Fuzzy Analytic Hierarchy Process (FAHP) for Green Supplier Selection in Indian Industries

Samadhan Deshmukh and Vivek Sunnapwar

Abstract The supplier selection has a significant impact on the manufacturing industries. Selecting the best green supplier among many alternatives is a multi-criteria decision-making (MCDM) problem. This research aims to survey current green activities in supplier selection in India and to evaluate best green supplier. Various environment factors affecting in the manufacturing sectors are considered in this study. Fuzzy analytic hierarchy process (FAHP) based on Chang's extent analysis, is utilized in order to select best green supplier. The data from pairwise evaluation of all criterions are given in triangular fuzzy numbers. The uncertainties of decision problem can be dealt with, and a more effective decision can be reached. A case study is conducted to illustrate the utilization of the model for the green supplier selection problem.

Keywords Green supplier selection · Multi-criteria decision-making (MCDM) Fuzzy analytic hierarchy process (FAHP)

1 Introduction

For sustainable supply chain partners, supplier selection using green manufacturing approach is one of the important tasks. The supplier should improve the performance of the supply chain keeping in mind environmental aspects along with social and economic aspects [1]. Green supply chain management (GSCM) is fast changing and growing concept in emerging countries. To address the influence and relation-

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ship between supply chain management and the natural environment, the 'green' dimension is added to supply chain management (SCM). The current awareness in the environmental aspects has made supplier to think and give more emphasis on the environment-friendly criteria [2]. Design for the environment, life-cycle analysis, and total quality environmental management are considered as popular environmentally conscious practices [3]. The fuzzy analytic hierarchy process (FAHP) approach is adopted in this study to develop a supplier selection model. Introduction to fuzzy sets and fuzzy numbers are given initially. In all, seven factors are considered, namely green manufacturing, green design, environment performance assessment, green logistic design, quality, customer co-operation, and green costs with 47 sub-factors.

2 Literature Review on Green Supplier Selection Criteria and Supplier Selection Models

In recent years, various researchers have identified approach toward green supply chain management (GSCM) practice. While the works on the evaluation and/or selection of suppliers are quite a few, those that concern environmental issues are limited. Baskaran et al. [4] assessed various vendors from Indian textile and clothing industry using different green manufacturing measures. For the purpose of metering the performance of the manufacturing sector, Bhateja et al. [5] studied different activities of the supply chain processes of the various Indian manufacturing industries. Deif [6] offered system model for the novel sustainability pattern with an architecture for the designing, planning, and controlling of various green manufacturing undertakings. Kumar et al. [7] explored different practices related to green supply chain management to be adopted by various industries of electrical and electronics products. The environmental performance and green supply chain management practices were studied, and findings were examined using mean score method. Relationships between green supply chain management (GSCM) practices and GSCM driver in Taiwan's textile and apparel manufacturers were investigated thoroughly [8]. The components and elements of green supply chain management were discussed to determine how those components served as a basis for the decision framework [9]. An integrated and fresh look into the area of GSCM was given comprehensively with the state-of-the-art literature review in the study. The literature on GSCM was covered from its conceptualization, primarily taking a reverse logistics angle [10]. Deshmukh and Sunnapwar [11] used factor analysis approach to discuss various environmental performance measures used in different manufacturing organizations. For green supplier selection, different performance measures were validated by mean method [12].

Based on the results of an investigation of 151 respondents, Punniyamoorthy et al. [13] established a new model using structural equation modeling and fuzzy analytic hierarchy process technique. Ataei et al. [14] utilized FAHP for determining the weights of the criteria. The ranking of the sawability of carbonate rocks

was also carried out. Chang [15] presented a methodology for management of fuzzy AHP. Ozdagoglu et al. [16] used analytic hierarchy process (AHP) and fuzzy AHP method. Comparison was made with a case study including the decision-making about employee selection for shop floor of manufacturing platform applied in food industry. To help the industrial specialists in the performance evaluation in a fuzzy environment, Sun [17] developed a model based on the fuzzy analytic hierarchy process (FAHP) and the technique for order performance by similarity to ideal solution (fuzzy TOPSIS). Fuzzy AHP was used by Kahraman et al. [18] for selecting best supplier firm for a white good manufacturer established in Turkey. Deshmukh and Sunnapwar [19] conducted study on use of AHP for green supplier selection in Indian industries.

3 Fuzzy Analytic Hierarchy Process, Fuzzy Sets, Fuzzy Numbers, Algorithm for Fuzzy AHP

To solve multiple-criteria decision-making problems, the analytic hierarchy process (AHP) has been widely used. Because of uncertainty and fuzziness in the individual's judgment, a pairwise comparison with an AHP may not be possible to accurately find the decision-makers' decision. The human preference model is uncertain in many real-world circumstances, and decision-makers might be hesitant to give precise numerical values to the comparison judgments. As human decisions are given with crisp numbers in AHP, there is a necessity to introduce fuzzy logic with pairwise comparison. The fuzzy AHP is based on the fuzzy interval arithmetic with triangular fuzzy numbers and the confidence index with an interval mean approach to determine the weights of evaluative elements. An approach based on fuzzy AHP can benefit to reach an operative decision. By using this method, the uncertainty and fuzziness in the decision process can be dealt with. Fuzzy set theory was introduced by Zadeh in 1965 to solve problems involving the absence of sharply defined criteria [15]. Fuzzy set theory looks a lot like human thinking in its use of estimated information and indecision to generate conclusions. It is designed to mathematically represent uncertainty and fuzziness that is intrinsic to many problems. Fuzzy set theory includes fuzzy logic, fuzzy arithmetic, fuzzy mathematical programming, fuzzy topology, fuzzy graph theory, and fuzzy data analysis; however, the term fuzzy logic is often used to define all of these [18]. Triangular fuzzy numbers are defined by three real numbers, given as (l, m, u). The parameters l, m, and u show the lowest possible value, the middle promising value, and the upper possible value that indicates a fuzzy event. A triangular fuzzy number (TFN), M, is shown in Fig. 1.

The extent FAHP is used in this study, which was introduced by Chang [15]. $X = \{x_1, x_2, x_3, \ldots, x_n\}$ to be considered as an object set, and $G = \{g_1, g_2, g_3, \ldots, g_n\}$ to be a goal set. Every object is considered, and extent analysis is done for each goal as per the method of Chang's extent analysis. M extent analysis values for each object can be obtained, with the signs given as follows:

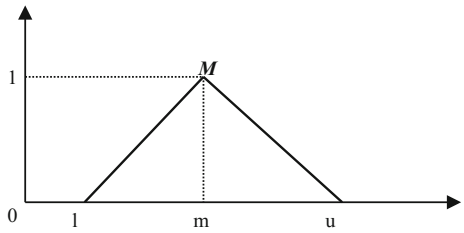

Fig. 1 A triangular fuzzy number, M

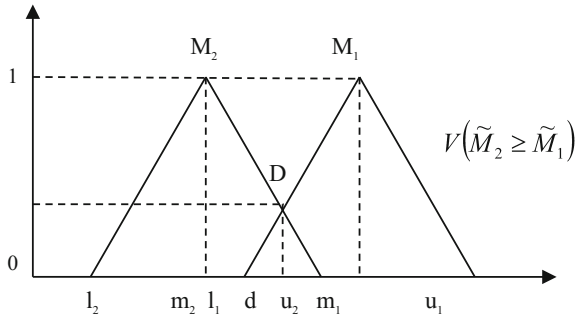

Fig. 2 Intersection between M_1 and M_2

where

$$M_{gi}^{1}, M_{gi}^{2}, M_{gi}^{j}, \quad i = 1, 2 \ldots n,$$

$M_{gi}^{j} (j = 1, 2, \ldots, m)$ all are triangular fuzzy numbers (TFNs).

Figure 2 illustrates intersection between M_1 and M_2 where D is the ordinate of the maximum juncture point d between μ_{M_1} and μ_{M_2} to associate M_1 and M_2; we need both the values of $V\ (M_1 \geq M_2)$ and $V\ (M_2 \geq M_1)$.

4 An Application in Organization (Case Study)

This study focuses on the procurement of various components from three local suppliers Supplier 1, Supplier 2, and Supplier 3, which have been preselected in the approved suppliers' list of one of the leading manufacturing organizations from India. The goal was to find the best supplier taking into account the green manufacturing approach. Figure 3 provides structure for selecting best green supplier. Seven main criteria are selected for assessment are green manufacturing (GM), green design (GD), customer co-operation (CC), green costs (GC), quality (QTY), environment performance assessment (EPA), and green logistics design (GLD). A sample of the questionnaire form is shown in Table 1.

A comparison is made in sub-attributes and main attributes by decision-maker after creating hierarchy. After the information is taken, the pairwise evaluations are

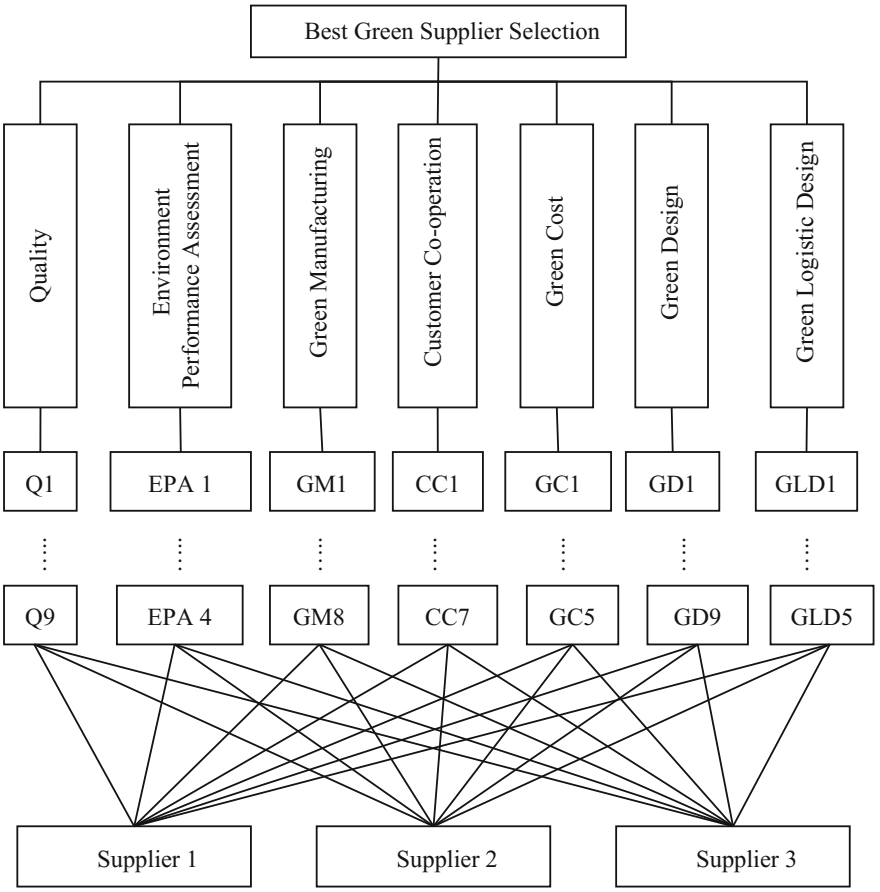

Fig. 3 Structure for the selection of the best green supplier

carried out. It is necessary to represent all pairwise comparison judgements into fuzzy triangular numbers. Table 2 represents relation between fuzzy comparison judgments and the main goal. Calculation is carried out according to fuzzy extent analysis. After the normalization of the values, priority weights with respect to main goal are calculated as—0.3010, 0.2488, 0.0903, 0.0984, 0.0313, 0.1350, 0.0951. It was found that the significant element in the green supplier selection procedure is quality as it is having maximum priority weight value (0.3010).

The same calculations were applied to the other pairwise comparison matrices and the priority weights of each main attribute, sub-attribute, and alternative were calculated. Mentioned priority weights have indicated for each criterion in Table 3. The priority weights of the alternatives with respect to sub-attributes are calculated. The combination of priority weights of main attributes and sub-attributes was done to find priority weights of the different vendors.

Table 1 A sample of the questionnaire form

With respect to GOAL	Importance (or preference) of one of the criteria over another						
	QTY	EPA	GM	CC	GC	GD	GLD
QTY	1	3	2	7	8	4	8
EPA	1/3	1	4	2	7	3	7
GM	½	1/4	1	1	1	1/3	1
CC	1/7	1/2	1	1	3	1	3
GC	1/8	1/7	1	1/3	1	1/5	2
GD	¼	1/3	3	1	5	1	2
GLD	1/8	1/7	1	1/3	1/2	1/2	1

Table 2 Fuzzy evaluation matrix with respect to goal

Goal	QLTY	EPA	GM	CC	GC	GD	GLD
QLTY	(1, 1, 1)	(1, 3, 5)	(1, 2, 4)	(5, 7, 9)	(6, 8, 10)	(2, 4, 6)	(6, 8, 10)
EPA	(1/5, 1/3, 1/1)	(1, 1, 1)	(2, 4, 6)	(1, 2, 4)	(5, 7, 9)	(1, 3, 5)	(5, 7, 9)
GM	(1/4, 1/2, 1/1)	(1/6, 1/4, 1/2)	(1, 1, 1)	(1, 1, 3)	(1, 1, 3)	(1/5, 1/3, 1/1)	(1, 1, 3)
CC	(1/9, 1/7, 1/5)	(1/4, 1/2, 1/1)	(1/3, 1/1, 1/1)	(1, 1, 1)	(1, 3, 5)	(1, 1, 3)	(1, 3, 5)
GC	(1/10, 1/8, 1/6)	(1/9, 1/7, 1/5)	(1/3, 1/1, 1/1)	(1/5, 1/3, 1/1)	(1, 1, 1)	(1/7, 1/5, 1/3)	(1, 2, 4)
GD	(1/6, 1/4, 1/2)	(1/5, 1/3, 1/1)	(1, 3, 5)	(1/3, 1/1, 1/1)	(3, 5, 7)	(1, 1, 1)	(1, 2, 4)
GLD	(1/10, 1/8, 1/6)	(1/9, 1/7, 1/5)	(1/3, 1/1, 1/1)	(1/5, 1/3, 1/1)	(1/4, 1/2, 1/1)	(1/4, 1/2, 1/1)	(1, 1, 1)

Table 3 Priority weights for main criteria

Criteria	Local weights	Global weights
Quality	1.0000	0.3010
Environment performance assessment	0.8266	0.2488
Green manufacturing	0.3000	0.0903
Customer co-operation	0.3269	0.0984
Green cost	0.1041	0.0313
Green design	0.4486	0.1350
Green logistic design	0.3158	0.0951

Table 4 Performance of suppliers with respect to each main criterion

Criteria	Supplier 1	Supplier 2	Supplier 3
Quality (QTY)	0.4626	0.3392	0.1983
Envt. performance assessment (EPA)	0.5585	0.2469	0.1946
Green manufacturing (GM)	0.5066	0.2879	0.2055
Customer co-operation (CC)	0.4869	0.3427	0.1704
Green costs (GC)	0.6209	0.2544	0.1247
Green design (GD)	0.4491	0.2976	0.2533
Green logistics design (GLD)	0.3886	0.3582	0.2532

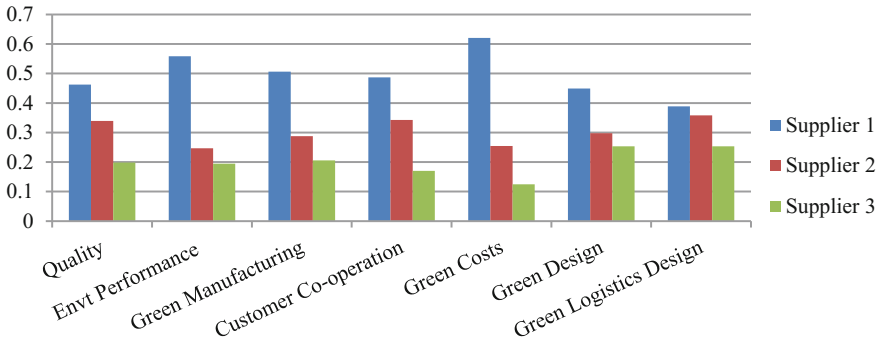

Fig. 4 Performance of suppliers w.r.t. main criterion

Main attributes and sub-attributes weights were used to select best alternative based on the questionnaire forms used. In order to reduce the complex calculations and to calculate the priority weights, macros in Excel were used. The performance of suppliers with respect to each main criterion is shown in Table 4, and corresponding values are shown diagrammatically in Fig. 4. Finally, the weights were calculated keeping into account different alternatives and the main attributes.

The priority weights for the alternatives are found to be 0.4834, 0.3377, and 0.1789.

5 Conclusion

Green supplier selection process plays an important role in today's complex environment. This work provides a scientific approach to the green supplier selection process. It first identifies those green supplier selection criteria which are consid-

ered to be important in Indian manufacturing sector. The extent fuzzy AHP is used in this study for selecting best green supplier. Fuzzy AHP approach appears more effective in decreasing the uncertainty in calculation of relative weights assigned to various criteria. For selecting the most appropriate supplier alternative, preferred degree related to each of the criteria was assessed. The uncertainties involved in the data acquired were efficiently represented and processed by using the extent fuzzy approach to make appropriate decision. Supplier 1, having highest priority weight, is determined as the best green supplier as a result of this study.

References

1. Kannan G., Sarkis J., Sivakumar R., Palaniappan M., Multi criteria decision making approaches for green supplier evaluation and selection: A literature review. Conference on the Greening of Industry Network, GIN 2012 (Linkoping—Sweden, 2012).
2. Lee A. H. I., Kang H. Y., Hsu C. F., Hung H. C., A green supplier selection model for high-tech industry. Expert Systems with Applications (2009) 36: 7917–7927.
3. Nimawat D. and Namdev V., An overview of green supply chain management in India. Research Journal of Recent Sciences (2012) 16:77–82.
4. Baskaran V., Nachiappan S., Rahman S., Indian textile suppliers' sustainability evaluation using the grey approach. Int. J. Production Economics (2012) 135: 647–658.
5. Bhateja A. K., Babbar R., Singh S., Sachdeva A., Study of Green Supply Chain Management in the Indian Manufacturing Industries: A Literature Review cum an Analytical Approach for the measurement of performance. International Journal of Computational Engineering & Management (2011) 13: 84–99.
6. Deif A. M., A system model for green manufacturing. Journal of Cleaner Production (2011), 19: 1553–1559.
7. Kumar S., Chattopadhyaya S., Sharma V., Green Supply Chain Management: A case study from Indian electrical and electronics industry. International Journal of Soft Computing and Engineering (2012) 1: 275–281.
8. Awasthi A., Chauhan S.S., Goyal S., A fuzzy multicriteria approach for evaluating environmental performance of suppliers. Int. J. Production Economics (2010) 126: 370–378.
9. Sarkis J., A strategic decision framework for green supply chain management. Journal of Cleaner Production (2003) 11: 397–409.
10. Srivastava S. K., Green supply-chain management: A state-of the- art literature review. International Journal of Management Reviews (2007) 9: 53–80.
11. Deshmukh S. and Sunnapwar V., Development and validation of performance measures for green supplier selection in Indian industries, International Journal of Engineering and Advanced Technology (2013) 2: 105–109.
12. Deshmukh S. and Sunnapwar V., Validation of performance measures for green supplier selection in Indian industries, International Journal of Modern Engineering Research (2013) 3: 1617–1622.
13. Punniyamoorthy M. and Mathiyalagan P, Parthiban P., A strategic model using structural equation modeling and fuzzy logic in supplier selection. Expert Systems with Applications (2011) 38: 458–474.
14. Ataei M., Mikaeil R., Hoseinie S. H., Hosseini S. M., Fuzzy analytical hierarchy process approach for ranking the sawability of carbonate rock. International Journal of Rock Mechanics & Mining Sciences (2012) 50: 83–93.
15. Chang D. Y., Applications of the extent analysis method on fuzzy AHP. European Journal of Operation Research (1996) 95: 649–655.

16. Ozdagoglu A. and Ozdagoglu G., Comparison of AHP and fuzzy AHP for the multi criteria decision making processes with linguistic evaluations. (2007). www.arastirmax.com/system/files/…/arastirmax_26635_pp_65–85.pdf
17. Sun C.C., A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods. Expert Systems with Applications (2010) 37: 7745–7754.
18. Kahraman C., Cebeci U., Ruan D., Multi-attribute comparison of catering service companies using fuzzy AHP: The case of Turkey. International Journal of Production Economics (2004) 87: 171–184.
19. Deshmukh S. and Sunnapwar V., Analytic Hierarchy Process (AHP) for green supplier selection in Indian industries, Proceedings of the international conference on Advanced Engineering Optimization through Intelligent Techniques, SVNIT, Surat, July 2013.