

Suppliers' green performance evaluation using fuzzy extended ELECTRE approach

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Abstract In the present context of the globalized market, sustainable manufacturing has become a major concern for all organizations. The sustainable manufacturing system includes economic, environmental, and social sustainabilities. Green manufacturing enhances the environmental sustainability but, it also affects the economic and social sustainabilities. The compulsion to follow the environmental rules and regulation in any business activity has increased the awareness for the use of green products, recyclable materials for packaging, reduction of carbon emission, etc. Due to the involvement of extra costs in green manufacturing, some ignorance in the implementation of green practices may be observed. To ensure sustainable systems, selection of suppliers based on green performance measures is very important. This study evaluates the suppliers' performances based on Green Practices

as follows: environmental management and pollution control, cost, quality, and flexibility using the fuzzy-extended Elimination and Choice Expressing Reality approach. This approach helps the managers to incorporate the linguistic decision of the decision makers and convert it into quantitative scale. This method is used to eliminate and outrank the poor performers. As poor performers are outranked, this approach helps to select the most suitable green suppliers as per organization's requirement.

Keywords Green supply chain management · Sustainability · Supplier evaluation · Outranking · Fuzzy sets · ELECTRE

Introduction

In the recent past, climate change and its impacts on the society had been gaining momentum; and managing pollution-free environment is becoming very important in today's business scenario (Mangla et al. 2014). Therefore, business managers/practitioners are under immense pressure to lessen the harmful ecological and social impacts in their supply chains (Ağan et al. 2016). Sancha et al. (2015) established the relationship between institutional pressures and the sustainable supplier development in various locations. Mansi (2015) discussed sustainable disclosure practices in the purchasing activities of Indian government's public sector enterprises. Green manufacturing is concerned with the replacement of hazardous or nonrenewable inputs by less-hazardous materials or renewable materials, respectively; better control of operations at higher efficiency; equipment modification; technology change; and product modification for minimization of the waste and the emission. The compulsion of linking the green practices

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with corporate strategies has attracted the attention of researchers and practitioners toward sustainable manufacturing and green supply chain management (Gunasekaran and Gallea 2012; Brockhaus et al. 2013). For ensuring green manufacturing, effective management of green supply chain activities is very important.

The concepts of green supply chain management have been evolved through a number of stages—from its inception to empirical studies (Fu et al. 2012). Many terms in green supply chain are concerned with sustainable supply chain concepts (Bai and Sarkis 2010), such as supply chain environmental management (Sharfman et al. 2009); green logistics (Murphy and Poist 2000); closed-loop supply chain (Zhu and Sarkis 2006); sustainable supply network management (Cruz and Matsypura 2009); and green procurement (Gunther and Scheibe 2006). Reverse logistics consists of a collection of discarded products, inspection, sorting, and recovery activities like recycling, remanufacturing, reuse, disposal, etc. (Govindan et al. 2015).

Amindoust et al. (2012) used fuzzy inference systems for sustainable supplier selection. They divided the selection criteria into three classes: economic, environmental, and social sustainabilities. For economic sustainability, they considered profit, quality, delivery and services as the subcriteria. For environmental sustainability, they considered environmental management systems and environmental competencies as the subcriteria. Similarly, for social sustainability, they considered the rights of stakeholders, work safety, and labor health as the subcriteria.

Büyükoçkan and Ciftci (2012) observed that most of the adverse effects of the product on the environment can be eliminated during the design phase of the product development. According to Eltayeb et al. (2011), eco-friendly design (known as ecodesign) process consists of design for reduction of environmentally hazardous substances, design for reuse of a product, design for recycling waste material, and design for remanufacturing. Green purchasing covers the area of waste reduction, environmental material substitution, minimization of hazardous material, etc. Hence, companies have to take care of suppliers' environmental performance and ensure that purchased materials are environmentally friendly for cleaner production (Lin 2013).

The World Business Council for Sustainable Development (WBCSD) and the World Resources Institute in 2009 have observed that at least 80 % of carbon emissions were produced through supply chains (Hsu et al. 2013). Witneben and Kiyar (2009) emphasized on the importance that the supplier declare the exact figure of greenhouse gas emissions and that of the objective to reduce their carbon emissions. Hsu et al. (2013) summarized the main attributes for green supplier selection in carbon management.

Supplier environmental collaboration covers activities that enhance supplier's environmental performance related to joint planning, shared knowledge, green product development, and innovations (Eltayeb et al. 2011). Environmental collaboration helps companies to assure that the purchased materials are environment-friendly and produced using green processes (Zhu and Sarkis 2007).

Environmental management systems (EMS) should include policies, procedures, and audit procedures to evaluate the environmental impact of an organization's operations. One of the most popular EMS is the International Organization for Standardization (ISO) 14000 series (Nawrocka et al. 2009). ISO 14001 directs all supply chain partners to select more environmentally friendly practices. It develops a systematic approach to reduce the negative environmental effects of organizations, decreases resource consumption and waste, and contributes to quality improvement (Eltayeb et al. 2011; Xu and Shen 2014).

This paper consists of four sections. The first section introduces the green supply chain management; the second section outlines the literature on the attributes for evaluation of supplier's green performance; the third section deals with the proposed methodology; the fourth section illustrates this approach with a case study, i.e., green supplier selection; and the fifth section concludes the research work.

Literature review

The green approach toward supply chain management ensures green manufacturing for sustainable performance. The operative GSCM (Green Supply Chain Management) performance leads to the decline of the solid/liquid wastes, reduction in emission levels, the use of hazardous and toxic materials, and improvement in the health-related concerns of employees and the community (Eltayeb et al. 2011). As suppliers can contribute significantly to ensuring a supply chain green, the environmental aspect of green supplier selection has gained more importance nowadays.

Supplier selection criteria and methodologies

In earlier research works, cost (Awasthi et al. 2010), delivery (Kuo et al. 2010), quality (Shaik and Abdul-Kader 2011), service (Buyukozkan 2012), strategic alliance (Awasthi et al. 2010), pollution control (Lee et al. 2009), green product (Awasthi et al. 2010), and environmental management (Kuo et al. 2010) are considered as the main factors in the green supplier selection.

It has been observed that a number of criteria have been used by the researchers to evaluate the suppliers. Some of the environmental factors are considered with other factors, such as cost, quality, reliability, flexibility, etc., of the

suppliers for performance measurement of suppliers or their selection. No reference has been found, which had used environmental factors in isolation for supplier selection. Thus, the review analysis shows that nowadays buyers are environmentally conscious in purchasing the goods/services, but other factors are equally important for them. In those references, no supplier is outranked, and all suppliers are considered for quota allocation as per their ranking and capacity constraints. Liu and Zhang (2011) used Elimination and Choice Expressing Reality (ELECTRE III) as an outranking method for supplier selection, but they have not considered the environmental factor at all in this process. However, they have used 19 criteria for supplier selection. Sevkli (2010) used fuzzy ELECTRE for supplier selection, but without giving any consideration to environmental factors. Tsui et al. (2015) used PROMETHEE for performance measurement of green suppliers in TFT-LCD industry and considered the environment and green management as factors with other factors for performance evaluation. Kuo et al. (2015) used DANP and VIKOR techniques to prioritize the 17 criteria and rank the suppliers. They have considered many environment-related criteria for supplier evaluation, and some criteria are related to management systems.

To incorporate all subcriteria individually in the analysis of supplier selection may be very complex; therefore, there is the need to show the overall impact of these subfactors in a broader perspective. For example, if cost is considered as one of the criteria for supplier selection, then it means that the different types of costs related to material processing, manufacturing, testing and inspection, packaging, transportation, etc. form parts of the main cost criteria. Similarly, in this paper, a total of 38 subfactors have been considered in supplier rating. These subfactors are grouped into six main clusters such as cost, quality, flexibility, service, green practices, environmental management, and pollution control, as shown in Fig. 1.

Cost

Cost components related to suppliers are purchasing, transportation, inventory, operation, maintenance, energy, inspection, delivery, security, ordering, holding, etc. (Ghodsypour and O'Brien 2001). There are some limitations of this process because all the performances should be measured in the same unit and there is complexity in developing a cost-accounting system (Petroni and Braglia 2000). Transportation cost is an important component of the logistics costs. It includes the cost of fuel or lubricants, penalties, driver salaries, maintenance costs, failure of the vehicle (Ongkunaruk and Piyakarn 2011). At the micro-level a number of cost components are there; it is very difficult to consider all the components at a time for

supplier selection. Therefore, only the macrolevels of the cost components are highlighted in the decision-making problem.

Quality

It deals with quality control and assurance. Quality assurance deals with the fulfillment of customer demands with optimal utilization of resources and to coincide with the firm's policy (Manning et al. 2006). "Business Process Reengineering (BPR)" and "Total Quality Management (TQM)" are two basic components of process organization, control, and improvement. There are many performance attributes such as certifications and awards that have been applied by the companies to benchmark the performance. ISO 9000, ISO 14000, EN 29000, and BS 5750 are some of the performance certifications and Quality improvement awards (Kardaras and Mentzas 1997).

Service

Nowadays, companies are able to provide products of a high quality, but high responsiveness, stock management, design capability, and low price, are some crucial issues in the improvement of service level to the customer. Suppliers play a crucial role in the supply chain; they provide a number of services such as assurance of fast deliveries, quick response, logistics Service, vendor managed inventory (VMI), and product design including components. Firms can improve their logistics performance through fast deliveries, quick response, low stocks, no damage, low costs, high productivity, fewer mistakes, minimum wastage, the high morale of staff, and so on. In order to meet customer's specific and rapidly changing needs, a firm is required to be more responsive (Gunasekaran et al. 2008). The success of order-fulfillment solutions depends on the integration of order-fulfillment planning, product execution, distribution management, and cross-application integration.

Flexibility

Flexibility is an important part of the supply chain to meet the changing business requirements. Kumar et al. (2008) discussed the various types of flexibility and relationship among the variables of flexibility for global supply chain. Flexibility includes the ability to change the systems as per the requirement of the buyer. In this paper, the authors have incorporated different attributes of the flexibility for the supplier rating, which are technological change, material change, equipment upgradation, process improvement, volume flexibility, and design flexibility to reduce the use of hazardous materials, to minimize the consumption of

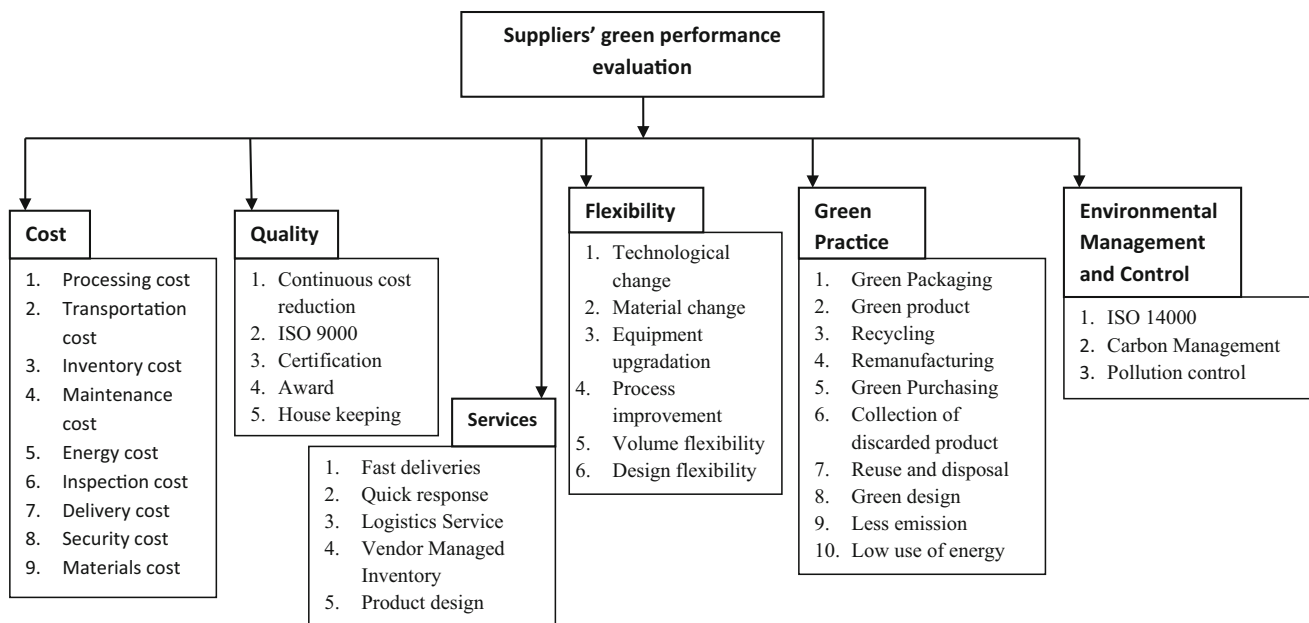


Fig. 1 A framework for Supplier performance evaluation for cleaner production

energy, and to control the pollution and wastes during the usage of the products.

Green practice

Green practice is a very broad term and covers a number of activities of green supply chain, such as green purchasing, green packaging of the product, green product, recycling of wastes and end products, remanufacturing, collection of discarded product, reuse and disposal, green design, less emission, and low use of energy. In the recent years, a “green” competency between vendors and suppliers has increased the value of the company in the market. Green packaging aims to use environmentally friendly packaging material to protect the environment. Its main characteristic is to get dissolved or degraded in nature rapidly without harming the environment. Green packaging can be explained in terms of 4R1D (reduce, reuse, reclaim, recycle, degradable) (Zhang and Zhao 2012). Another important green practice is *recycling*. It is a process in which the used product is reduced to its raw materials and new and different products are generated from them. Recycling can be implemented if the scrapped product could not be reused again. Recycling needs a few processes, such as extraction, separating, etc., which require energy and harm the environment (Zhang and Zhao 2012). *Reuse* of a product is the extension of its life at the end with little or no treatment. Reuse can also be explained utilizing the material for a second or further time. There is no addition of any new value to the product. It is the process of getting a green product (Ke et al. 2011). *Remanufacturing* is also

considered an important green practice. It is a process of restoring a large quantity of the products to a new state. Damaged components are repaired, but it does not ensure attaining the same performance level as the original product. The manufacturers can add some values or features to the product. It can be seen similar to the recycling, but it differs from it. Recycling is concerned with the raw materials, but remanufacturing is concerned with the original function (Zhang and Zhao 2012).

Environmental management and pollution control

Recently, the environmental obligation has been added to the procurement processes. Due to the high stress on Environmental Management Systems (EMS) and the increasing awareness of the negative impacts of productions to the environment, buyers have started to evaluate the green performance of suppliers. It influences the decision-making process, and many buyers expect from their supplier for applying EMS (Handfield et al. 2002). Ozone-depleting chemicals (ODCs) such as CFC (chlorofluorocarbon) and NO_x are the human-made chemical compounds which are responsible for the depletion of the ozone layer (Ravishankara et al. 2009). International Organization for Standardization (ISO 14001) is an institution for producing guidelines to provide certification to the firm based on “environmental aspects.” All policies, regulations, goals, and targets are reassessed and reevaluated for the continuous improvement (Bansal and Bogner 2002). Supplier’s attitude toward the pollution control is very important for the buyer to work together. With the growing production rate, energy

consumption grows rapidly, and the pollution is the byproduct of energy use. Therefore, pollution-control programs that imply a proper usage of energy consumption are propagated (Yanqing and Mingsheng 2012).

Shaw et al. (2012) have used fuzzy Analytic Hierarchy Process (FAHP) and multiobjective goal programming for supplier selection and quota allocation. They laid emphasis on the development of low-carbon supply chain. For supplier selection, they gave the importance to greenhouse gas emission with some of the other criteria, such as cost, quality, lead time, and demand. The quota allocation among the shortlisted suppliers is based on four objective functions: the minimization of total purchasing cost, minimization of rejection due to quality problem, minimization of late delivery, and minimization of carbon footprints.

Chaharsooghi and Ashrafi (2014) used a risk-management system, transparently, and culture and strategy in addition to economic, environmental, and social sustainabilities as the criteria for sustainable supplier evaluation and selection. They used neofuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) as the methodology for supplier selection. Deviating from simple fuzzy TOPSIS, they inserted two absolute conditions (Bad and Good) in the decision-making matrix in neofuzzy TOPSIS methodology. Neofuzzy TOPSIS compares the candidates (suppliers) with these two standards, so the distance between candidates becomes real.

It has been observed that the environmental sustainability strongly influences the economic and social sustainabilities in terms of cost- and health-related issues. Most of the researchers have talked about the environmental sustainability with economic and social sustainabilities and some other factors for supplier selection. The uniqueness of this paper is that the authors have given weights to the green practices and environmental management systems and control with some other conventional factors, such as cost, quality, flexibility, services, etc. for supplier evaluation.

Research methodology

For the ranking of suppliers for green supply chain, the Fuzzy ELECTRE approach has been applied in this paper. A number of variants of ELECTRE method have been in use for the decision-making process. In this paper, the concept of decision making with the help of fuzzy ELECTRE has been taken from the research work of Hatami-Marbini et al. (2013). Basic steps of this approach will be described in this section.

Definition 1 Let X be a universe set. The fuzzy set \tilde{A} is defined by a membership function, $\mu_{\tilde{A}}(x) = [0, 1]$, where $\mu_{\tilde{A}}(x), \forall x \in X$, indicates the degree of membership of \tilde{A} to X (Zadeh 1965).

Definition 2 A triangular fuzzy number \tilde{A} is defined as (a^l, a^v, a^u) , $a^l \leq a^v \leq a^u$. The membership function $\mu_{\tilde{A}}(x)$ is defined as (Zimmerman 1991; Kahraman et al. 2004)

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & x \leq a^l \\ \frac{x - a^l}{a^v - a^l}, & a^l < x < a^v \\ \frac{a^u - x}{a^u - a^v}, & a^v < x < a^u \\ 0, & x \geq a^u \end{cases} \quad (1)$$

Definition 3 The mathematical operations of TFN (Triangular Fuzzy Number) can be done using the following equations (Chen 2014):

$$\tilde{A} + \tilde{B} = (a^l + b^l, a^v + b^v, a^u + b^u)$$

$$\tilde{A} - \tilde{B} = (a^l - b^l, a^v - b^v, a^u - b^u)$$

$$\tilde{A}/\tilde{B} = (a^l/b^u, a^v/b^v, a^u/b^l)$$

$$\tilde{A} \otimes \tilde{B} = (a^l \times b^l, a^v \times b^v, a^u \times b^u)$$

$$\text{Reciprocal of } \tilde{A} = (1/a^u, 1/a^v, 1/a^l).$$

Definition 4 Hamming distance between two fuzzy numbers (\tilde{A}, \tilde{B}) is defined as (Hamming 1950)

$$\int_R |\mu_{\tilde{A}}(x) - \mu_{\tilde{B}}(x)| \quad (2)$$

where R is the set of real numbers.

However, for simplicity in calculation, the distance between two fuzzy numbers (Chen 2000; Li and Yang 2004), especially in ELECTRE method can be represented by

$$d(\tilde{A}, \tilde{B}) = \sqrt{\sum_{k=1}^3 (A_k - B_k)^2}. \quad (3)$$

Definition 5 Standard intersection, $A \cap B$ and standard union, $A \cup B$ of two fuzzy sets, \tilde{A} and \tilde{B} are defined as $(\tilde{A} \cap \tilde{B})(x) = \min[\tilde{A}(x), \tilde{B}(x)]$ and $(\tilde{A} \cup \tilde{B})(x) = \max[\tilde{A}(x), \tilde{B}(x)]$ respectively.

Definition 6 Comparison of fuzzy numbers on the basis of outranking

The outranking relations in ELECTRE are shown as S, which means ‘‘at least as good as.’’ Considering two alternatives A_f and A_g , four situations may arise (Hatami-Marbini and Tavana 2011):

- $A_f S A_g$ and not $A_g S A_f$ (A_f is strictly preferred to A_g),
- $A_g S A_f$ and not $A_f S A_g$ (A_g is strictly preferred to A_f),
- $A_f S A_g$ and $A_g S A_f$ (A_f is indifferent to A_g)
- Not $A_f S A_g$ and not $A_g S A_f$ (A_f is incomparable to A_g).

Fuzzy ELECTRE

Fuzzy ELECTRE is a process of multicriteria decision making. In this process, poor performers are outranked, and only comparable performers are ranked. This outranking is based on the concordance and discordance values. Fuzzy sets are used to incorporate the linguistic variables or vague state of mind of the decision-makers. The major steps of the fuzzy TOPSIS are discussed as follows (Pl refer Appendix 1 for framework):

Step 1: Preparation of fuzzy decision matrix

To prepare a fuzzy decision matrix of ‘m’ alternatives and ‘n’ attributes, first, the fuzzy importance of the attributes is determined. The decision makers are given different weightages on the basis of their respective experiences and levels in organization hierarchy, e.g., the first, second, and third decision makers among the three levels are assigned with the weights of 40, 35, and 25 % respectively.

After deciding the weights for the decision makers, the fuzzy importance(s) of attributes is(are) decided by a weighted average of the ratings of attributes by the decision makers using the following formula:

$$\tilde{w}_j = \frac{1}{K} \left(\sum_{k=1}^3 \tilde{w}_{jk} \right), \tag{4}$$

where $k = 1, 2, \dots, K$ is the number of decision makers; $j = 1, 2, \dots, n$ is the number of attributes; and \tilde{W}_{jk} is the importance of j th attributes assigned by k th decision makers.

After deciding the importance(s) of the various attributes, various alternatives are rated against each attribute

by all the K decision makers, and the final fuzzy rating of alternatives is determined by weighted average using the following formula:

$$\tilde{x}_{ij} = \frac{1}{K} \left(\sum_{k=1}^3 \tilde{x}_{ijk} \right), \tag{5}$$

where $k = 1, 2, \dots, K$ is the number of decision makers; $i = 1, 2, \dots, m$ is the number of alternatives; $j = 1, 2, \dots, n$ is the number of attributes; and \tilde{x}_{ijk} is the rating of i th alternative against the j th attributes by the k th decision maker.

The decision matrix can be represented as

$$\tilde{U} = \begin{matrix} & \tilde{W}_1 & \tilde{W}_2 & \dots & \tilde{W}_n \\ \begin{matrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{matrix} \end{matrix} \tag{6}$$

Step 2: Preparation of normalized decision matrix

Linear-scale normalization is applied to ensure that all values of the elements in the decision matrix have homogeneous and comparable units. Moreover, this transformation guarantees that every triangular fuzzy number belongs to $[0, 1]$ which reduces the complexity in the mathematical operations. The normalized fuzzy decision matrix is shown below:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n}. \tag{7}$$

$$\tilde{r}_{ij} = \left(r_{ij}^l, r_{ij}^v, r_{ij}^u \right) = \left(\frac{x_{ij}^l}{c_j^*}, \frac{x_{ij}^v}{c_j^*}, \frac{x_{ij}^u}{c_j^*} \right) \tag{8}$$

$$c_j^* = \max_i (x_{ij}^u), j \in B,$$

where B is the set of benefit attributes; $i = 1, 2, \dots, m$; and $j = 1, 2, \dots, n$.

$$\tilde{r}_{ij} = \left(r_{ij}^l, r_{ij}^v, r_{ij}^u \right) = \left(\frac{a_j^-}{x_{ij}^u}, \frac{a_j^-}{x_{ij}^v}, \frac{a_j^-}{x_{ij}^l} \right) \tag{9}$$

$$a_j^- = \min_i (x_{ij}^l), j \in C,$$

where C is the set of cost attributes; $i = 1, 2, \dots, m$; and $j = 1, 2, \dots, n$.

Step 3: Computing the weighted normalized matrix

Multiply the standard rating of the alternatives with the importance of corresponding attributes to compute the weighted normalized matrix using the following formula:

$$\tilde{v}_{ij} = (\tilde{r}_{ij}) \times (\tilde{w}_j) = \left(r_{ij}^l, r_{ij}^v, r_{ij}^u \right) \times \left(w_j^l, w_j^v, w_j^u \right). \tag{10}$$

Step 4: Calculating the distance between any two alternatives

The concordance and discordance matrices are prepared using the weighted normalized fuzzy decision matrix and pairwise comparison of the alternatives. Considering two alternatives A_x and A_y , the concordance set is formed as $J^C = \{J | \tilde{v}_{xj} \geq \tilde{v}_{yj}\}$ where J^C is the concordance coalition of the attributes and the assertion is A_xSA_y . The discordance set is defined as $J^D = \{J | \tilde{v}_{xj} \leq \tilde{v}_{yj}\}$ where J^D is the discordance coalition, and it is against the assertion, A_xSA_y . Note that S is the outranking relation, and A_xSA_y means that ‘ A_x is at least as good as A_y .’

In order to compare any two alternatives A_x and A_y , with respect to each attribute, and to define the concordance and discordance sets, we specify the least upper bound of the alternatives, $\max(\tilde{v}_{xj}, \tilde{v}_{yj})$, and then, the distance is used with the following assumptions:

$$\tilde{v}_{xj} \geq \tilde{v}_{yj} \Leftrightarrow d(\max(\tilde{v}_{xj}, \tilde{v}_{yj}), \tilde{v}_{yj}) \geq d(\max(\tilde{v}_{xj}, \tilde{v}_{yj}), \tilde{v}_{xj}), \text{ and} \tag{11}$$

$$\tilde{v}_{xj} \leq \tilde{v}_{yj} \Leftrightarrow d(\max(\tilde{v}_{xj}, \tilde{v}_{yj}), \tilde{v}_{yj}) \leq d(\max(\tilde{v}_{xj}, \tilde{v}_{yj}), \tilde{v}_{xj}). \tag{12}$$

Step 5: Constructing the concordance and discordance sets, and concordance and discordance matrices

The concordance set is the set of attributes for which $\tilde{v}_{xj} \geq \tilde{v}_{yj}$ and the discordance set is the set of the attributes for which $\tilde{v}_{xj} \leq \tilde{v}_{yj}$. The following concordance matrix is formed in which the elements are the fuzzy summation of the fuzzy importance weights for all the attributes in the concordance set.

$$\tilde{C} = \begin{bmatrix} \tilde{c}_{11} & \dots & \tilde{c}_{1x} & \dots & \tilde{c}_{1(m-1)} & \tilde{c}_{1m} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \tilde{c}_{x1} & \dots & \dots & \dots & \tilde{c}_{x(m-1)} & \tilde{c}_{xm} \\ \dots & \dots & \dots & \tilde{c}_{xy} & \dots & \dots \\ \tilde{c}_{(m-1)1} & \dots & \tilde{c}_{(m-1)y} & \dots & \dots & \dots \\ \tilde{c}_{m1} & \dots & \dots & \dots & \tilde{c}_{m(m-1)} & \tilde{c}_{mm} \end{bmatrix}, \tag{13}$$

where $\tilde{c}_{xy} = (c_{xy}^l, c_{xy}^g, c_{xy}^u) = \left(\sum_{J \in J^C} w_j^l, \sum_{J \in J^C} w_j^g, \sum_{J \in J^C} w_j^u \right)$.

Now, we determine the concordance level as

$$\tilde{c} = \sum_{x=1}^m \sum_{y=1}^{(m-1)} \frac{\tilde{c}_{xy}}{m(m-1)}. \tag{14}$$

The discordance matrix is prepared as

$$\tilde{D} = \begin{bmatrix} \tilde{d}_{11} & \dots & \tilde{d}_{1x} & \dots & \tilde{d}_{1(m-1)} & \tilde{d}_{1m} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \tilde{d}_{x1} & \dots & \dots & \dots & \tilde{d}_{x(m-1)} & \tilde{d}_{xm} \\ \dots & \dots & \dots & \tilde{d}_{xy} & \dots & \dots \\ \tilde{d}_{(m-1)1} & \dots & \tilde{d}_{(m-1)y} & \dots & \dots & \dots \\ \tilde{d}_{m1} & \dots & \dots & \dots & \tilde{d}_{m(m-1)} & \tilde{d}_{mm} \end{bmatrix}, \tag{15}$$

where

$$d_{xy} = \frac{\max_{j \in J^D} |\tilde{v}_{xj} - \tilde{v}_{yj}|}{\max_j |\tilde{v}_{xj} - \tilde{v}_{yj}|} = \frac{\max_{j \in J^D} |d(\max(\tilde{v}_{xj}, \tilde{v}_{yj}), \tilde{v}_{xj})|}{\max_j |d(\max(\tilde{v}_{xj}, \tilde{v}_{yj}), \tilde{v}_{yj})|}. \tag{16}$$

Now, we determine the disconcordance level as

$$\bar{d} = \sum_{x=1}^m \sum_{y=1}^{(m-1)} \frac{d_{xy}}{m(m-1)}. \tag{17}$$

Step 6: Preparing the Boolean matrices E and F for the concordance and discordance matrices

$$E = \begin{bmatrix} e_{11} & \dots & e_{1x} & \dots & e_{1(m-1)} & e_{1m} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ e_{x1} & \dots & \dots & \dots & e_{x(m-1)} & e_{xm} \\ \dots & \dots & \dots & e_{xy} & \dots & \dots \\ e_{(m-1)1} & \dots & e_{(m-1)y} & \dots & \dots & \dots \\ e_{m1} & \dots & \dots & \dots & e_{m(m-1)} & e_{mm} \end{bmatrix}, \tag{18}$$

where

$$\begin{cases} \tilde{c}_{xy} \geq \tilde{c} \Leftrightarrow e_{xy} = 1 \\ \tilde{c}_{xy} \leq \tilde{c} \Leftrightarrow e_{xy} = 0 \end{cases}$$

$$F = \begin{bmatrix} f_{11} & \dots & f_{1x} & \dots & f_{1(m-1)} & f_{1m} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ f_{x1} & \dots & \dots & \dots & f_{x(m-1)} & f_{xm} \\ \dots & \dots & \dots & f_{xy} & \dots & \dots \\ f_{(m-1)1} & \dots & f_{(m-1)y} & \dots & \dots & \dots \\ f_{m1} & \dots & \dots & \dots & f_{m(m-1)} & f_{mm} \end{bmatrix}, \tag{19}$$

where

$$\begin{cases} d_{xy} \geq \bar{d} \Leftrightarrow d_{xy} = 0 \\ d_{xy} \leq \bar{d} \Leftrightarrow d_{xy} = 1 \end{cases}$$

Step 7: Preparing the final matrix

A final matrix G is prepared by peer-to-peer multiplication of the elements of the matrices, E and F, which can be represented as

$$G = E \otimes F. \tag{20}$$

Step 8: Constructing a decision graph and ranking the alternatives

A decision graph is drawn using the final matrix G in order to determine the ranking order of the alternatives. Let A_x and A_y be two alternatives. There is an arc between the two alternatives from A_x to A_y if alternative A_x outranks A_y ; there is no arc between the two alternatives if alternatives A_x and A_y are incomparable; and there are two arcs between the two alternatives in both directions if these alternatives are not different.

Case illustration

In an automotive supply chain, supplier plays an important role, and the success of the supply chain depends on the performance of the supplier. Only a few parts of the automobile are of strategic importance and produced in-house. Most of the components are outsourced, and the buyer depends on his supplier for those components. Therefore, the buyer develops a strategic relationship with the supplier. Some of the autocomponents are supplied in the integrated form to the OEM or assembler. These components may be supplied by the tier-1 or tier-2 suppliers. A detailed structure of a typical automotive supply chain is shown in Fig. 2. It has been observed that many components, such as tires, tubes, and electric, and electronic parts are directly supplied or supplied from the regional distributors to the assembler.

In this research, about twenty autocomponent suppliers were considered for green performance evaluation at the initial stage, but finally, eight suppliers were shortlisted on the basis of their market shares. These suppliers are supplying the autocomponents to the world's leading car manufacturers in India and abroad. All the suppliers are certified by the ISO certification and awarded with different quality awards. Some suppliers are more concerned with the environment and pollution. However, most of the suppliers in developing countries have a lack of awareness and show ignorant behavior toward the green product, carbon footprint, and the emission control. This ignorance may be due to lack of infrastructure, intention to provide the products at low cost to meet the competition, no strict control of the government over the implementation of environmental management systems, etc. In the developed nation, implementation of the environmental rules and regulation is more strict in comparison with developing nation due to the availabilities of infrastructure and technology, awareness among the buyers and suppliers related to environmental rules and regulations, strict control of the government over the implementation of the green practices

in manufacturing, mandatory nature of ISO 14000 certification, social health awareness, etc.

Therefore, to know the suppliers' efforts toward the green supply chain management, a framework has been proposed to evaluate the suppliers' green performance. To gather the exact information about the suppliers, all the three levels of management of a buyer company were consulted for their opinion. The decision maker from the top-level management is given the highest weightage (40 %), from middle-level management is given the moderate weightage (35 %), and from lower-level management is given less weightage (25 %). On the basis of these decision makers, total six groups of attributes were short-listed to rate the suppliers. These attributes are cost, quality, services, flexibility, green practice, environmental management, and pollution control. The importance of these attributes is based on the weighted average of the ratings of the decision makers. Table 1 shows the linguistic and the fuzzy quantitative scales that are used in this paper. In this table, the first column shows the linguistic scale for the importance ratings of the criteria; the second column shows the linguistic scale for the performance ratings of the alternatives with respect to the various criteria, and the last column shows the fuzzy quantitative scale for the corresponding linguistic scale. Since the linguistic scale cannot be directly used in mathematical operations, it is converted to fuzzy quantitative scale.

The final weights of the attributes for supplier evaluation are calculated using a weighted average of the opinion given by the decision makers: for example, the first decision maker, second decision maker, and the third decision maker rate the importance of the attributes 'cost' as very high, high, and very high, respectively. The weighted average of the importance of cost can be calculated using Eq. (4). The importance ratings of the attributes by these three decision makers and their weighted averages are shown in Table 2.

After finding the weighted average of the importance of all the attributes, suppliers are evaluated by these decision makers against all the attributes on a linguistic scale as shown in Table 1. The ratings of suppliers by all the three decision makers against the various attributes are shown in Table 3.

Then the weighted average of the ratings of the suppliers for all the decision makers is calculated using Eq. (5). The fuzzy decision matrix is prepared using the weighted average of ratings of suppliers against the various attributes. The elements of the fuzzy decision matrix are normalized using Eqs. (8) and (9) to represent the elements on a uniform scale, i.e., on the scale between 0 and 1. Equation (8) is used for the benefit attributes, and Eq. (9) is used for the cost Attributes.

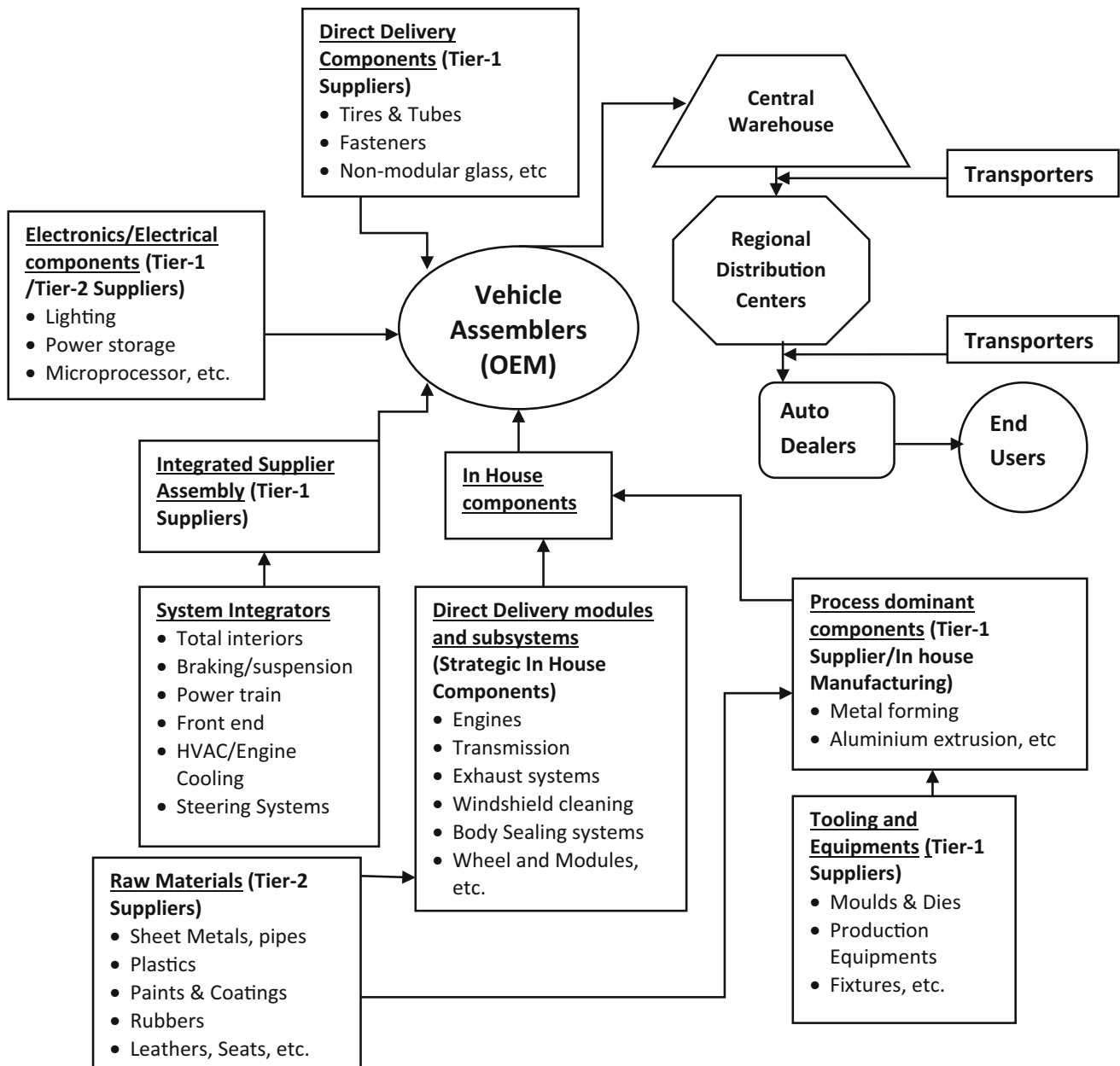


Fig. 2 A structure of automotive supply chain

Table 1 Linguistic and Fuzzy quantitative scales for importance ratings of criteria and performance ratings of alternatives

Linguistic Scale for the importance of criteria	Linguistic scale for the rating of alternatives	Fuzzy quantitative scale
Very low (VL)	Poor (P)	(1, 1, 3)
Low (L)	Satisfactory (S)	(1, 3, 5)
Medium (M)	Good (G)	(3, 5, 7)
High (H)	Very good (VG)	(5, 7, 9)
Very high (VH)	Excellent (EX)	(7, 9, 9)

Table 2 Importance ratings of Attributes by three decision makers

Attributes	Decision Makers			Fuzzy weight
	D1 (0.4)	D2 (0.35)	D3 (0.25)	
C1 (cost)	VH	H	VH	(2.10, 2.77, 3.00)
C2 (quality)	VH	VH	VH	(2.33, 3.00, 3.00)
C3 (services)	H	H	VH	(1.67, 2.33, 3.00)
C4 (flexibility)	VH	VH	H	(2.17, 2.83, 3.00)
C5 (green practice)	M	M	L	(0.83, 1.50, 2.17)
C6 (environmental management and pollution control)	M	M	H	(1.17, 1.83, 2.50)

Table 3 Ratings of suppliers by three decision makers against the various attributes

Attributes	Decision Makers (weight)	Alternatives							
		A1	A2	A3	A4	A5	A6	A7	A8
C1	D1 (0.4)	H	M	L	H	VL	M	M	H
	D2 (0.35)	H	M	L	M	VL	L	H	M
	D3 (0.25)	M	H	M	M	M	M	H	H
C2	D1 (0.4)	G	EX	G	VG	Ex	G	VG	G
	D2 (0.35)	G	VG	G	VG	EX	G	VG	VG
	D3 (0.25)	VG	VG	VG	G	VG	VG	EX	VG
C3	D1 (0.4)	VG	VG	VG	VG	Ex	VG	VG	VG
	D2 (0.35)	G	G	VG	VG	VG	VG	G	G
	D3 (0.25)	G	G	G	VG	VG	G	VG	G
C4	D1 (0.4)	S	G	VG	G	VG	EX	G	G
	D2 (0.35)	S	VG	G	VG	G	VG	VG	VG
	D3 (0.25)	G	VG	G	VG	G	VG	VG	G
C5	D1 (0.4)	G	VG	S	VG	G	G	VG	VG
	D2 (0.35)	VG	VG	S	VG	VG	G	EX	VG
	D3 (0.25)	G	G	S	EX	VG	S	G	G
C6	D1 (0.4)	G	VG	S	VG	VG	S	VG	VG
	D2 (0.35)	G	VG	S	VG	G	S	VG	G
	D3 (0.25)	S	VG	G	VG	G	G	EX	G

After the preparation of fuzzy normalized matrix, the elements of the fuzzy normalized matrix are multiplied by the weights of corresponding attributes using the Eq. (10). Thus, the weighted normalized matrix is prepared.

From the weighted normalized matrix, the distance between two alternatives such as \tilde{v}_{A1C1} and \tilde{v}_{A2C1} for an attribute C_1 , is calculated using Eq. (3). Similarly, distance matrices of all the alternatives for each attribute are prepared using Eqs. (11) and (12).

Now concordance sets of the attributes are prepared for all the attributes based on the distance matrix. The j th attributes will be the elements of the respective concordance sets of attributes, x and y , if $\tilde{v}_{xj} \geq \tilde{v}_{yj}$. A concordance matrix is prepared based on the weights of the attributes of the concordance set. For example, the concordance set between the alternatives A1 and A3 is represented as {2, 5,

6}. The elements for A1 and A3 in the concordance matrix will be the fuzzy sum of the importance weights of attributes 2, 5, and 6.

Now discordance matrix is also prepared from the distance matrix. Considering two alternatives, i.e., suppliers A_x and A_y , the j th attribute is placed in the discordance set assuming that $A_x S A_y$, where S is the outranking relation, if and only if A_x is preferred to A_y . In the fuzzy environment, the discordance set is formed as $J^D = \{J | \tilde{v}_{xj} \leq \tilde{v}_{yj}\}$ where J^D is the discordance coalition of the attributes. The discordance matrix is constructed using Eq. (16).

For example, let us consider Suppliers, A1 and A2. In the evaluations of A1 and A2, the distances in terms of each attribute are (0.21, 0), (1.09, 0), (0, 0), (1.39, 0), (0.24, 0), and (0.92, 0), respectively, in the distance matrix, and the all the pair values satisfy the definition of the

discordance set. Therefore, the discordance set includes all the pairs and the corresponding discordance levels by means of Eq. (16) as follows:

$$\frac{\max\{|0 - 1.39|\}}{\max\{|0 - 0.21|, |0 - 1.09|, |0 - 0|, |0 - 1.39|, |0 - 0.24|, |0 - 0.92|\}} = 1.$$

After preparing the concordance and discordance matrices, we prepare the Boolean matrices E and F for the both concordance and discordance matrices, respectively. The values of \tilde{C} are calculated as (5.62, 7.68, 8.98) from concordance matrix using Eq. (14). If the individual element of concordance matrix is greater than or equal to \tilde{C} , then the value of that element in Boolean matrix will be 1, and if the individual element of concordance matrix is less than \tilde{C} , then the value of that element in Boolean matrix will be 0.

The value of \bar{D} is calculated as (0.7) from discordance matrix using Eq. (17). If the individual element of discordance matrix is greater than or equal to \bar{D} , then the value of that element in Boolean matrix will be 0, and if the individual element of concordance matrix is less than \bar{D} , then the value of that element in Boolean matrix will be 1. Detailed analysis of above-mentioned steps in tabular forms is given in Appendix 2.

Both the Boolean matrices derived from concordance and discordance matrices are aggregated by peer-to-peer multiplication of their elements to capture their simultaneous effects, and the constructed general matrix G thus is presented in Table 4.

Finally, the decision graph is constructed based on the final matrix G as shown in Fig. 3. The decision graph enabled us to identify the ranking order of the Suppliers. The outgoing arc shows the domination of one supplier over another, and the incoming arc shows the domination of other suppliers over the arrow-headed supplier.

A's are shown in this decision graph (Fig. 3):

Table 4 General matrix G

	A1	A2	A3	A4	A5	A6	A7	A8
A1	–	0	0	0	0	0	0	0
A2	1	–	0	0	0	0	0	1
A3	1	0	–	0	0	0	0	0
A4	1	0	0	–	0	0	1	1
A5	1	1	0	1	–	1	0	1
A6	0	0	1	0	0	–	0	0
A7	1	1	0	0	0	0	–	1
A8	0	0	0	0	0	0	0	–

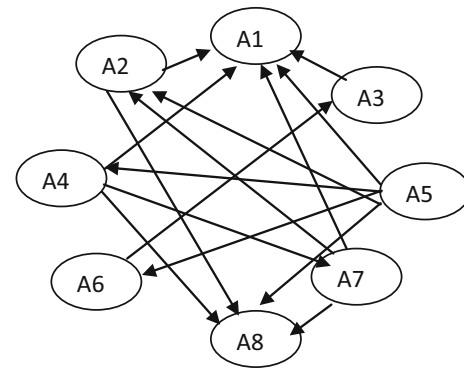


Fig. 3 Decision graph for ranking of suppliers

Supplier A1 is dominated by Suppliers A2, A3, A4, A5, A6, A7, and A8.

Supplier A2 dominates A1 and A8, while it is dominated by Suppliers A5 and A7.

Supplier A3 dominates Supplier A1, while it is dominated by A6.

Supplier A4 dominates Suppliers A1, A7, and A8, while it is dominated by Suppliers A5.

Supplier A5 dominates Suppliers A1, A2, A4, and A8.

Supplier A6 dominates Supplier A3, while it is dominated by A5.

Supplier A7 dominates Suppliers A1, A2, and A8, while it is dominated by Supplier A4.

Supplier A8 is dominated by A2, A4, A5, and A7.

From Fig. 3, It can be observed that A5 is the first-ranked supplier as it dominates the suppliers A1, A2, A4, A6, and A8. Supplier A4 dominates Suppliers, A1, A7, and A8 and Supplier A6 dominates A3. Thus, indirectly, Supplier A5 dominates all the other suppliers and has the first rank. Similarly, Supplier A4 gets the second rank; Supplier A7 gets the third rank. Suppliers A6 and A2 have the fourth and fifth ranks, respectively. Suppliers A1 and A8 are outranked as they do not show domination over any supplier.

This method leads us to the other multicriteria decision-making methods such as AHP, TOPSIS, ANP (Analytic Network Process), etc. where outranking of the poor performers is not possible. These methods provide ranks to all the alternatives or DMUs (Decision-making Units); even poor performers get some ranks. In the ELECTRE method, the decision maker uses concordance and discordance indices to analyze outranking relations among different alternatives and to choose the best alternative. The poor performers are outranked by all the good performers and do not get any rank. Thus, it may help the manager to eliminate and shortlist only comparable performers or suppliers.

There are some limitations of the ELECTRE method. The lowest performances under certain criteria are not

displayed due to the way preferences are incorporated. The outranking method prevents the strengths and weaknesses of the alternatives from being directly identified, nor results and impacts to be verified (Konidari and Mavrakakis 2007). ELECTRE has been used in energy, economics, environmental, water management, transportation problems, etc. Like other methods, it also takes the uncertainty and vagueness factors into account.

Conclusions

Nowadays, sustainability has become a major concern for all organizations to survive in global markets. Organizations have become very particular in the procurement of raw materials and selection of suppliers accordingly. Supplier selection is usually done in terms of traditional measures without considering sustainability perspective. This paper has tried to illustrate an approach for supplier selection to ensure environmental sustainability with other factors in the whole value chain. This study considers thirty-eight factors which are grouped into six clusters such as cost, quality, flexibility, service, green practice, environmental management, and pollution control. Suppliers are evaluated and ranked using fuzzy outranking approach.

The fuzzy ELECTRE, a fuzzy outranking approach of supplier evaluation/selection is a very effective multiattribute decision-making tool which is used to outrank the suppliers having poor performance. The uniqueness of this approach is that it eliminates the suppliers performing very poorly, whereas, in other multiattribute decision-making tools, each alternative has some rank. Thus, using the fuzzy ELECTRE method, the decision makers can discard many suppliers who are not performing up to a certain minimum level. By following this approach, decision makers can concentrate only on selected top ranked suppliers for further development as per their business requirement. Moreover, suppliers also know their relative performance with respect to other suppliers. Therefore outranked suppliers can also work on their performance improvement to meet emerging requirements of the market. The findings of the paper will also motivate suppliers to adopt green initiatives in their processes. However, findings may further be validated with some cases and empirically based studies.

Future scope of the research

The future work related to supplier selection may be more focused on green production and green practices such as solid waste, chemical waste, air emission, water waste, energy, environmental friendly materials, redesign of product, staff training, recycling, reuse, remanufacturing, disposal, environmental policy, training, ISO 14001, top

management commitment, etc. to improve the environmental sustainability and its relationship with economic and social sustainability. This approach can be applied for selection of sustainable supplier in other sectors also, where the number of suppliers is more and difficult to choose. As it outranks poor performers, therefore buyers would be able to focus on performing suppliers only.

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