Received 21 April 2014
Revised 17 May 2014
6 June 2014
Accepted 13 June 2014

An application of hybrid data envelopment analytical hierarchy process approach for supplier selection

Vinod Yadav and Milind Kumar Sharma
Production and Industrial Engineering, MBM Engineering College, JNV University, Jodhpur, India

Abstract

Purpose – The problem of supplier selection gets complicated when a company looks for various criteria to evaluate different suppliers. The decision criteria used for supplier selection process can be different for different organizations due to a large number of factors. Hence, it can be said that supplier selection is basically, a multiple criteria decision-making (MCDM) problem. The purpose of this paper is to propose a hybrid data envelopment analytical hierarchy process (DEAHP) approach to solve the supplier selection problem for an automobile company.

Design/methodology/approach – In this study, the data envelopment analysis (DEA) approach is embedded into analytic hierarchy process (AHP) methodology. Literature review suggested that majority of researches found it appropriate using DEA and AHP methodologies for supplier selection process; hence it is felt that a hybrid DEAHP would be a useful methodology to offer a MCDM model for supplier selection problem.

Findings – First, the key criteria of the supplier selection problem for the company are identified. Then a model is developed and implemented for supplier selection using DEAHP approach. This study concluded that quality, cost and service are the most crucial criteria for an automobile company operational in a developing country like India. Sensitivity analysis further helped to evaluate suppliers based on each criterion.

Research limitations/implications – As this analysis and findings are based on only one case study of an Indian automobile company, 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. 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. Also in some cases technique used in the study may pose some extra computational efforts.

Practical implications – This study points out the importance of the supplier selection problem. It provides key criteria for supplier selection in Indian context also proposes a framework to deal with multiple criteria. proposed model deals with two crucial criteria long term relationships and flexibility which were relatively less discussed and considered in the literature in past.

Originality/value – The proposed MCDM model can provide the guidelines and directions for the decision makers to effectively choose suppliers in the current competitive environment.

Keywords Case study, Supplier selection, Data envelopment analytical hierarchy process (DEAHP), Multi-criteria decision making (MCDM)

Paper type Research paper

Journal of Enterprise Information Management
Vol. 28 No. 2, 2015
pp. 218-242

1741-0398
DOI 10.1108/JEIM-04-2014-0041

The authors thank anonymous reviewers for their helpful and constructive comments.

1. Introduction

Today's competitive environment is characterized by thin profit margins, high consumer expectations for quality products and short lead-times, companies are required to take advantage of every opportunity to optimize their business processes. Globalization forces companies to innovate fast, not only in advanced manufacturing technology, but also in managerial practices (Bititci *et al.*, 2011). To meet this aim, academicians and practitioners have concluded that for a company to remain competitive, it has to work with its supply chain partners to improve overall performance. Thus, being the main process in the upstream chain and affecting all areas of an organization, the purchasing function has gained an inevitable importance.

Success of supply chain depends on effective strategy for improving coordination among the members to make it more responsive for market needs by optimizing available resources (Singh and Sharma, 2014). The most important purchasing decision is undoubtedly selecting and maintaining close relationships with a few, reliable and high-quality vendors, in order to reduce product costs while maintaining excellent product quality and customer services (Dobler *et al.*, 1984; Mummalaneni *et al.*, 1996). Thomas and Janet (1996) investigated the importance of supplier selection, and noted that "it commits resources while simultaneously impacting such activities as inventory management, production planning and control, cash flow requirements, and product quality." Additionally, 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). Therefore, there is a strong need for a systematic approach to purchasing decision making especially in the area of identifying appropriate suppliers and assigning orders among them (Weber *et al.*, 1991; Vonderembse and Tracey, 1999; Tempelmeier, 2002). Reliable suppliers allow enterprises to achieve consistency in manufacturing performance and thus achieving excellence in business operations.

The problem of supplier selection gets complicated when a company looks for various criteria to evaluate different suppliers. Dickson (1966) identified 23 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) for supplier selection based on the survey of 273 purchasing managers. In a survey, Weber *et al.* (1991) classified all published papers (from 1967 to 1990) according to the studied criteria and identified quality, cost and on-time delivery as the most important supplier selection criteria in the evaluation of supplier performance. Muralidharan *et al.* (2002) proposed nine criteria for supplier selection. These nine criteria are quality, delivery, price, technical capability, financial position, past performance attitude, facility, flexibility and service. 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.

The decision criteria used for supplier selection process can be different for different organizations due to a large number of factors:

- the demographic characteristics of the purchasing managers (Kamann and Bakker, 2004; Murray *et al.*, 2005);

- the size of the buyer organization i.e. small, medium or large;
- the preferred sourcing strategy (i.e. single vs multiple) and the existence of a supply chain (purchasing) strategy (Lin *et al.*, 2005); and
- the type of products and/or services purchased (Svensson, 2004).

Hence, it can be said that supplier selection is basically, a MCDM problem. MCDM approaches may be classified into two categories as individual approaches and integrated ones (Ho *et al.*, 2010). The most widespread individual approaches are: the data envelopment analysis (DEA) (Songhori *et al.*, 2011; Dotoli and Falagario, 2012; Partovi, 2013), mathematical programming, the analytic hierarchy process (AHP) (Kumar and Roy, 2011; Bruno *et al.*, 2012), case-based reasoning, fuzzy decision making (Ahamady *et al.*, 2013; Ghorbani *et al.*, 2013), genetic algorithms, the analytic network process (ANP), the simple multi-attribute rating technique and many more. The integrated approaches are combining different individual approaches together (e.g. integrated AHP and DEA (Sevkli *et al.*, 2007; Zhang *et al.*, 2011), integrated fuzzy and AHP (Tas, 2012), integrated AHP and goal programming, etc.) to propose supplier selection models.

In this paper, an attempt is made to propose a MCDM supplier selection model based on hybrid data envelopment analytical hierarchy process (DEAHP) methodology. According to a study conducted by Deloitte (2010) and the US Council on Competitiveness in 2010, India ranks second in manufacturing competitiveness and India's talented pool of engineers and managers are rapidly grasping the techniques and strategies necessary to achieve success in the highly competitive global markets. An automobile company from Indian context is chosen for the study. Second section of the paper presents the review of literature on the supplier selection methodologies. The third section illustrates the AHP, DEA and DEAHP methodologies. The fourth Section presents a case study of an automobile company. The last Section reports on results and key conclusions of the paper.

2. Literature review

There are many MCDM approaches that have been suggested in the literature; however, supplier selection problem may be classified into two broad categories: individual approaches and integrated ones (Ho *et al.*, 2010). 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 the year 2000 to 2011. According to it, the distribution of the articles under various classes of MCDM methods is as follows: DEA 30 percent, mathematical programming 17 percent, AHP 15 percent, case based reasoning 11 percent, fuzzy sets theory 10 percent, ANP 5 percent and rest are other methodologies. A close study of it reveals that 45 percent researches find it appropriate using DEA and AHP methodologies for supplier selection; hence a hybrid DEAHP would be a useful methodology for such problems, which are based on large number of criteria. The major supplier selection approaches are reported in Table I.

Supplier selection process is influenced by variety of criteria (Aissaoui *et al.*, 2007). Based on a questionnaire sent to 273 purchasing agent and managers from USA and Canada, Dickson (1966) identified 23 different criteria for evaluation and supplier selection process as stated in the preceding section. 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 *et al.*, (1968) identified possible

Methodology	Authors
Data envelopment analysis	Liu *et al.* (2000)
	Forker and Mendez (2001)
	Garfamy (2006)
	Seydel (2006)
	Wu *et al.* (2007)
	Songhori *et al.* (2011)
	Dotoli and Falagario (2012)
	Partovi (2013)
Analytical hierarchy process	Muralidharan *et al.* (2002)
	Chan and Chan (2004)
	Hou and Su (2007)
	Chan and Chan (2010)
	Kumar and Roy (2011)
	Bruno *et al.* (2012)
Analytical network process	Gencer and Gurpinar (2007)
	Bayazit (2006)
	Sarkis and Talluri (2002)
Fuzzy set theory	Chen *et al.* (2006)
	Florez-Lopez (2007)
	Chang *et al.* (2011)
	Jiang and Chan (2011)
	Ahmady *et al.* (2013)
	Ghorbani *et al.* (2013)
Linear programming	Talluri and Narasimhan (2003)
	Talluri and Narasimhan (2005)
	Ng (2008)
Integer programming	Talluri (2002)
	Hong *et al.* (2005)
Goal programming	Karpak *et al.* (2001)
Data envelopment analytical hierarchy process	Sevkli *et al.* (2007)
	Zhang *et al.* (2011)
Integrated AHP-GP	Cebi and Bayraktar (2003)
	Percin (2006)
	Kull and Talluri (2008)
	Mendoza *et al.* (2008)
Integrated fuzzy-AHP	Kahraman *et al.* (2003)
	Chan and Kumar (2007)
	Tas (2012)

Table I. Supplier selection methods

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. Weber *et al.* (1991) observed that price, delivery, quality, production capacity and localization were 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) after reviewing a plethora of literature highlighted on forty four suppler selection criteria. Authors found quality as the highest frequency criterion appeared in literature followed by delivery and cost. Wu and Blackhurst (2009) identified price, quality and delivery performance as selection criteria in their supplier selection model. Sevkli (2010) used delivery performance, quality performance, price\cost, financial strength, management and organizational strength in its supplier selection model.

Liu *et al.* (2000) proposed a simplified DEA model to evaluate the overall performances of suppliers with respect to three input and two output criteria. The model aimed at selecting a supplier having higher supply variety so that the number of suppliers could be reduced. Forker and Mendez (2001) applied DEA to measure the comparative efficiencies of suppliers. For each supplier, a measure of comparative efficiency was calculated as the maximum ratio of a single input to multiple outputs. Those outputs were based on the critical factors of quality management proposed by other scholars. Garfamy (2006) applied DEA to measure the overall performances of suppliers based on total cost of ownership concept. A supplier providing a single unit of output charging the least amount of costs was regarded as the most efficient. Wu *et al.* (2007) presented a so-called augmented imprecise DEA for supplier selection. The proposed model was able to handle imprecise data (i.e. to rank the efficient suppliers) and allowed for increased discriminatory power (i.e. to discriminate efficient suppliers from poor performing suppliers). A web-based system was developed to allow potential buyers for supplier evaluation and selection. Songhori *et al.* (2011) presented a structured framework to help decision makers in selecting the best supplier for their firm using DEA. This model had two separate but dependent phases as selection and allocation phases. Ghorbani *et al.* (2013) proposed a three-phase approach for supplier selection based on the Kano model and fuzzy MCDM. Ahmady *et al.* (2013) developed a novel fuzzy DEA approach with double frontiers for supplier selection. Partovi (2013) developed a quantitative methodology based on DEA, including the constraint of "self-efficiency" for supplier selection.

Muralidharan *et al.* (2002) proposed a five-step AHP-based model to aid decision makers in rating and selecting suppliers with respect to nine evaluating criteria. People from different functions of the company, such as purchasing, stores, and quality control, were involved in the selection process. Chan and Chan (2004) applied AHP to evaluate and select suppliers. The AHP hierarchy consists of six evaluating criteria and 20 sub-factors, of which the relative importance ratings were computed based on the customer requirements. Hou and Su (2007) developed an AHP-based decision support system for the supplier selection problem in a mass customization environment. Factors from external and internal influences were considered to meet the needs of markets within the global changing environment. Chan and Chan (2010) proposed an AHP based model to solve the supplier evaluation and selection problem taking the example of 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 twenty nine criteria were identified out of which 19 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 were considered under four criteria i.e. process and product quality, service level, management and innovation and financial position. It further threw light on identification of strengths and weaknesses of using formalized supplier selection models to tackle the supplier evaluation problem. It also highlighted potential barriers preventing firms to adopt such methods.

Ramanathan (2006) first proposed the DEAHP methodology. Ramanathan (2007) further suggested that DEA could be used to evaluate the performance of suppliers using both quantitative and qualitative information obtained from the total cost of ownership and AHP. Specifically, costs based on the concept of total cost of ownership were regarded as inputs, whereas the AHP weights were considered as outputs in the DEA model. Sevkli *et al.* (2007) applied an integrated AHP-DEA approach for supplier selection. In the approach, AHP was used to derive local weights from a given pair wise comparison matrix, and aggregated local weights to yield overall weights. Each row and column of the matrix was assumed as a decision-making unit (DMU) and an output, respectively. A dummy input that had a value of one for all DMUs was deployed in DEA to calculate the efficiency scores of all suppliers. However, the authors pointed out that the approach was relatively more cumbersome to apply than the individual AHP. Zhang *et al.* (2011) developed a hybrid methodology combining the DEAHP and activity-based costing. It is evident from it that using this hybrid model, decisions on supplier selection and order quantity can easily be made within an integrated single objective function, which is based on consideration of the budget of the buyer and of the capacity of the supplier.

Hence, after scanning a plethora of literatures, following gaps are found:

- The literature lacks essential elements to recognize some of the elements of long term relationships between buyer and supplier.
- It is further observed that very less articles have proposed MCDM approach based on DEAHP methodology for supplier selection despite of the fact that this approach offers various benefits over other approaches.
- Very few researchers reported on flexibility criteria, one of the most crucial factors in today's competitive manufacturing environment, for supplier selection. Singh and Sharma (2014) also stressed on prioritizing flexibility in supply chain management.
- The literature lacks the case application in developing countries setting such as India.

3. Methodology

Literature review presented in the preceding section observed that about 45 percent researches find it appropriate using DEA and AHP methodologies for supplier selection process; hence it is felt that a hybrid DEAHP would be a useful methodology to offer a MCDM model for supplier selection problem. Hence, in the present study DEAHP methodology is used in which DEA approach is embedded into AHP methodology for supplier selection process. First problem hierarchy is formed for the identified criteria and alternatives and pair-wise comparisons are performed using managerial preferences. Subsequently DEA is used to generate the local weights/priorities of the criteria and alternatives. The DEA approach is further used to synthesize weights. Inputs for DEAHP analysis are taken from managerial level staff of an automobile company discussed later in the paper. Figure 1 explains the research methodology used in this study diagrammatically.

3.1 Analytic hierarchy process

Many researchers (Saaty, 1980) have concluded that AHP is a useful, practical and systematic method for supplier selection. The AHP methodology, which was developed

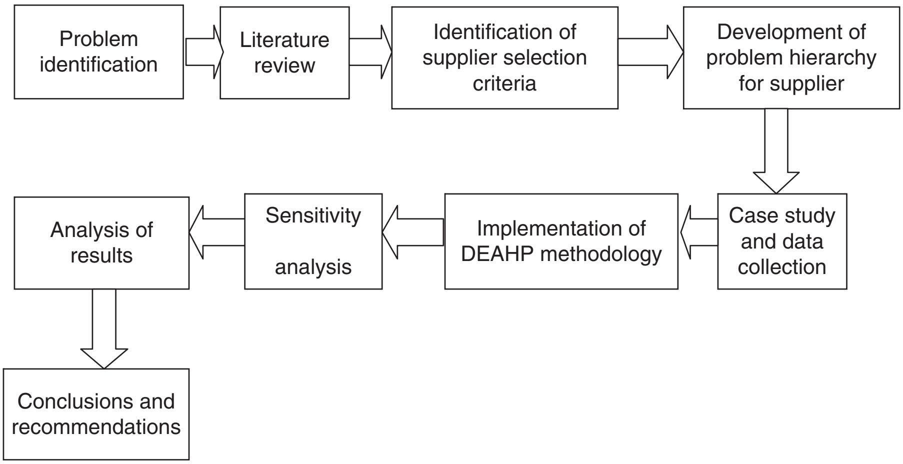

Figure 1.
Diagrammatical representation of research methodology used

by Saaty (1980), is a powerful tool in solving complex decision problems. In the AHP approach, the decision problem is structured hierarchically at different levels with each level consisting of a finite number of decision elements as shown in Figure 2. The upper level of the hierarchy represents the overall goal, while the lower level consists of all possible alternatives. One or more intermediate levels embody the decision criteria and sub-criteria.

AHP uses pair wise comparison of the same hierarchy elements in each level using a Saaty scale indicating the importance of one element over another element with respect to the higher-level element. The scaling process yields a relative priority or weights of elements with respect to the criterion or element of the highest level. The comparisons are done for all elements in a level with respect to all elements in level above. The final and global weights of the elements at the lowest level of the hierarchy are found by adding all the contributions of the elements in a level with respect to all elements in higher level.

3.2 DEA

DEA is data oriented approach for evaluating the performance of a set of peer entities called DMUs which convert multiple inputs into multiple outputs. Charnes *et al.* (1978) described DEA as a "mathematical programming model applied to observational data [that] provides a new way of obtaining empirical estimates of relations such as the production functions and/or efficient production possibility surfaces that are cornerstones

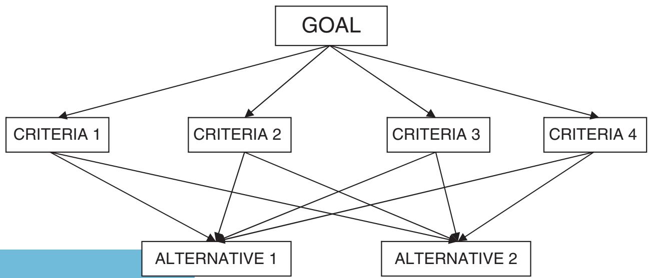

Figure 2.
Structure of AHP

of modern economics." The efficiency score in the presence of multiple input and output factors is defined as:

$$\text{Efficiency} = \frac{\text{weighted sum of output}}{\text{weighted sum of inputs}} \tag{1}$$

Assuming that there are n DMUs, each with m inputs and s outputs, the relative efficiency score of a test DMU p is obtained by solving the following model:

$$\max Z = \frac{\sum_{k=1}^{s} W_k \cdot y_{kp}}{\sum_{j=1}^{m} w_j \cdot x_{jp}}$$

$$\textit{Subjected to } \frac{\sum_{k=1}^{s} W_k \cdot y_{ki}}{\sum_{j=1}^{m} w_j \cdot x_{ji}} \leqslant 1,\ W_k,\quad w_j \leqslant 0 \tag{2}$$

where $k = 1$ to s; $j = 1$ to m; $i = 1$ to n; y_{ki} is the amount of output k produced by DMU i; x_{ji} is the amount of input j utilized by DMU i; W_k is the weight given to output k; w_j is the weight given to input j.

The fractional program shown as (2) can be converted to a linear program as shown in (3):

$$\max Z = \sum_{k=1}^{s} W_k \cdot y_{kp},$$

$$\text{s.t.} \quad \sum_{j=1}^{m} w_j \cdot x_{ji} = 1,$$

$$\sum_{k=1}^{s} W_k \cdot y_{kp} - \sum_{j=1}^{m} w_j \cdot x_{ji} \leqslant 0,$$

$$W_k,\quad w_j \geqslant 0 \tag{3}$$

The above problem is run n times in identifying the relative efficiency scores of all the DMUs. Each DMU selects input and output weights that maximize its efficiency score. In general, a DMU is considered to be efficient if it obtains a score of 1 and a score of < 1 implies that it is inefficient.

3.3 The DEAHP

Ramanathan (2006) first proposed the DEAHP methodology, in which DEA method is embedded into AHP method. The structure of DEAHP is same as AHP structure, i.e. the upper level of the hierarchy represents the overall goal, while the lower level consists of all possible alternatives. One or more intermediate levels embody the decision criteria and subcriteria.

In this methodology, each row of the pair wise matrix is assumed as DMU and each column is assumed as output. But according to DEA method, the efficiency scores of each DMU cannot be calculated entirely with outputs and requires at least one input.

So, dummy inputs for all the DMU's are employed which has a value of 1 as shown in Table II.

In DEAHP methodology the efficiency scores are calculated using the DEA method for each pair-wise comparison matrix and could be interpreted as local weights of the DMUs. Once the local weights of DMUs are calculated, the next step is to aggregate the local weights to get overall weight. Again, the DEA method is used to derive the overall weights from the local weights. Ramanathan (2006) also approves that DEA method correctly derives the weights for consistent judgment matrix. Further, Sevkli *et al.* (2007) and Zhang *et al.* (2011) applied this approach for supplier selection problem. Hence, it is impetrative to use an integrated DEAHP approach for the present study also.

4. Case study

The objective of this study is to develop a generic model, which may help to solve the supplier selection problem based on multiple criteria in the heterogeneous manufacturing environment. For this study qualitative research using case study methodology is used in an automobile company. This data collection technique was chosen for three main reasons (Eisenhardt, 1989). First, the research was explorative as there is a lack of research on the topic studied in Indian context. Second, the case studies were considered very useful for revealing possible contingency effects and for finding empirically grounded explanations for them. Finally, case studies have proven to be one of the most powerful research methods, particularly in development theory (Voss *et al.*, 2002). The data were collected by visiting the company and interviewing managers at different organizational levels. Company documents and interviews with company consultants were used to collect additional information and to better understand the data gathered. The interview protocol was dynamically adjusted to maximize insights into the themes that emerged during the interviews (Eisenhardt, 1989). The case study was tested for construct validity and internal validity. Construct validity is the extent to which we establish correct operational measures for the concepts being studied. To ensure construct validity, authors have looked for multiple sources of evidence for each of the important elements in the propositions, using the important technique of triangulation. Use of multiple – informants and use of archival data helped authors crosscheck pertinent information and verify the reliability of data obtained. To demonstrate the internal validity, the authors recorded evidence of other factors that might be alternative explanations for the observed patterns. Internal validity is the extent to which we can establish a casual relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships (Yin, 1989). The results obtained in case study are analyzed using a mathematical technique DEAHP. The company chosen for the present study is an automobile, motor vehicles and internal combustion Engines Company founded in 1921 and started operations in Indian market to built medium and heavy duty commercial vehicles in 2010. It is a leading car and truck manufacturing company. The company desired to choose the best supplier from three suppliers for one of its crucial items. This paper

Table II.
Pair-wise comparison matrix for DEAHP

Output→	1	2	…	m	Dummy input
DMU 1	1	a_{12}	…	a_{1m}	1
DMU 2	$1/a_{12}$	1	…	a_{2m}	1
…	…	…	…	…	1
DMU n	$1/a_{1m}$	$1/a_{2m}$	…	1	1

attempts to address this problem by using DEAHP as MCDM approach. In order to maintain the confidentiality and anonymity of the supplier companies, the suppliers are numbered as S1, S2, S3, etc. in this study.

The model presented in this study utilizes the DEAHP approach. The main steps of the model are as follows:

(1) development of hierarchy;

(2) preparing the judgment matrix;

(3) calculating weights of alternatives at third level;

(4) calculating weights of alternatives at second level; and

(5) computing the overall score of suppliers.

4.1 Development of hierarchy

After reviewing literature and constant interaction with managers working in the purchase department of the company chosen for the study, six key supplier selection criteria are identified which are quality, cost, delivery, service, long term relationship and flexibility. To evaluate the suppliers further on the basis of these identified key criteria, twenty two attributes as sub-criteria are chosen, which are illustrated as follows.

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 should perform efficiently, consistently and satisfactorily. 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. Hence the quality of a product can be determined by the following attributes: meeting minimum standards and requirements, reliability, customer rejection and defect rates.

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.

The suppliers can also be rated with respect to delivery term. "Justice delayed is justice denied" is a common complaint of the most customers. Every customer expects to receive orders at right time with good packaging. 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.

In a country like India, more emphasize placed on the after sales service as it not only provides competitive advantage but also contributes significantly in profit generation and retaining customers on long term basis. After sale service keeps customer satisfied and influences customer purchasing decisions. However, the service of the supplier can be evaluated under the criteria such as Technical support, Information sharing, Warranty and claim policy and Capabilities.

Successful business is run on cordial relations in stiff competition. The supplier is often treated as an intangible asset of an organization. Good buyer-supplier relationship enhances mutual motivation and results in better development of the total economy. The buyer-supplier relationship can be evaluated by attributes: honesty, reputation, trust and partnership and ease of communication.

Flexibility is defined as the ability of a system to adapt to external changes, while maintaining satisfactory system performance. System performance is characterized by parameters such as capacity, level of service, maintainability and profitability. External changes are uncontrolled conditions that affect the system, including changes in level of demand or use, shifts in spatial traffic patterns, infrastructure loss and degradation, and changes in the price and availability of important resources such as fuel, etc. Indeed flexibility is vital to the success of supply chain, since the supply chains generally operate in uncertain business environment. It has a variety of dimensions attached with it (Singh and Sharma, 2014). Flexibility measures are broadly divided under the four headings:

(1) Volume flexibility: the ability to respond to change in demand.

(2) Mix flexibility: the ability to change the variety of products produced.

(3) Delivery flexibility: the ability to respond quickly to tight delivery requests.

(4) New product flexibility: the ability to introduce and produce new products (also includes modification of the existing system).

Therefore, the flexibility of the supplier can be evaluated under four attributes: ability to quick change program, short new product line time, Short lead time and solve conflict.

All these criteria as discussed above are arranged in a hierarchical structure as shown in Figure 3. This fulfills the initial requirement of DEAHP methodology to define the criteria in hierarchical manner.

4.2 Preparing the judgment matrix

The second step is to prepare pair wise comparison matrix. For this purpose, questionnaires and interviews were conducted with the managerial staff employed in the purchase department of the company. The aim here was to collect the extent of preference of pairs between those criteria at different levels as shown in the hierarchical structure (Figure 2). A nine-point scale (Saaty's scale) ranging from "1 for equally preferred" to "9 for extremely preferred" is used for this purpose. The pair-wise comparison with respect to the criteria "quality" is shown in Table V which has five subsection named as A, B, C and D. In Table III part A, four supplier selection criteria related to quality, which include meeting minimum standard and requirements, reliability, customer rejection, defect rate are pair wise compared. Part B-E in Table III show pair-wise comparisons of suppliers with respect to criteria include meeting minimum standard and requirements, reliability, customer rejection and defect rate, respectively and indicate the weight of each criterion related to quality using DEAHP approaches.

4.3 Calculating weights of alternatives at third level

The next step is to calculate the local weights of alternatives at third level of the hierarchy. The local weights of alternatives using DEAHP methods are shown in the last column of Tables III-VIII. To derive the local weight for a consistent pair wise matrix DEA methodology is used. For example, to derive the local weight for criterion meeting minimum standard and requirements in Table III the following model is used:

$$Objective\ function:\ maximization\ Z = 1y_{11} + 3y_{12} + 4y_{13} + 2y_{14}$$

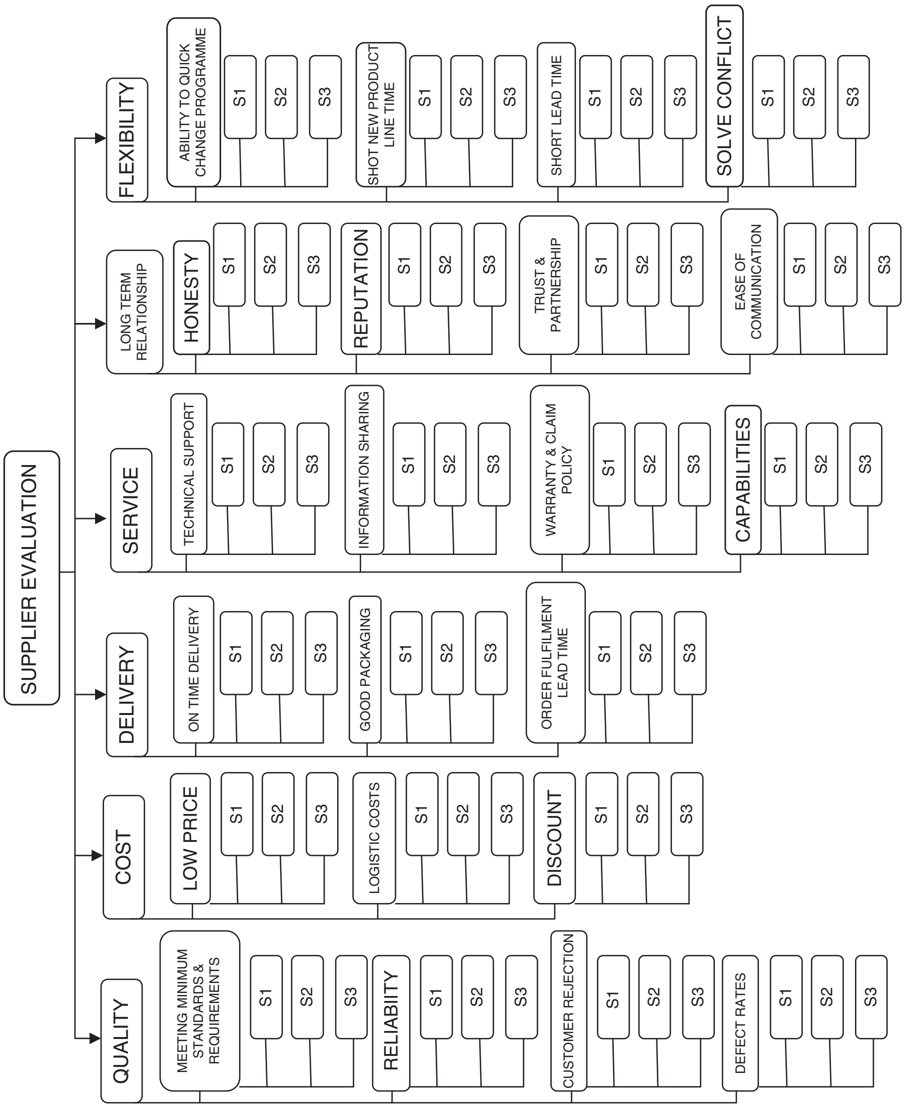

Figure 3.
Hierarchical structure of supplier selection problem

Subject to:

$$x_{11} = 1,$$

$$1y_{11} + 3y_{12} + 4y_{13} + 2y_{14} \leqslant 0,$$

$$1/3y_{11} + 1y_{12} + 1/2y_{13} + 1/3y_{14} \leqslant 0,$$

$$1/4y_{11} + 2y_{12} + 1y_{13} + 1/3y_{14} \leqslant 0,$$

$$1/2y_{11} + 3y_{12} + 3y_{13} + 1y_{14} \leqslant 0,$$

$$y_{11},\ y_{12},\ y_{13},\ y_{14},\ x_{11},\ x_{12},\ x_{13},\ x_{14} \geqslant 0.$$

Similarly, to obtain the local weight of other criteria, similar model is used by changing the objective function, i.e.:

$$Maximization\ \ Z = 1/3y_{11} + 1y_{12} + 1/2y_{13} + 1/3y_{14}\ \ (for\ reliability)$$

$$Maximization\ \ Z = 1/4y_{11} + 2y_{12} + 1y_{13} + 1/3y_{14}\ \ (for\ customer\ rejection)$$

$$Maximization\ \ Z = 1/2y_{11} + 3y_{12} + 3y_{13} + 1y_{14}\ \ (for\ defectrate)$$

A: evaluation of criteria with respect to Quality							
DMU	*Output 1*	*Output 2*	*Output 3*	*Output 4*	*Input*	*AHP*	*DEAHP*
Meeting minimum standard and requirements	1	3	4	2	1	0.462	1.000
Reliability	1/3	1	1/2	1/3	1	0.103	0.333
Customer rejection	1/4	2	1	1/3	1	0.134	0.666
Defect rate	1/2	3	3	1	1	0.301	1.000
B: evaluation of suppliers with respect to Meeting minimum standard and requirement							
DMU	*Output 1*	*Output 2*	*Output 3*		*Input*	*AHP*	*DEAHP*
S1	1	1/4	3		1	0.218	0.500
S2	4	1	6		1	0.691	1.000
S3	1/3	1/6	1		1	0.091	0.167
C: evaluation of suppliers with respect to Reliability							
S1	1	2	3		1	0.528	1.000
S2	1/2	1	3		1	0.333	1.000
S3	1/3	1/3	1		1	0.14	0.333
D: evaluation of suppliers with respect to Customer rejection							
S1	1	1/3	1/4		1	0.122	0.250
S2	3	1	1/2		1	0.32	0.750
S3	4	2	1		1	0.558	1.000
E: evaluation of suppliers with respect to Defect rate							
S1	1	3	1/3		1	0.243	0.428
S2	1/3	1	1/7		1	0.088	0.142
S3	3	7	1		1	0.669	1.000

Table III.
Third level judgment matrixes for quality

A: evaluation of criteria with respect to Cost						
Output→	*1*	*2*	*3*	*Input*	*AHP*	*DEAHP*
Low price	1	4	1/3	1	0.271	0.667
Logistic cost	1/4	1	1/6	1	0.085	0.167
Discount	3	6	1	1	0.644	1.000
B: evaluation of suppliers with respect to Low price						
S1	1	1/2	3	1	0.320	0.750
S2	2	1	4	1	0.558	1.000
S3	1/3	1/4	1	1	0.122	0.250
C: evaluation of suppliers with respect to Logistic cost						
S1	1	3	2	1	0.528	1.000
S2	1/3	1	1/3	1	0.140	0.333
S3	1/2	3	1	1	0.333	1.000
D: evaluation of suppliers with respect to Discount						
S1	1	1/2	3	1	0.320	0.750
S2	2	1	4	1	0.558	1.000
S3	1/3	1/4	1	1	0.122	0.250

Table IV.
Third level judgment matrixes for Cost

A: evaluation of criteria with respect to Delivery						
Output →	*1*	*2*	*3*	*Input*	*AHP*	*DEAHP*
On time delivery	1	4	4	1	0.661	1.000
Good packaging for delivery	1/4	1	1/2	1	0.131	0.250
Order fulfilment lead time	1/4	2	1	1	0.208	0.500
B: evaluation of suppliers with respect to On time delivery						
S1	1	2	2	1	0.493	1.000
S2	1/2	1	1/2	1	0.196	0.500
S3	1/2	2	1	1	0.311	1.000
C: evaluation of suppliers with respect to Good packaging for delivery						
S1	1	3	1/2	1	0.333	1.000
S2	1/3	1	1/3	1	0.140	0.333
S3	2	3	1	1	0.528	1.000
D: evaluation of suppliers with respect to Order fullfilment lead time						
S1	1	1/2	4	1	0.345	1.000
S2	2	1	4	1	0.547	1.000
S3	1/4	1/4	1	1	0.109	0.250

Table V.
Third level judgment matrixes for Delivery

The local weights of criteria are subsequently obtained after solving above DEA model. Tora software is used to solve this model (Taha, 2010).The local weights of suppliers with respect to meeting minimum standards and requirements, reliability, customer rejection and defect rate are shown in the last column of Table V (parts B-E of Table V), respectively. Similarly, as shown in Tables VI-X the third level local weights for other criteria i.e. Cost, Delivery, Service, Long-term relationship and Flexibility are also calculated (Tables IV-VII).

4.4 Calculating weights of alternatives at second level

Once local weights of suppliers are obtained in the third level, then the next step is to aggregate the local weights of suppliers at third level to obtain second level of weights of the decision alternatives. The calculations for second level are same as third level but

A: evaluation of criteria with respect to Service							
Output →	*1*	*2*	*3*	*4*	*Input*	*AHP*	*DEAHP*
Technical support	1	3	1/3	2	1	0.242	0.750
Information sharing	1/3	1	1/4	1/3	1	0.084	0.250
Warranty and claim policy	3	4	1	3	1	0.502	1.000
capability	1/2	3	1/3	1	1	0.172	0.750
B: evaluation of suppliers with respect to Technical support							
Output →	*1*	*2*	*3*		*Input*	*AHP*	*DEAHP*
S1	1	3	1/2		1	0.320	0.750
S2	1/3	1	1/4		1	0.122	0.250
S3	2	4	1		1	0.558	1.000
C: evaluation of suppliers with respect to Information sharing							
S1	1	3	1/2		1	0.309	0.600
S2	1/3	1	1/5		1	0.109	0.200
S3	2	5	1		1	0.582	1.000
D: evaluation of suppliers with respect to Warranty and claim policy							
S1	1	1/2	4		1	0.323	0.667
S2	2	1	6		1	0.588	1.000
S3	1/4	1/6	1		1	0.089	0.167
E: evaluation of suppliers with respect to Capabilities							
S1	1	3	1/3		1	0.250	0.500
S2	1/3	1	1/6		1	0.095	0.167
S3	3	6	1		1	0.655	1.000

Table VI.
Third level judgment matrixes for Service

A: evaluation of criteria with respect to Long term relationship							
Output →	*1*	*2*	*3*	*4*	*Input*	*AHP*	*DEAHP*
Honesty	1	3	5	5	1	0.556	1.000
Reputation	1/3	1	3	3	1	0.249	0.600
Trust and partnership	1/5	1/3	1	3	1	0.115	0.600
Ease of communication	1/5	1/3	1/3	1	1	0.081	0.200
B: evaluation of suppliers with respect to Honesty							
Output →	*1*	*2*	*3*		*Input*	*AHP*	*DEAHP*
S1	1	2	3		1	0.540	1.000
S2	1/2	1	2		1	0.297	0.666
S3	1/3	1/2	1		1	0.163	0.333
C: evaluation of suppliers with respect to Reputation							
S1	1	1/4	2		1	0.200	0.400
S2	4	1	5		1	0.683	1.000
S3	1/2	1/5	1		1	0.117	0.200
D: evaluation of suppliers with respect to Trust and partnership							
S1	1	2	1/5		1	0.167	0.285
S2	1/2	1	1/7		1	0.094	0.142
S3	5	7	1		1	0.740	1.000
E: evaluation of suppliers with respect to Ease of communication							
S1	1	1/2	3		1	0.320	0.750
S2	2	1	4		1	0.558	1.000
S3	1/3	1/4	1		1	0.122	0.250

Table VII.
Third level judgment matrixes for Long term relationship

	1	2	3	4	Input	AHP	DEAHP
A: evaluation of criteria with respect to Flexibility							
Output→	*1*	*2*	*3*	*4*	*Input*	*AHP*	*DEAHP*
Ability to quick change program	1	1/3	2	1/3	1	0.142	0.667
Short new product line time	3	1	4	1/2	1	0.327	1.333
Short lead time	1/2	1/4	1	1/3	1	0.095	0.333
Solve conflict	3	2	3	1	1	0.436	1.000
B: evaluation of suppliers with respect to Ability to quick change program							
Output→	*1*	*2*	*3*		*Input*	*AHP*	*DEAHP*
S1	1	2	1/4		1	0.200	0.400
S2	1/2	1	1/5		1	0.117	0.200
S3	4	5	1		1	0.683	1.000
C: evaluation of suppliers with respect to Short new product line time							
S1	1	2	3		1	0.540	1.000
S2	1/2	1	2		1	0.297	0.666
S3	1/3	1/2	1		1	0.163	0.333
D: evaluation of suppliers with respect to Short lead time							
S1	1	4	1/2		1	0.333	0.800
S2	1/4	1	1/5		1	0.097	0.200
S3	2	5	1		1	0.570	1.000
E: evaluation of suppliers with respect to Solve conflict							
S1	1	1/4	2		1	0.200	0.400
S2	4	1	5		1	0.683	1.000
S3	1/2	1/5	1		1	0.117	0.200

Table VIII. Third level judgment matrixes for Flexibility

the only difference is the additional constraints that are related to the local weights of criteria at the third level. For example, DEA model for supplier 1 at second level (for quality) is expressed as:

$$\textit{Objective function maximization } Z = 0.5y_{11} + 1y_{12} + 0.25y_{13} + 0.428y_{14}$$

Subject to:

$$x_{12} = 1,$$

$$0.5_{11} + 1y_{12} + 0.25y_{13} + 0.428y_{14} \leqslant 0,$$

$$1y_{11} + 1y_{12} + 0.75y_{13} + 0.142y_{14} \leqslant 0,$$

$$0.167y_{11} + 0.333y_{12} + 1y_{13} + 1y_{14} \leqslant 0$$

$$y_{11} = 3y_{12} = 3/2y_{13} = y_{14} \quad (\textit{additional constraints})$$

$$y_{11},\ y_{12},\ y_{13},\ y_{14},\ x_{11},\ x_{12},\ x_{13} \geqslant 0$$

First three constraints are related to the local weights of the suppliers at the third level (Table IX) and the last additional constraints are related to the local weights of criteria of third level (in Table III). When this model is solved, the local weight of supplier 1 for criterion quality is obtained. In the same manner, the local weights

A: weights of suppliers with respect to Quality[a]							
DMU	*Output 1*	*Output 2*	*Output 3*	*Output 4*	*Input*	*AHP*	*DEAHP*
S1	0.5000	1.000	0.250	0.428	1	0.244	0.722
S2	1.000	1.000	0.750	0.142	1	0.423	1.000
S3	0.167	0.333	1.000	1.000	1	0.333	0.984
B: weights of suppliers with respect to Cost							
DMU	*Output 1*	*Output 2*	*Output 3*		*Input*	*AHP*	*DEAHP*
S1	0.750	1.000	0.750		1	0.337	0.822
S2	1.000	0.333	1.000		1	0.523	1.000
S3	0.250	1.000	0.250		1	0.140	0.338
C: weights of suppliers with respect to Delivery							
S1	1.000	1.000	1.000		1	0.441	1.000
S2	0.500	0.333	1.000		1	0.262	0.619
S3	1.000	1.000	0.250		1	0.297	0.785
D: weights of suppliers with respect to Service							
DMU	*Output 1*	*Output 2*	*Output 3*	*Output 4*	*Input*	*AHP*	*DEAHP*
S1	0.750	0.600	0.667	0.500	1	0.309	1.287
S2	0.250	0.200	1.000	0.167	1	0.350	1.000
S3	1.000	1.000	0.167	1.000	1	0.341	1.406
E: weights of suppliers with respect to Long-term relationship							
S1	1.000	0.400	0.285	0.750	1	0.394	1.000
S2	0.667	1.000	0.142	1.000	1	0.391	0.994
S3	0.333	0.200	1.000	0.250	1	0.215	0.706
F: weights of suppliers with respect to Flexibility							
S1	0.400	1.000	0.800	0.400	1	0.324	1.084
S2	0.200	0.667	0.200	1.000	1	0.421	1.000
S3	1.000	0.333	1.000	0.200	1	0.256	0.786

Note: [a] $y_{11} = 3y_{12} = 3/2y_{13} = y_{14}$

Table IX.
Second level weights of suppliers

of other suppliers can be found using similar model by changing the objective function as shown in Table IX.

Similarly, each supplier's local weight is calculated using the same model for the other criteria in cost, delivery, service, long-term relationship and flexibility. These results are shown in Table IX.

4.5 Computing the overall score of suppliers

The last step of the DEAHP is to derive the overall scores/weights of the suppliers at first level. Table X shows the weights of supplier selection criteria calculated for DEAHP methodology. Based on the results the most important category of selection criteria is found to be quality with their weights being 1.0. On the other hand, the least

DMU	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Input	AHP	DEAHP
Quality	1	3	4	4	5	5	1	0.420	1.000
Cost	1/4	1	3	3	4	4	1	0.243	0.800
Delivery	1/4	1/3	1	1/2	2	2	1	0.093	0.400
Service	1/4	1/3	2	1	3	2	1	0.126	0.600
LTR	1/5	1/4	1/2	1/3	1	1/2	1	0.051	0.200
Flexibility	1/5	1/4	1/2	1/2	2	1	1	0.068	0.400

Table X.
Weights calculation for criteria

important category of selection criteria was related to long-term relationship with their respective weight being 0.2.

Aggregation procedures are same as the calculation of the second level. The results of Table IX are providing the DEA model for the overall weights calculations whereas; the results of Table X are providing the additional constraints. The overall weights of all three suppliers are shown in Table XI. For example the DEA model for supplier 1 is expressed as follows:

$$\textit{Objective function maximization } Z = 0.722y_{11} + 0.822y_{12} + 1y_{13} + 1.287y_{14} + 1y_{15} + 1.084y_{16}$$

Subject to:

$$x_{12} = 1,$$

$$0.722y_{11} + 0.822y_{12} + 1y_{13} + 1.287y_{14} + 1y_{15} + 1.084y_{16} \leqslant 0,$$

$$1y_{11} + 1y_{12} + 0.619y_{13} + 1y_{14} + 0.994y_{15} + 1y_{16} \leqslant 0,$$

$$0.984y_{11} + 0.338y_{12} + 0.785y_{13} + 1.406y_{14} + 0.706y_{15} + 0.789y_{16} \leqslant 0,$$

$$y_{11} = 5/4y_{12} = 5/2y_{13} = 5/3y_{14} = 5y_{15} = 5/2y_{16}, \ (\textit{additional constraint})$$

$$y_{11},\ y_{12},\ y_{13},\ y_{14},\ y_{15},\ y_{16},\ x_{11},\ x_{12},\ x_{13} \geqslant 0.$$

5. Results and discussions

The final results of the model are illustrated in Table XI. Due to the maximum overall weight, supplier 2 has been ranked as most appropriate candidate (as ranked with highest priority) from both methodologies (i.e. AHP and DEAHP). However, suppliers 1 and 3 have been found as numbers 2 and 3, respectively, from both methodologies, so in this model, results from both methodologies are same. Therefore, this analysis suggests supplier 2 to be recommended as the most eligible supplier to supply the material.

However, evaluating suppliers based on each criterion (out of the six criteria) also offers some interesting insights into analysis. Hence, sensitivity analysis is done for this purpose. Figure 4 shows the sensitivity analysis graph with respect to the goal. It may be clearly seen from the graph that supplier 1 is ranked as number 1 with respect to criteria delivery, service, long term relationship and flexibility. Whereas, supplier 2 is ranked as number 1 with respect to criteria quality and cost. Table X shows that top two ranked criteria are quality and cost and highest weighed supplier with respect to these criteria is supplier 2. However, the overall weights of supplier 1 (0.981) and

DMU	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Input	AHP	DEAHP
S1	0.722	0.822	1.000	1.287	1.000	1.084	1	0.306	0.981
S2	1.000	1.000	0.619	1.000	0.994	1.000	1	0.421	1.000
S3	0.984	0.338	0.785	1.406	0.706	0.786	1	0.273	0.883

Note: $y_{11} = 5/4y_{12} = 5/2y_{13} = 5/3y_{14} = 5y_{15} = 5/2y_{16}$

Table XI. Overall weights of suppliers

Figure 4.
Sensitivity graph with respect to the goal

supplier 2 (1.000) are also quite close. It would be pertinent to suggest here that a minor change in input parameters may change these results.

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 X). 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.

5.1 AHP vs DEAHP

In AHP, local weights of the elements are calculated from the judgment matrices using the eigenvector method (EVM). The normalized eigenvector corresponding to the principal eigen value of the judgment matrix provides the weights of the corresponding elements. The ranking of alternatives determined by the traditional AHP may be altered by any addition or deletion of another alternative for consideration. For example, when a new alternative is added/deleted to the list of alternatives discussed earlier, there will be change it in their rankings.

In DEAHP, the weights of alternatives (i.e. the efficiency scores) are calculated separately for each alternative using a separate linear programming model. However, in AHP weights of all the alternatives are derived simultaneously with the help of EVM. In addition to it, while traditional AHP uses arithmetic normalization, no such normalization is done in case of DEAHP. Further, the DEAHP weights are calculated relative to the weight of the best rated alternative. Efficient alternatives are interpreted as relevant alternatives because they play an important role in the rank ordering of all the alternatives. In case the alternative other than the best one is eliminated from the model, then the new ranking calculated will again be relative to the highest ranked one alternative, and the ordering of alternatives will not change.

In the present study, supplier 2 has been founded as most preferred supplier from both methodologies (i.e. AHP and DEAHP). Suppliers 1 and 3 have been ranked as numbers 2 and 3, respectively, from both methodologies. It is interesting to note here that in the present case results obtained from both methodologies are same.

6. Conclusion

Timely following best practices helped companies to regain their status in the market and, considering the performance indicators identified by Bititci *et al.* (2011), they are recognized as leading companies in their respective sectors in India. For an automobile industry supplier selection is a difficult problem to address due to several items in inventory and multiple criteria. Hence, an effective and systematic procedure is required for supplier selection problem. Here, a DEAHP based model has been developed and applied to a real case application. In this model 22 sub criteria under six criteria are used. According to Ramanathan's (2006) work, DEAHP method provides a better decision than the AHP method for supplier selection and Sevkli *et al.* (2007) also articulates to support DEAHP method over AHP by providing some empirical evidences.

6.1 Research implications

Supplier selection as a MCDM problem is an area of growing interest among industries, managers, practitioners and scholars. Yet, to date, very limited work has been conducted in industries in a typical developing economy like India. Such studies would greatly help develop and practice methods, models, managerial practices and theories of the supplier selection problem for the survival and success of manufacturing enterprises in the present competitive globalized business era. This study throws light on the importance of the supplier selection problem. It provides key criteria for supplier selection in Indian context and also proposes a framework to deal with multiple criteria.

From this study it may be concluded that quality, cost and service are the most crucial criteria for an automobile company operational in a developing country like India. In this study DEAHP model validates the outcomes of the AHP model.

This study has contributed important issues of supplier selection process:

- it points out the importance of the supplier selection problem;
- it provides key criteria for supplier selection 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; and
- it proposes a DEAHP based supplier selection model for an automobile industry.

7. Limitation and direction for future research

This paper should be viewed in the light of some limitations. As this analysis and findings are based on only one case study of an Indian automobile company, 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, for a single judgment matrix having n alternatives, DEA requires that n different linear programming problems are solved to arrive at the weights. Hence, when compared to EVM, DEA requires more computational efforts. Therefore, the DEAHP model is relatively more complex to apply, its application will be more appropriate for high-value components where stringent purchasing criteria are required. In contrast, AHP would remain to be an appropriate approach for relatively lower value components.

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.

Lastly, similar type of work may be extended in future by using an integrated use of fuzzy and AHP approaches as MCDM techniques for supplier selection and then comparing with DEAHP analysis.

References

Agarwal, P., Sahai, M., Mishra, V., Bag, M. and Singh, V. (2011), "A review of multi-criteria decision making techniques for supplier evaluation and selection", *International Journal of Industrial Engineering Computations*, Vol. 2 No. 4, pp. 801-810.

Ahamady, N., Azadi, M., Sadeghi, S.A.H. and Saen, R.F. (2013), "A novel fuzzy data envelopment analysis model with double frontiers for supplier selection", *International Journal of Logistic Research and Applications: A Leading Journal of Supply Chain Management*, Vol. 16 No. 2, pp. 87-98.

Aissaoui, N., Haouari, M. and Hassini, E. (2007), "Supplier selection and order lot sizing modeling: a review", *Computer & Operation Research*, Vol. 34 No. 12, pp. 3516-3540.

Bayazit, O. (2006), "Use of analytic network process in vendor selection decisions", *Benchmarking: An International Journal*, Vol. 13 No. 5, pp. 566-579.

Bititci, U., Ackermann, F., Ates, A., Davies, J.D., Garengo, P., *et al.* (2011), "Managerial processes: business process that sustain performance", *International Journal of Operation and Production Management*, Vol. 31 No. 8, pp. 851-887.

Bruno, G., Esposito, E., Genovese, A. and Passaro, R. (2012), "AHP-based approaches for supplier evaluation: problems and perspectives", *Journal of Purchasing & Supply Management*, Vol. 18 No. 3, pp. 159-172.

Cebi, F. and Bayraktar, D. (2003), "An integrated approach for supplier selection", *Logistics Information Management*, Vol. 16 No. 6, pp. 395-400.

Chan, F.T.S. and Chan, H.K. (2004), "Development of the supplier selection model – a case study in the advanced technology industry", *Proceedings of the Institution of Mechanical Engineers Part B – Journal of Engineering Manufacture*, Vol. 218 No. 12, pp. 1807-1824.

Chan, F.T.S. and Chan, H.K. (2010), "An AHP model for selection of suppliers in the fast changing fashion market", *International Journal of Advanced Manufacturing Technology*, Vol. 51 No. 4, pp. 1195-1207.

Chan, F.T.S. and Kumar, N. (2007), "Global supplier development considering risk factors using fuzzy extended AHP-based approach", *OMEGA – International Journal of Management Science*, Vol. 35 No. 4, pp. 417-431.

Chang, B., Chang, C. and Wu, C. (2011), "Fuzzy DEMATEL method for developing supplier selection criteria", *Expert Systems with Applications*, Vol. 38, pp. 1850-1858.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978), "Measuring the efficiency of decision making units", *European Journal of Operational Research*, Vol. 2 No. 6, pp. 429-444.

Chen, C.T., Lin, C.T. and Huang, S.F. (2006), "A fuzzy approach for supplier evaluation and selection in supply chain management", *International Journal of Production Economics*, Vol. 102 No. 2, pp. 289-301.

Deloitte (2010), "Global manufacturing competitiveness index", June, p. 15.

Dickson, G.W. (1966), "An analysis of vendor selection systems and decisions", *Journal of Purchasing*, Vol. 2 No. 1, pp. 5-17.

Dobler, D.W., Lee, L. and Burt, D.N. (1984), *Purchasing and Materials Management: Text Cases*, 4th ed., McGraw-Hill, NewYork, NY.

Dotoli, M. and Falagario, M. (2012), "A hierarchical model for optimal supplier selection in multiple sourcing contexts", *International Journal of Production Research*, Vol. 50 No. 11, pp. 2953-2967.

Eisenhardt, K.M. (1989), "Building theories from case study research", *Academy of Management Review*, Vol. 14 No. 4, pp. 532-550.

Florez-Lopez, R. (2007), "Strategic supplier selection in the added-value perspective: a CI approach", *Information Sciences*, Vol. 177 No. 5, pp. 1169-1179.

Forker, L.B. and Mendez, D. (2001), "An analytical method for benchmarking best peer suppliers", *International Journal of Operations and Production Management*, Vol. 21 Nos 1-2, pp. 195-209.

Garfamy, R.M. (2006), "A data envelopment analysis approach based on total cost of ownership for supplier selection", *Journal of Enterprise Information Management*, Vol. 19 No. 6, pp. 662-678.

Gencer, C. and Gurpinar, D. (2007), "Analytic network process in supplier selection: a case study in an electronic firm", *Applied Mathematical Modeling*, Vol. 31 No. 11, pp. 2475-2486.

Ghorbani, M., Arabzad, S.M. and Shahin, A. (2013), "A novel approach for supplier selection based on the Kano model and fuzzy MCDM", *International Journal of Production Research*, Vol. 51 No. 8, pp. 5469-5484.

Ho, W., Xu, X. and Dey, P.K. (2010), "Multi-criteria decision making approaches for supplier evaluation and selection: a literature review", *European Journal of Operational Research*, Vol. 202 No. 1, pp. 16-24.

Hong, G.H., Park, S.C., Jang, D.S. and Rho, H.M. (2005), "An effective supplier selection method for constructing a competitive supply-relationship", *Expert Systems with Applications*, Vol. 28 No. 4, pp. 629-639.

Hou, J. and Su, D. (2007), "EJB–MVC oriented supplier selection system for mass customization", *Journal of Manufacturing Technology Management*, Vol. 18 No. 1, pp. 54-71.

Inemek, A. and Tuna, O. (2009), "Global supplier selection strategies and implications for supplier performance: Turkish suppliers' perception", *International Journal of Logistics Research and Applications: A Leading Journal of Supply Chain Management*, Vol. 12 No. 5, pp. 381-406.

Jain, V., Wadhwa, S. and Deshmukh, S.G. (2009), "Select supplier-related issues in modelling a dynamic supply chain: potential, challenges and direction for future research", *International Journal of Production Research*, Vol. 47 No. 11, pp. 3013-3039.

Jiang, W. and Chan, F.T.S. (2011), "A new fuzzy dempster MCDM method and its application in supplier selection", *Expert Systems with Applications*, Vol. 38 No. 8, pp. 9854-9861.

Kahraman, C., Cebeci, U. and Ulukan, Z. (2003), "Multi-criteria supplier selection using fuzzy AHP", *Logistics Information Management*, Vol. 16 No. 6, pp. 382-394.

Kamann, D.-J.F. and Bakker, E.F. (2004), "Changing supplier selection and relationship practices: a contagion process", *Journal of Purchasing and Supply Management*, Vol. 10 No. 2, pp. 55-64.

Karpak, B., Kumcu, E. and Kasuganti, R.R. (2001), "Purchasing materials in the supply chain: managing a multi-objective task. *European Journal of Purchasing and Supply Management*, Vol. 7 No. 3, pp. 209-216.

Krajewski, L.J. and Ritzman, L.P. (1996), *Operations Management Strategy and Analysis*, Addison-Wesley Publishing Co, London.

Kull, T.J. and Talluri, S. (2008), "A supply-risk reduction model using integrated multicriteria decision making", *IEEE Transactions on Engineering Management*, Vol. 55 No. 3, pp. 409-419.

Kumar, J.and Roy, N. (2011), "Analytic hierarchy process (AHP) for a power transmission industry to vendor selection decisions", *International Journal of Computer Applications*, Vol. 12 No. 11, pp. 26-30.

Lin, C., Chow, W.S., Madu, C.N., Kuei, C.H. and Yu, P.P. (2005), "A structural equation model of supply chain quality management and organizational performance", *International Journal of Production Economics*, Vol. 96 No. 3, pp. 355-365.

Liu, J., Ding, F.Y. and Lall, V. (2000), "Using data envelopment analysis to compare suppliers for supplier selection and performance improvement", *Supply Chain Management: An International Journal*, Vol. 5 No. 3, pp. 143-150.

Mendoza, A., Santiago, E. and Ravindran, A.R. (2008), "A three-phase multicriteria method to the supplier selection problem", *International Journal of Industrial Engineering*, Vol. 15 No. 2, pp. 195-210.

Mummalaneni, V., Dubas, K. and Chao, C. (1996), "Chinese purchasing managers'preferences and trade-offs in supplier selection and performance evaluation", *Industrial Marketing Management*, Vol. 25 No. 2, pp. 115-124.

Muralidharan, C., Anantharaman, N. and Deshmukh, S.G. (2002), "A multi-criteria group decision-making model for supplier rating", *Journal of Supply Chain Management*, Vol. 38 No. 4, pp. 22-33.

Murray, J.Y., Kotabe, M. and Zhou, J.N. (2005), "Strategic alliance-based sourcing and market performance: evidence from foreign firms operating in China", *Journal of International Business Studies*, Vol. 36 No. 2, pp. 187-208.

Ng, W.L. (2008), "An efficient and simple model for multiple criteria supplier selection problem", *European Journal of Operational Research*, Vol. 186 No. 3, pp. 1059-1067.

Partovi, F.Y. (2013), "Selecting suppliers for a long-term relationship", *International Journal of Management Science and Engineering Management*, Vol. 8 No. 2, pp. 109-116.

Percin, S. (2006), "An application of the integrated AHP–PGP model in supplier selection", *Measuring Business Excellence*, Vol. 10 No. 4, pp. 34-49.

Ramanathan, R. (2006), "Data envelopment analysis for weight derivation and aggregation in the analytic hierarchy process", *Computer & Opererations Research*, Vol. 33 No. 5, pp. 1289-1307.

Ramanathan, R. (2007), "Supplier selection problem: Integrating DEA with the approaches of total cost of ownership and AHP", *Supply Chain Management: An International Journal*, Vol. 12 No. 4, pp. 258-261.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill Book Co., New York, NY.

Sarkis, J. and Talluri, S. (2002), "A model for strategic supplier selection", *Journal of Supply Chain Management*, Vol. 38 No. 1, pp. 18-28.

Sen, C.G., Sen, S. and Baslıgil, H. (2010), "Pre-selection of suppliers through an integrated fuzzy analytic hierarchy process and max-min methodology", *International Journal of Production Research*, Vol. 48 No. 6, pp. 1603-1625.

Sevkli, M. (2010), "An application of the fuzzy ELECTRE method for supplier selection", *International Journal of Production Research*, Vol. 48 No. 12, pp. 3393-3405.

Sevkli, M., Koh, S.C.L., Zaim, S., Demirbag, M. and Tatoglu, E. (2007), "An application of data envelopment analytic hierarchy process for supplier selection: a case study of BEKO in Turkey", *International Journal of Production Research*, Vol. 45 No. 9, pp. 1973-2003.

Seydel, J. (2006), "Data envelopment analysis for decision support", *Industrial Management and Data Systems*, Vol. 106 No. 1, pp. 81-95.

Singh, R.K. and Sharma, M.K. (2014), "Prioritising the alternatives for flexibility in supply chains", *Production Planning and Control*, Vol. 25 No. 2, pp. 179-192.

Songhori, M.J., Tavana, M., Azadeh, A. and Khakbaz, M.H. (2011), "A supplier selection and order allocation model with multiple transportation alternatives", *International Journal of Advanced Manufacturing Technology*, Vol. 52 Nos 1-4, pp. 365-376.

Svensson, G. (2004), "Supplier segmentation in the automotive industry: a dyadic approach of a managerial model", *International Journal of Physical Distribution & Logistics Management*, Vol. 34 Nos 1/2, pp. 12-38.

Taha, H.A. (2010), *Operations Research: An Introduction*, Prentice-Hall of India Pvt Ltd, New Delhi.

Talluri, S. (2002), "A buyer–seller game model for selection and negotiation of purchasing bids", *European Journal of Operational Research*, Vol. 143 No. 1, pp. 171-180.

Talluri, S. and Narasimhan, R. (2003), "Vendor evaluation with performance variability: a max min approach", *European Journal of Operational Research*, Vol. 146 No. 3, pp. 543-552.

Talluri, S. and Narasimhan, R. (2005), "A note on a methodology for supply base optimization", *IEEE Transactions on Engineering Management*, Vol. 52 No. 1, pp. 130-139.

Tas, A. (2012), "A Fuzzy AHP approach for selecting a global supplier in pharmaceutical industry", *African Journal of Business Management*, Vol. 6 No. 14, pp. 5073-5084.

Tempelmeier, H. (2002), "A simple heuristic for dynamic order sizing and supplier selection with time-varying data", *Production and Operations Management*, Vol. 11 No. 4, pp. 499-515.

Thomas, Y.C. and Janet, L.H. (1996), "An exploration of supplier selection practices across the supply chain", *Journal of Operations Management*, Vol. 14 No. 4, pp. 333-343.

Vonderembse, M.A. and Tracey, M. (1999), "The impact of supplier selection criteria and supplier involvement on manufacturing performance", *The Journal of Supply Chain Management: A Global Review of Purchasing and Supply*, Vol. 35 No. 3, pp. 33-39.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002), "Case research in operations management", *International Journal of Operations & Production Management*, Vol. 22 No. 2, pp. 195-219.

Weber, C.A., Current, J.R. and Benton, W.C. (1991), "Vendor selection criteria and methods", *European Journal of Operational Research*, Vol. 50 No. 1, pp. 2-18.

Wind, Y., Green, P. and Robinson, J.P. (1968), "The determinants of vendor selection: the evaluation function approach", *Journal of Purchasing*, Vol. 4 No. 3, pp. 29-42.

Wu, T. and Blackhurst, J. (2009), "Supplier evaluation and selection: an augmented DEA approach", *International Journal of Production Research*, Vol. 47 No. 16, pp. 4593-4608.

Wu, T., Shunk, D., Blackhurst, J. and Appalla, R. (2007), "AIDEA: a methodology for supplier evaluation and selection in a supplier-based manufacturing environment", *International Journal of Manufacturing Technology and Management*, Vol. 11 No. 2, pp. 174-192.

Yin, R. (1989). *Case Study Research: Design and Methods*, 2nd ed., Sage, Newbury Park, CA.

Zhang, X., Lee, C.K.M. and Chen, S. (2011), "Supplier evaluation and selection: a hybrid model based on DEAHP and ABC", *International Journal of Production Research*, Vol. 50 No. 7, pp. 1-13.

About the authors

Vinod Yadav has earned his Undergraduate Degree in Production & Industrial Engineering and a Postgraduate Degree in Industrial Management & Engineering from the Department of Production & Industrial Engineering, M.B.M. Engineering College, Faculty of Engineering & Architecture, J.N.V. University, Jodhpur, Rajasthan State, India. His research interest include multi-criteria decision making, supplier selection and supply chain management. His articles are accepted in *Benchmarking: An International Journal* and *Journal of Modelling in Management*.

Associate Professor Milind Kumar Sharma has taught many subjects related to Production & Industrial Engineering and Operations Management. Prior to joining the Department of Production & Industrial Engineering, M.B.M. Engineering College, J.N.V. University, Jodhpur in 1998, he has served in industry for four years. He has been awarded research projects under the SERC fast track scheme for young scientist by Department of Science & Technology (DST), Career Award for Young Teacher Scheme by the All India Council for Technical Education (AICTE) and University Grants Commission (UGC), New Delhi, India. His areas of research interests include management information system, performance measurement, supply chain management and small business development. He has published research papers in *Production Planning and Control*, *Computers & Industrial Engineering*, *International Journal of Productivity and Quality Management*, *Journal of Manufacturing Technology Management*, *International Journal of Globalization and Small Business*, *International Journal of Enterprise Network Management*, *Measuring Business Excellence*. Associate Professor Milind Kumar Sharma is the corresponding author and can be contacted at: milindksharma@rediffmail.com