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Abstract

Purpose – The purpose of this paper is to propose a multi-criteria supplier selection model using fuzzy analytical hierarchy process (FAHP) approach for a leading automobile company in India.

Design/methodology/approach – FAHP approach followed by a sensitivity analysis has been used.

Findings – In this study, a FAHP-based supplier selection model is proposed to provide useful insights in choosing appropriate suppliers in dynamic situations in order to enhance long-term relationship with them.

Practical implications – This study proposes a supplier selection model for an automobile industry which often faces heterogeneous supply environments. This model may have a high acceptability where a large number of suppliers are available to supply the materials or provide the services. As analytic hierarchy process is the most widely used methodology for supplier selection, however, it becomes less efficient in case of inconsistencies observed in the data. However a FAHP-based approach may overcome this difficulty.

Originality/value – It contributes to supplier selection process and points out the importance of supplier selection problem, especially in the context of multi-criteria decision-making in Indian scenario.

Keywords Case study, Analytical hierarchy process, Multi-criteria decision-making, Supplier selection, Fuzzy analytical hierarchy process, Supplier evaluation

Paper type Research paper

1. Introduction

In today's competitive manufacturing environment, it is a challenge to produce high-quality products while offering competitive prices to the customers. Having reliable and competent suppliers is one of the critical factors for it. The key objective of the purchasing department in any industry is to source the right quality of material in the right quantity from the right source at the right time and also at a reasonable price. In today's era of competition, the manufacturing organizations pay particular attention to the selection of alternative supply sources. Hence, supplier selection process has become the most significant variable in the modern supply chain management as it helps in achieving high-quality products and customer satisfaction (Gonzaile *et al.*, 2004). Effective supplier selection needs robust analytical methods and decision support systems (Ni *et al.*, 2007) that are able to deal with multiple criteria. Supplier evaluation and selection assumes very important role in any industry as the cost and quality of goods and services sold are directly related to the cost and quality of goods

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and services purchased. However, it becomes a complex issue to address for manufacturing firms when it considers multiple subjective and objective criteria. Criteria may vary depending on the type of product or industry being considered and include many qualitative factors in addition to the quantitative criteria (Vokurka *et al.*, 1996). An efficient supplier selection process is capable to handle the complexity of the current business scenario.

Supplier selection gets complicated due to consideration of various criteria and sub-criteria in decision-making. Every buyer has different expectations from the suppliers. Different companies may have different organizational and cultural backgrounds, which may also affect the supplier selection process. Therefore, which criteria are suitable and should be used for evaluation of suppliers for an enterprise is crucial. The selection criteria may vary from industry to industry. The single criterion approach of the lowest cost supplier is no more accepted in this challenging and continuously changing environment (Agarwal *et al.*, 2011). Quality, delivery performance, services, etc. need to be considered by the manufacturing firms. Dickson (1966) identified 23 criteria for supplier selection based on the survey of 273 purchasing managers. Weber *et al.* (1991) classified papers published since 1966 and identified quality, cost and on-time delivery as the most important supplier selection criteria in the evaluation of supplier performance. After scanning a plethora of literatures Jain *et al.* (2009) grouped all criteria into six categories, i.e. cost, quality, cycle time, service, relationship and organizational profile.

Multi-criteria decision-making (MCDM) approaches are formal methods to structure the decision problems with multiple, conflicting criteria or goals. MCDM methods have been widely used in many research fields. Supplier selection is basically, a MCDM problem. Numerous MCDM approaches have been suggested in the literature to solve the supplier selection problem. However the supplier selection problem may be classified into individual approaches and integrated ones (Ho *et al.*, 2010). The most widespread individual approaches are: the data envelopment analysis (DEA), mathematical programming, the analytic hierarchy process (AHP), the analytic network process (ANP), neural networks, structural equation modeling, multi-attribute utility theory, dimensional analysis (DA), fuzzy decision-making, genetic algorithms, the simple multi-attribute rating technique (SMART), etc. The integrated approaches use more than one approach jointly (e.g. integrated AHP and DEA, integrated AHP and goal programming, etc.). Agarwal *et al.*, 2011 present a review of various MCDM methodologies reported in the literature for solving the supplier evaluation and selection process. The review is solely based on 68 research articles, including eight review articles in the academic literature from 2000 to 2011. Further, the distribution of the articles under various classes of MCDM methods in the literature suggested the use of AHP and fuzzy approach by 15 and 10 percent researchers, respectively. Hence, it is observed that AHP and fuzzy-based approaches accounts significantly as MCDM methods for supplier selection, therefore, authors made an attempt to develop a fuzzy analytical hierarchy process (FAHP) model in this study.

This study proposes a fuzzy extended analytical hierarchy process (FEAHP) approach to select the best supplier for an automobile company from Indian context using triangular fuzzy numbers (TFN). AHP approach is used to structure the problem into hierarchy. Fuzzy numbers represent decision makers' comparison judgments and extent analysis method is used to decide the final priority of different decision criteria.

The outline of the paper is as follows: Section 2 throws light on review of literature of supplier selection and MCDM problems. Section 3 discusses methodology of FEAHP.

The application of the FEAHP approach to an automobile company is reported in Section 4. Section 5 gives results and discussions of the proposed model. Section 6 concludes the study and finally limitation and direction for future research are presented in last Section 7.

2. Literature review

During the recent years supplier selection process has received considerable attention in the literature. Supplier selection process is influenced by a variety of criteria (Aissaoui *et al.*, 2007). Based on a questionnaire sent to 273 purchasing agents and managers from USA and Canada, Dickson (1966) identified 23 different criteria (i.e. quality, delivery, performance history, warranties and claim policies, production facilities and capacity, price, technical capability, financial position, procedural compliance, communication system, reputation and position in industry, desire for business, management and organization, operating controls, repair service, attitude, impression, packaging ability, labor relations record, geographical location, amount of past business, training aids and reciprocal arrangements) evaluated in supplier selection process. Among these, the price, delivery and quality objectives of the buyer are particularly important factors in deciding how much to order from the available suppliers. Wind and Robinson (1968) identified possible contradictions such as the supplier offering the lowest price may not have the best quality, or the supplier with the best quality may not deliver on-time. As a result, it is necessary to make a trade-off between conflicting criteria to find the best suppliers. Observe that in compensatory models, a poor performance on one criterion can be compensated by a high performance in another one whereas in non-compensatory models, different minimum levels for each criterion are required. Weber *et al.* (1991) observed that price, delivery, quality, production capacity and localization are the criteria most often treated in the literature. Sevkli *et al.*, (2007) considered 25 sub-criteria under six criteria, i.e. performance assessment, human resources, quality system assessment, manufacturing, business criteria and information technology. Inemek and Tuna (2009) reviewing a plethora of literature highlight 44 criteria which have use for supplier selection in and found quality had highest frequency and followed by delivery and cost. Wu and Blackhurst (2009) identify price, quality and delivery performance as selection criteria for supplier selection model. Sevkli (2010) used delivery performance, quality performance, price\cost, financial strength, management and organizational strength in his supplier selection model. Bruno *et al.* (2012) proposed an AHP model in which process and product quality, service level, management and innovation and financial position are attributes for supplier selection.

After determining criteria, the decision makers should choose an appropriate and systematic method to evaluate the alternative suppliers. De Boer *et al.*, 2001 presented a comprehensive review for all phases in supplier selection process covering various MCDM methods for supplier selection. These MCDM methods may be classified into individual approaches and integrated ones. The individual approaches use the DEA, mathematical programming, the AHP, case-based reasoning, fuzzy decision-making, genetic algorithms, the ANP, the SMART (Ho *et al.*, 2010). The integrated approaches use more than one technique such as integrated AHP and DEA, integrated fuzzy and AHP, integrated AHP and goal programming, etc. Agarwal *et al.* (2011) presented a review of various MCDM methodologies reported in the literature for solving the supplier evaluation and selection process. The review is solely based on 68 research articles, including eight review articles in the academic literature from 2000 to 2011.

The distribution of the articles under various classes of MCDM methods is as follows-DEA, mathematical programming, AHP, case base reasoning, fuzzy sets theory, ANP cover 30, 17, 15, 11, 10 and 5 percent, respectively and rest are other methodologies.

AHP is widely used in supplier selection problems since it is one of the extensively used MCDM approach. It effectively keeps both qualitative and quantitative data in decision-making problems and is easier to understand its process. Muralidharan *et al.* (2002) introduced an AHP-based model for rating and selecting suppliers with respect to nine decision criteria. Chan and Chan (2010) proposed an AHP-based model to solve the supplier evaluation and selection problem taking an example of a fashion industry. The paper was mainly pivoted around the quick response (responsive) strategy, largely followed by apparel industry. The researchers divided the criteria into two major groups of performance criteria and company strategy-based criteria. A total of 29 criteria were identified out of which nineteen belonged to performance group and the rest belonged to company strategy-based criteria group, to have a strategic fit with the supplier. Kumar and Roy (2011) proposed a rule-based model with the application of AHP to aid the decision makers in vendor evaluation and selection taking the power transmission industry. The paper presented a three-step model to calculate the performance scores of various vendors and select the best vendor. The researchers also validated the proposed model taking the data from a multinational transformer company. Bruno *et al.* (2012) proposed a hierarchical model for supplier selection in corporate environment. In this model 12 sub-criteria are considered under four criteria, i.e. process and product quality, service level, management and innovation and financial position. The analysis of the implementation process of the methodology allows the identification of strengths and weaknesses of using formalized supplier selection models to tackle the supplier evaluation problem, also highlighting potential barriers preventing firms to adopt such methods.

In order to deal with uncertainties of the decision problem and eliminate the disadvantages of AHP, FAHP is preferred in supplier selection studies. First, FAHP was introduced by Van laarhoven and Pedrycz (1983). To synthesize extent values of pair-wise comparison, Chang (1996) introduced a new extent analysis approach for handling FAHP. Many researchers have used this approach in different types of decision problem. Kahraman *et al.* (2003) used FAHP to select the best supplier providing the most satisfaction for the three criteria (and 11 sub-criteria) determined in the white good sector. Chan and Kumar (2007) discussed a FEAHP approach using TFNs to represent decision makers' comparison judgments and fuzzy synthetic extent analysis method to decide the final priority of different decision criteria. Chan *et al.* (2008) discussed the FAHP to efficiently tackle both quantitative and qualitative decision factors involved in global supplier selection. Aydin and Kahraman (2010) proposed a fuzzy analytic hierarchy process-based methodology in the supplier selection of an air conditioner firm. Chiouy *et al.* (2011) used FAHP method to prioritize and rank the various performance evaluation criteria for the sustainable suppliers' selection and evaluation in the Taiwanese electronic industry. Kilincci and Onal (2011) used FAHP-based model to tackle supplier selection problem of a washing machine company in Turkey. Yu *et al.* (2012) investigated a fuzzy multi-objective vendor selection program under lean procurement based on cost minimization, delivery schedule violation minimization and maximizing the quality level of the purchased quantity. Rezaei and Ortt (2013) proposed a fuzzy analytic hierarchy process-based methodology to segment the suppliers of a boiler company.

Hence on the basis of above literature survey, following gaps are identified:

- very few researchers reported on flexibility criteria, one of the most crucial factors in today's competitive manufacturing environment for supplier selection;
- the literature lacks essential elements to recognize some of the elements of long-term relationships between buyer and supplier;
- further hardly there is any case application from Indian context reported in the literature; and
- also majority of studies considers limited number of criteria and sub-criteria for MCDM analysis.

3. Methodology

A FAHP approach is proposed here to address the supplier selection problem of an automobile company. Basically, FAHP is an integrated approach, which consist fuzzy sets theory and analytical hierarchy process. Fuzzy sets theory resembles the human reasoning and mathematically represents the uncertainty and vagueness. In this study Chang's extent analysis method is used to select the best supplier among the number of alternative supplier available. Chang (1996) uses TFN for the pair-wise comparison in AHP. Chang's approach is less time taking and less computational expense than many other FAHP approaches.

Let $X=(x_1, x_2, x_3, \ldots, x_n)$ be an object set, and $U=(u_1, u_2, u_3, \ldots, u_{\mathrm{m}})$ be a goal set. According to the method of Chang's extent analysis, each object is taken and extent analysis for each goal, g_i, is performed, respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{gi}^1,\ M_{gi}^2,\ M_{gi}^3,\ \ldots\ldots,\ M_{gi}^m;\ i = 1,2,3,\ \ \ldots\ \ ,n$$

Where all M_{gi}^j are TFN; $j=1,2,3,\ldots,m$

The steps of Chang's (1996) extent analysis can be given as in the following:

Step 1. The fuzzy synthetic extent with respect to ith object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{1}$$

to obtain $\sum_{j=1}^{m} M_{gi}^j$ the fuzzy addition operation of m extent analysis values for a particular matrix is performed such that:

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{2}$$

and to obtain $[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j]^{-1}$ the fuzzy addition operator of M_{gi}^j values is performed such that:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_i,\ \sum_{i=1}^{n} m_i,\ \sum_{i=1}^{n} u_i \right) \tag{3}$$

and then inverse of the vector of computed, such that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{4}$$

Step 2. The degree of possibility of $M_2 = (l_2, m_2, u_2) \geqslant M_1 = (l_1, m_1, u_1)$ can be defined as:

$$V(M_2 \geqslant M_1) = \sup_{y \geqslant x}\left[\min\left(\mu_{M1}(x), \mu_{M2}(y)\right)\right] \tag{5}$$

Equation 5 can be expressed as follows:

$$V(M_2 \geqslant M_1) = hgt(M_1 \cap M_2) = \mu_{M2}(d) = \begin{bmatrix} 1, & if\ m_2 \geqslant m_1 \\ 0, & if\ l_1 \geqslant u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{bmatrix} \tag{6}$$

where d is the ordinate of the highest intersection point D between μ_{M1} and μ_{M2}. In Figure 1, the intersection between M_1 and M_2 can be seen. To compare M_1 and M_2, both the values of $V(M_1 \geqslant M_2)$ and $V(M_1 \leqslant M_2)$ are needed.

Step 3. The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i ($i = 1, 2, \ldots, k$) can be defined by Equation (9):

$$\begin{aligned} V(M \geqslant M_1, M_2, \ \ldots \ , M_k) &= V[(M \geqslant M_1)\ and\ (M \geqslant M_2)\ and \ldots\ldots and\ (M \geqslant M_k)] \\ &= \min V(M \geqslant M_i) \end{aligned} \tag{7}$$

Assume that:

$$d'(A_i) = min\ V(S_i \geqslant S_k) \tag{8}$$

For $k = 1,2, \ldots, n$; $k \neq i$, weight vector is given by:

$$W' = \left(d'(A_1), d'(A_2), \ \ldots \ , d'(A_n)\right)^T \tag{9}$$

where A_i ($i = 1,2, \ldots,$ n) are n elements.

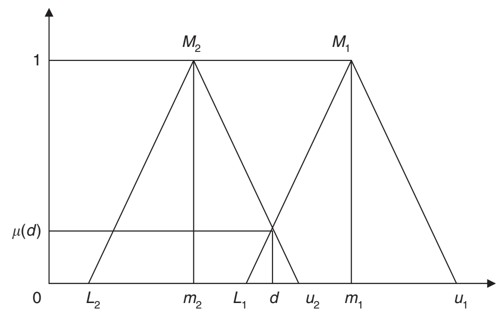

Figure 1. Intersection of M_1 and M_2

Step 4. after normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), \ \dots \ , \ d(A_n))^T \tag{10}$$

where W is a non-fuzzy number.

4. Application of FAHP extent analysis method to supplier selection problem

One of the leading car and truck manufacturing company in India wants to select the best supplier for one of its critical component used in truck. The company providing the context for this application is a multinational manufacturer of automobiles, motor vehicles and internal combustion engines founded in 1921 enters the Indian market to built medium and heavy duty commercial vehicles in 2010. It is a leading car and truck manufacturing company. In addition to automobiles, it manufactures buses and provides financial services through its sister concern. It set up a manufacturing plant for trucks in southern India. The company considered in the study is new in this sector and is trying to increase and widen its customer base. The purchasing managers are of the view that suppliers have a major influence on customers' satisfaction level. Therefore, the company decided to develop an effective supplier selection policy for the responsive market. The managers of the company recognized that a wide range of factors must be considered in the supplier selection process, and the selection decisions should not be made merely on the basis of price factor alone.

4.1 Problem hierarchy

On the basis of the literature review and interaction with the case company, six criteria and 22 sub-criteria are chosen for suppliers' selection in this study. These criteria are quality, cost, delivery, service, long-term relationship and flexibility:

(1) Quality is closely related to the end use of the product. A good quality product must meet the minimum standards and the requirements of the customer and it must perform efficiently, consistently and satisfactorily.

(2) The customers can reject a poor quality product or a defective product so, the customer rejection and defects rates are also the measure of quality. In the competitive environment, every purchasing manager is looking for the economical products. Therefore, the cost of the product is also a very important decision criterion for supplier selection. Logistic cost is also associated with the product; the total cost is sum of cost of the product and logistic costs associated with it. Sometimes, some discount also attracts the customer.

(3) The suppliers can also be rated with respect to delivery term. Every customer expects to receive goods at right time. Good packaging is essential for protection of goods against pilferage, damage and deterioration. The degree and type of packaging depends on the nature of product. Order fulfillment lead time is also a critical factor to rate the supplier.

(4) In a developing country like India, more emphasize is placed on service after sale because service not only provide competitive advantage but also contributes significantly in profit generation. After sale service keeps customer satisfied and

influences customer purchasing decisions. The service performance of the suppliers can be evaluated under following attributes: technical support, information sharing, warranty and claim policy and capabilities.

(5) Healthy competition is run on maintaining cordial relations in stiff competition. The supplier is often treated as an intangible asset of an organization. Good buyer-supplier relationship enhances mutual trust and results in long-term and sustained partnerships. The long-term relationship between buyer and supplier can be evaluated under following attributes: honesty, reputation, trust and partnership and ease of communication.

(6) Flexibility is defined as the ability of a system to adapt to external changes, while maintaining satisfactory system performance. Indeed flexibility is vital to the success of supply chain, since supply chain generally operates in uncertain business environment. It has a variety of dimensions attached to it (Singh and Sharma, 2014). Broadly, there are four types of flexibility in this context: volume flexibility (the ability to respond to change in demand); mix flexibility (the ability to change the variety of products produced); delivery flexibility (the ability to respond quickly to tights delivery requests); and new product flexibility (the ability to introduce and produce new products or modify the existing one). Therefore, the flexibility of the supplier can be evaluated under following attributes: ability to quick change program, short new product line time, short lead time and resolve conflict.

Based on the supplier selection criteria discussed above the problem hierarchy is structured, as shown in Figure 2. In order to maintain the confidentiality of the supplier companies, the suppliers are numbered as S_1, S_2 and S_3.

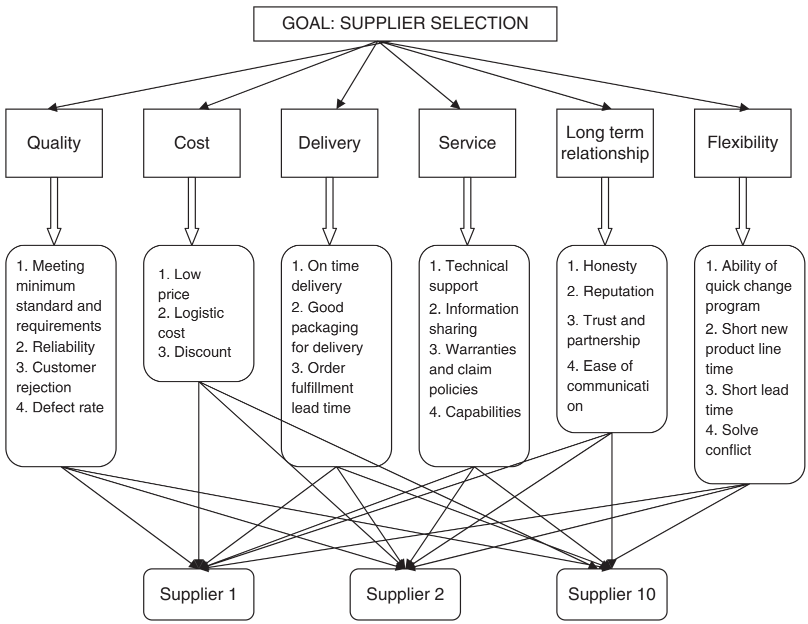

Figure 2.
Problem hierarchy

4.2 Calculation of weights for criteria, sub-criteria and suppliers

After construction of the problem hierarchy, the different priority weights of each criterion, sub-criterion and alternative suppliers were calculated using the extent analysis method of FAHP approach. The comparison of the importance of criteria, sub-criteria and alternative suppliers over another were achieved by the help of the questionnaire administered to managerial staff of the company responsible for purchase of stores. The questionnaires facilitated the answering of pair-wise comparison questions. The preference of one measure over another was decided by the experience of managers.

First, the managers compared the criteria with respect to the goal; then compared the sub-criteria with respect to the main criteria. At the end, the managers compared the supplier with respect to each sub-criterion. The linguistic variables were used to make the pair-wise comparisons. Then the linguistic variables were converted to TFNs. Table I shows the linguistic variables and their corresponding TFNs.

Table II shows the feedback of the managers for comparison of the alternative suppliers using linguistic variables with respect to the criterion "Meeting minimum standard and requirements." By using the values in Table I, the linguistic variables in the comparison matrix were converted to TFNs. The fuzzy evaluation matrix with respect to the criterion "Meeting minimum standard and requirements" with TFNs can be seen in Table III.

Table I. Linguistic variables with corresponding fuzzy numbers

Linguistic variables	Corresponding fuzzy numbers
Equally preferred	(1,1,1)
Weakly preferred	(2/3,1,3/2)
Fairly strongly preferred	(3/2,2,5/2)
Very strongly preferred	(5/2,3,7/2)
Absolutely preferred	(7/2,4,9/2)

Table II. Comparison matrix for alternative suppliers using linguistic variables with respect to "Meeting minimum standard and requirements"

Meeting minimum standard and requirements	S_1	S_2	S_3
S_1	EP		FSP
S_2	VSP	EP	WP
S_3			EP

Table III. Comparison matrix for alternative suppliers using triangular fuzzy numbers with respect to "Meeting minimum standard and requirements"

Meeting minimum standard and requirements	S_1	S_2	S_3
S_1	(1,1,1)	(2/7,1/3,2/5)	(3/2,2,5/2)
S_2	(5/2,3,7/2)	(1,1,1)	(2/3,1,3/2)
S_3	(2/5,1/2,2/3)	(2/3,1,3/2)	(1,1,1)

In order to find the priority weights of the alternative suppliers, first the fuzzy synthetic extent values of the suppliers were calculated by using Equation (1). The different values of fuzzy synthetic extent of the three different suppliers were denoted by S_{S1}, S_{S2} and S_{S3}:

$$S_{S1} = (2.79, 3.33, 3.9) \otimes \left(1/13.07, 1/10.83, 1/9.03\right) = (0.22, 0.30, 0.43)$$

$$S_{S2} = (4.17, 5, 6) \otimes \left(1/13.07, 1/10.83, 1/9.03\right) = (0.33, 0.45, 0.66)$$

$$S_{S3} = (2.07, 2.5, 3.17) \otimes \left(1/13.07, 1/10.83, 1/9.03\right) = (0.16, 0.22, 0.35)$$

The degree of possibility of S_i over S_i $(i \neq j)$ was determined by using Equation (6).

$$V(S_{S1} \geqslant S_{S2}) = \frac{(0.33-0.43)}{(0.30-0.43)-(0.45-0.33)} = 0.4$$

$$V(S_{S1} \geqslant S_{S3}) = 1$$

$$V(S_{S2} \geqslant S_{S1}) = 1$$

$$V(S_{S2} \geqslant S_{S3}) = 1$$

$$V(S_{S3} \geqslant S_{S1}) = \frac{(0.22-0.35)}{(0.22-0.35)-(0.30-0.22)} = 0.62$$

$$V(S_{S3} \geqslant S_{S2}) = \frac{(0.33-0.35)}{(0.33-0.35)-(0.45-0.33)} = 0.14$$

With the help of Equation (8), the minimum degree of possibility was stated as below:

$$d'(S_1) = min\ (0.4, 1) = 0.4$$

$$d'(S_2) = min\ (1, 1) = 1$$

$$d'(S_3) = min\ (0.62,\ 0.14) = 0.14$$

Therefore the weight vector was given as $W' = (0.4,\ 1,\ 0.14)$. After normalization process, the local weight vector of the alternative suppliers was found to be $W = (0.26, 0.65, 0.09)^T$. The supplier S_2 got highest weight (0.65) with respect to the sub-criteria "Meeting minimum standard and requirements." Same calculations were performed to the other pair-wise comparison matrices and the priority weights of each criterion, sub-criterion and alternative supplier were calculated. The local priority weights of each main criterion, sub-criterion and alternative supplier are shown in Table IV.

4.3 Synthesize the local weights into overall weights of alternative suppliers

Finally, the priority weights of the criteria and sub-criteria were synthesized to determine the overall priority weights of the alternative suppliers. In Table V, each

Criteria	Priority	Sub-criteria	Priority	Alternative	Priority
Quality	0.41	Meeting minimum standards and requirements	0.50	S_1	0.26
				S_2	0.65
				S_3	0.09
		Reliability	0.10	S_1	0.45
				S_2	0.03
				S_3	0.52
		Customer rejections	0	S_1	0.00
				S_2	0.96
				S_3	0.04
		Defect rates	0.40	S_1	0.00
				S_2	0.14
				S_3	0.86
Cost	0.25	Low price	0.68	S_1	0.45
				S_2	0.03
				S_3	0.52
		Logistic costs	0.27	S_1	0.44
				S_2	0.20
				S_3	0.36
		Discounts	0.05	S_1	0.43
				S_2	0.57
				S_3	0.00
Delivery	0.11	On-time delivery	1	S_1	0.33
				S_2	0.33
				S_3	0.33
		Good packing	0	S_1	0.47
				S_2	0.06
				S_3	0.47
		Order fulfillment lead time	0	S_1	0.46
				S_2	0.21
				S_3	0.33
Service	0.11	Technical support	0.27	S_1	0.45
				S_2	0.52
				S_3	0.03
		Information sharing	0.15	S_1	0.44
				S_2	0.36
				S_3	0.20
		Warranty and claim policy	0.29	S_1	0.56
				S_2	0.00
				S_3	0.44
		Capabilities	0.29	S_1	0.36
				S_2	0.20
				S_3	0.44
Long-term relationship	0.06	Honesty	0.53	S_1	0.45
				S_2	0.03
				S_3	0.52
		Reputation	0.36	S_1	0.03
				S_2	0.52
				S_3	0.45
		Trust and partnership	0.11	S_1	0.00
				S_2	0.35
				S_3	0.65

Table IV.
Priority vectors for problem hierarchy

(*continued*)

Criteria	Priority	Sub-criteria	Priority	Alternative	Priority
		Ease of communication	0	S_1	0.43
				S_2	0.57
				S_3	0.00
Flexibility	0.06	Ability to modify product	0	S_1	0.03
				S_2	0.45
				S_3	0.52
		Short new product line time	0.55	S_1	0.44
				S_2	0.33
				S_3	0.23
		Short lead time	0	S_1	0.68
				S_2	0.27
				S_3	0.05
		Solve conflict	0.45	S_1	0.03
				S_2	0.52
				S_3	0.45

Table IV.

Quality	Meeting minimum standard and requirements	Reliability	Customer rejection	Defect rate	Priority weights
Weights→	0.50	0.10	0.00	0.40	
S_1	0.26	0.45	0	0	0.175
S_2	0.65	0.03	0.96	0.14	0.384
S_3	0.09	0.52	0.04	0.86	0.441

Table V.
Priority vector with respect to "quality"

column of the matrix was multiplied by the priority weight at the top of the column and then those values were added up for each row. At the end, the priority weights of the alternatives with respect to quality criteria were calculated. Same calculations were performed for other criteria also (cost, delivery, service, long-term relationship and flexibility) as shown in Tables VI-X.

Finally the priority weights of the alternative supplier with respect to the criteria were combined and the priority weights of the alternative supplier with respect to the goal were determined. The overall priority weights of the alternative suppliers can be seen in Table XI.

5. Results and discussions

According to the final scores as shown in Table XI, S_3 (supplier 3) is the most preferred supplier because it has the highest priority weight. S_1 is the next recommended

Cost	Low price	Logistic cost	Discount	Priority weights
Weights→	0.68	0.27	0.05	
S_1	0.44	0.44	0.43	0.4395
S_2	0.03	0.20	0.57	0.1029
S_3	0.53	0.36	0	0.4576

Table VI.
Priority vector with respect to "cost"

alternative. The difference between priority weight of S_1 and S_3 is very high, so, it is strongly recommended to select the alternative S_3.

However, to evaluate suppliers based on each criterion (out of the six criteria) may bring valuable insights to the problem in question. Figure 3 shows the sensitivity analysis graph with respect to the goal. It is evident from the graph that the alternative S_3 has highest priority weight with respect to the criteria quality, cost and long-term relationship while the alternatives S_1 and S_2 have highest weights with respect to criteria service and flexibility, respectively. It is clearly seen from the Table VII that all the alternative supplier got equal priority weight with respect to the criterion delivery. Therefore, there is no need to consider delivery criterion any more.

Table VII. Priority vector with respect to "delivery"

Delivery	On-time delivery	Good packaging for delivery	Order fulfillment lead time	Priority weights
Weights→	1	0	0	
S_1	0.33	0.47	0.46	0.33
S_2	0.33	0.06	0.21	0.33
S_3	0.33	0.47	0.33	0.33

Table VIII. Priority vector with respect to "service"

Service	Technical support	Information sharing	Warranties and claim policies	capabilities	Priority weights
Weights→	0.27	0.15	0.29	0.29	
S_1	0.45	0.44	0.56	0.36	0.4543
S_2	0.52	0.36	0	0.20	0.2524
S_3	0.03	0.20	0.44	0.44	0.2933

Table IX. Priority vector with respect to "long-term relationship"

Long-term relationship	Honesty	Reputation	Trust and partnership	Ease of communication	Priority weights
Weights→	0.53	0.36	0.11	0	
S_1	0.45	0.03	0	0.43	0.2493
S_2	0.03	0.52	0.35	0.57	0.2416
S_3	0.52	0.45	0.65	0	0.5091

Table X. Priority vector with respect to "flexibility"

Flexibility	Ability of quick change program	Short new product line time	Short lead time	Solve conflict	Priority weights
Weights→	0	0.55	0	0.45	
S_1	0.03	0.44	0.67	0.03	0.2555
S_2	0.45	0.33	0.27	0.52	0.4155
S_3	0.52	0.23	0.05	0.45	0.3290

Hence, it can be concluded from this study that quality and cost are the most crucial criteria for an automobile company (as suggested by the results obtained in Table XI). Other researchers also identified quality (Bruno *et al.*, 2012; Zhang *et al.*, 2011; Sen *et al.*, 2010) and cost (Zhang *et al.*, 2011; Sevkli *et al.*, 2007) as key criteria for supplier selection problem. In this study, criterion quality got the highest weight (0.41) followed by the cost (0.25). Interestingly, delivery and service criteria got the same weight as 0.11 while long-term relationship and flexibility criteria got the lowest weight as 0.06.

6. Conclusion

After scanning a plethora of literatures it can be concluded that the supplier selection process is one of the most popular issues within the supply chain management and it becomes more important in the context of an automobile industry. A typical manufacturer spends 60 percent of its total sales on purchased items such as raw materials, parts, subassemblies components, etc. (Krajewski and Ritzman, 1996). In automotive industries, these costs may be more than 50 percent of the total revenues. That can go up to 80 percent of the total product costs for high technology firms (Weber *et al.*, 1991). Selection of the best suppliers significantly reduces the purchasing costs and improves corporate competitiveness.

In this study, a FAHP-based approach is used to select the best supplier for the company chosen for the study on the basis of the criteria determined. Six main criteria and 22 sub-criteria are determined based on literature survey and the experience of the managers of the company. Comparison of the main criteria and sub-criteria and suppliers are made using a questionnaire and weights are calculated using FAHP approach. Best supplier is selected after computing the overall score of each supplier.

Goal	Quality	Cost	Delivery	Service	Long-term relationship	Flexibility	Priority weights
Weights→	0.41	0.25	0.11	0.11	0.06	0.06	
S_1	0.175	0.4395	0.33	0.4543	0.2493	0.2555	0.299
S_2	0.384	0.1029	0.33	0.2524	0.2416	0.4155	0.287
S_3	0.441	0.4576	0.33	0.2933	0.5091	0.3290	0.414

Table XI. Overall priority weights with respect to "goal"

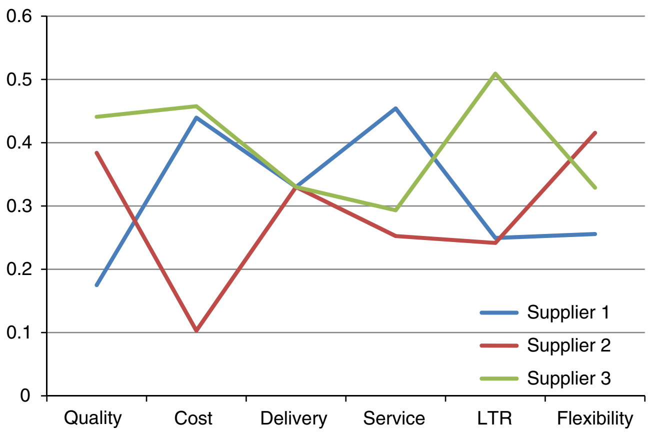

Figure 3. Sensitivity analysis graphs

The salient contribution of this study may be summarized as follows:

- It contributes to supplier selection process and points out the importance of supplier selection problem, especially in the context MCDM.
- This study proposes a supplier selection model for an automobile industry which often faces heterogeneous supply environments.
- This model may have a high acceptability where a large number of suppliers are available to supply the materials or provide the services. As AHP is the most widely used methodology for supplier selection, however, it becomes less efficient in case of inconsistencies observed in the data. However a FAHP-based approach may overcome this difficulty.
- This model also provides useful insights in choosing appropriate suppliers in dynamic situations in order to enhance long-term relationship with them.
- It provides key criteria for supplier selection in automobile company in Indian context.
- It also provides a framework to deal with multiple criteria.
- This model deals with two crucial criteria long-term relationships and flexibility which were relatively less discussed and considered in the literature in past.

7. Limitations and direction for future research

This paper should be viewed in light of some limitations. As this analysis and findings are based on only a case study of an automobile company operational in India, and this necessitates caution in interpreting the results. The limited number of interviewed managers in a company restricts the generalizability of the results. Though the company selected for this study is typical of developing country businesses, the findings of the paper may not be readily extensible to other companies. Future research could examine these results using a larger sample set or field surveys in developing country settings. Second, this study used retrospective settings, based on the interviewed feedback after the events had occurred. This method naturally poses limitations due to respondent recall and the accuracy of information provided. Third, the problem chosen for this study is based in a single country context and further additional research will be required to examine if the findings could be extended to other automobile companies in other developing nations. Fourth, this study, however, can be extended to add more supplier alternatives, which encompass both domestic and international suppliers, but this can increase the computational complexities. Some environmental criteria can be added to this model to deal in green supply chain environment.

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