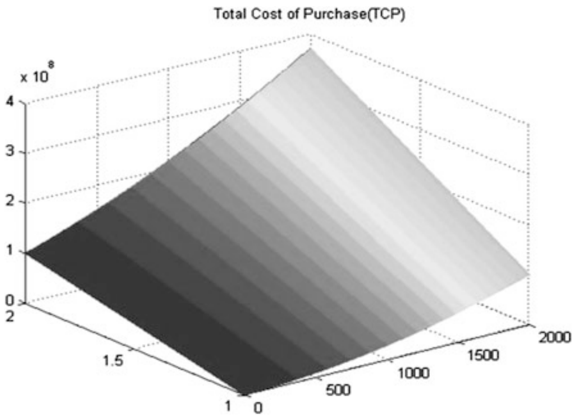


Fig. 2.10 Objective function for total cost of purchase (TCP)

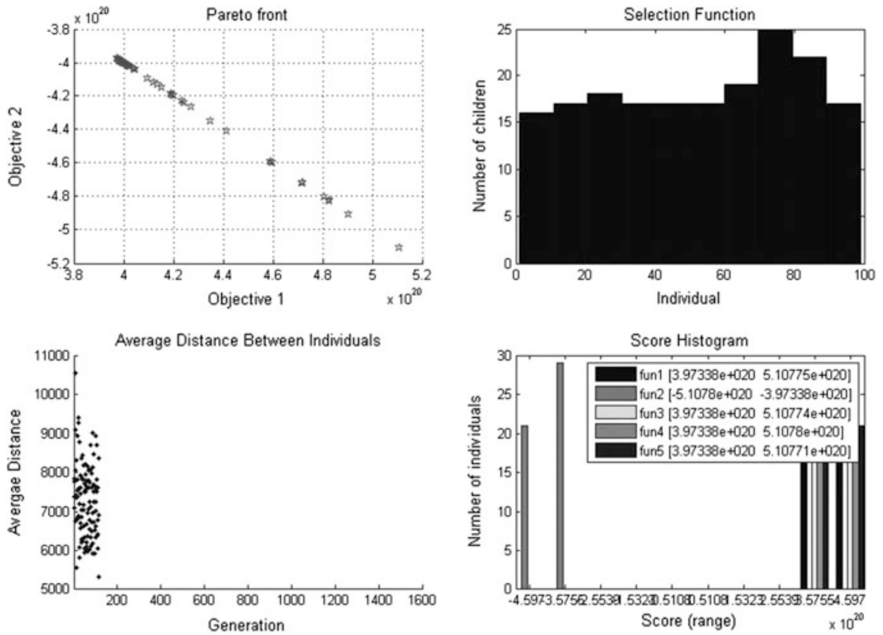


Fig. 2.11 Result of multi-objective GA

The multi-objective problem consists of nonlinear objective function with one nonlinear constraint. It cannot be solved with MATLAB GA solver. **Penalty function** approach is considered to convert constraint optimization problem to **unconstrained optimization** problem. Multi-objective GA finds multiple and diverse Pareto-optimal (or near Pareto-optimal) solutions in a single simulation run. Therefore, it is important to choose a particular solution from a set of nondominated solutions. A discontinuous Pareto front is obtained, shown in Fig. 2.11.

The number of points on the Pareto front was 50. The **average distance measure** of the solutions on the Pareto front was 0.0574885. The **spread measure** of the Pareto front was 0.0700832. Finally, ordered quantities to three suppliers are {2666, 2666, 2668}.

2.9 Conclusion

Supplier selection is not a mere clerical process. It encompasses several palpable and nonpalpable criteria. It is a multi-criteria-based optimization process. Effective selection of supplier could reduce uncertainty of availability of raw material, assure quality throughout the supply chain, reduce upstream supply chain risk, and, finally, reduce cost of manufacturing of product. About 70% of total cost is usually spent in procurement. Thus, procurement is most important for any company. In this chapter, several methods and criteria are mentioned through rigorous literature survey. Most cited criteria are identified with latest trend of supplier selection. As per the latest trend, two methods are discussed in detail with a case study. This chapter discusses in detail supplier pool preparation, supplier selection, evaluation, and order allocation with the above two methods.

Majority of the supplier selection models proposed by different researchers are for electronics industries, automobile industries, etc. In this chapter, an attempt has been made to prepare mathematical model to select suppliers for cement industries. Cement is a localized product and needs some extra constraints that are required to select and allocate order to suppliers. Proposed model in this chapter is prepared accordingly. It is pertinent to mention that application of the proposed models is not limited to the cement industries alone. It can be used for any industry with simple modification.

Total value of purchase is commonly used to allocate order to selected suppliers. In this chapter, total value of reliable purchase (TVRP) is considered instead of total value of purchase (TVP) to reduce the upstream supply chain risk, if any. TVRP is a weighted nonlinear objective function which is prepared with the priority obtained from the proposed MCDA tools. Industries such as cement and R&D usually face high risk to manufacture their product within due time. In such cases, TVRP should be used instead of TVP.

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