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Ranking green electronic supplier in auto industry using fuzzy Delphi

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This paper presents a study to rank different green supplier involved in supplement of electronic parts in auto industry using fuzzy Delphi. The proposed study uses the fuzzy analytic hierarchy process for weighing criteria and VIKOR method to rank the suppliers. The results show that measures of corporate social responsibility, environmental management system, green procurement and green production are the most important criteria for green supplier selection. In addition, product quality, online tracking of orders, delivery time and quality of online information are the most important criteria for choosing a green electronic supplier.

1. Introduction

Supplier selection plays essential role for the success of any businesses and there are several studies associated with supplier selection techniques (Heikkilä, 2002; Hsieh, 2002; Hsu et al., 2006). Suppliers' development is an important function within supply chain management and green supplier development is essential for effective green supply chain management (Bai & Sarkis, 2010). Awasthi et al. (2010) presented a fuzzy multicriteria technique for assessing environmental performance of suppliers. The study has three steps: The first step includes identification of criteria for evaluating environmental performance of suppliers. In step 2, the experts rate the selected criteria and the different alternatives (suppliers) against each of the criteria. They used linguistic assessments to rate the criteria and the alternatives. These linguistic ratings were then combined through fuzzy TOPSIS (Hwang & Yoon, 1981) to build an overall performance score for each alternative. The alternative with the highest score is selected as the one with highest environmental performance. The benefit of applying fuzzy TOPSIS is that it distinguishes between advantages and the disadvantage category criteria and selects solutions that are close to the positive ideal solutions and far from negative ideal solutions. Finally, the method performs sensitivity analysis to assess the effect of criteria weights on the environmental performance evaluation of suppliers.

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Chai et al. (2013) provided a review on papers published from 2008 to 2012 on the application of decision making techniques for supplier selection. Chang and Hung (2010) presented a study of using rough set theory to create the supplier selection model and decision-making rules. Chou and Chang (2008) presented a strategy-aligned fuzzy simple multi-attribute rating technique (SMART) method for handling the supplier/vendor selection problem from the perspective of strategic management of the supply chain (SC). The majority of supplier rating systems reach their optimal solutions without looking at firm's operations management (OM)/SC strategy. They utilized OM/SC strategy to determine supplier selection criteria and by using a fuzzy SMART they evaluated the alternative suppliers, and dealt with the ratings of both qualitative and quantitative criteria. The final decision-maker included the supply risks of individual suppliers into final decision making.

Deng and Chan (2011) presented a new Multi-Criterion Decision Making (MCDM) methodology, using fuzzy sets theory (FST) and Dempster Shafer Theory of evidence (DST) to deal with supplier selection problem. Deng et al. (2014) proposed a method, which is based on a new effective and feasible representation of uncertain information, called D numbers for the supplier selection problem. Dou et al. (2014) introduced a grey analytical network process-based technique to determine green supplier development programs, which would effectively improve suppliers' performance. They evaluated green supplier development programs with explicit consideration of suppliers' involvement propensity levels. Handfield et al. (2005) reviewed how companies could develop environmental supply chain strategies.

2. The proposed study

This paper presents a study to rank different green supplier involved in supplement of electronic parts in auto industry using fuzzy Delphi. The proposed study uses the fuzzy analytic hierarchy process for weighing criteria and VIKOR method to rank the suppliers. The proposed fuzzy VIKOR method of this paper is developed according to the concept of fuzzy logic and the VIKOR method, which consists of the following steps (Chen & Wang, 2008):

Step 1: Create feasible alternatives, determining the evaluation criteria, and setting a group of decision makers,

Step 2: Define linguistic variables and their corresponding triangular fuzzy numbers.

According to Chou & Chang (2008) studies, a nine-scale linguistic variable fuzzy number is implemented. This linguistic scales and corresponding triangular fuzzy numbers for the rating of alternatives show in Table 1.

Table 1
Linguistic terms for the fuzzy rating

Corresponding Fuzzy numbers	Linguistic terms
Extremely preferable	(9‹9‹9)
Middle	(7‹8‹9)
Very preferable	(6‹7‹8)
Middle	(5‹6‹7)
Strong	(4‹5‹6)
Middle	(3‹4‹5)
relatively	(2‹3‹4)
Middle	(1‹2‹3)
Equal	(1‹1‹1)

Step 3: Combine decision makers' preferences and opinions. The preferences and opinions of n decision-maker in terms of j^{th} criterion for the i^{th} alternative can be measured by:

$$\tilde{x}_{ij} = \frac{1}{n}\left(\sum_{e=1}^{n} \tilde{x}_{ij}\right), \quad i = 1,2,3,\ldots,m \tag{1}$$

Step 4: Compute fuzzy weighted average and construct the (normalized) fuzzy decision matrix (D):

$$\tilde{w} = [\tilde{w}_1\ \tilde{w}_2 \ldots \tilde{w}_k] \quad j = 1,2,3,\ldots,k \tag{2}$$

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{matrix} C_1 & C_2 & \cdots & C_k \end{matrix} \\ \begin{pmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \tilde{x}_{13}\cdots\tilde{x}_{1k} \\ \tilde{x}_{21} & \tilde{x}_{22} & \tilde{x}_{23}\cdots\tilde{x}_{2k} \\ \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \tilde{x}_{m3}\cdots\tilde{x}_{mk} \end{pmatrix} \end{array} \tag{3}$$

where $\tilde{w}_j$ represents the important weight of the j^{th} criterion.

Step 5: Determine the fuzzy best value (FBV) and fuzzy worst value (FWV):

$$\tilde{f}_j^* = \max_i \tilde{x}_{ij}, \tilde{f}_j^- = \min_i \tilde{x}_{ij} \tag{4}$$

Step 6: Calculate the values:

$$\tilde{S}_i = \sum_{i=1}^{k} \frac{\tilde{w}_j(\tilde{f}_j^* - \tilde{x}_{ij})}{(\tilde{f}_j^* - \tilde{f}_j^-)} \tag{5}$$

$$\tilde{R}_i = \max_j \left[\frac{\tilde{w}_j(\tilde{f}_j^* - \tilde{x}_{ij})}{(\tilde{f}_j^* - \tilde{f}_j^-)}\right] \tag{6}$$

where $\tilde{S}_i$ and $\tilde{R}_i$ state the utility measure and the regret measure, respectively, and W_j is the weight of the j^{th} criterion (Tong et al., 2005). In fact, $\tilde{S}_i$ is A_i with respect to all criteria calculated by the sum of the distance for the FBV, and $\tilde{R}_i$ is A_i with respect to the j^{th} criterion, computed by the maximum distance of FBV.

Step 7: Calculate the values of $\tilde{S}^*;\tilde{S}^-;\tilde{R}^*;\tilde{R}^-;\tilde{Q}_i$:

$$\tilde{S}^* = \min_i \tilde{S}_i, \tilde{S}^- = \max_i \tilde{S}_i$$
$$\tilde{R}^* = \min_i \tilde{R}_i, \tilde{R}^- = \max_i \tilde{R}_i \tag{10}$$

$$\tilde{Q}_i = v\frac{(\tilde{S}_j - \tilde{S}^*)}{(\tilde{S}^- - \tilde{S}^*)} + (1-v)\frac{(\tilde{R}_j - \tilde{R}^*)}{(\tilde{R}^- - \tilde{R}^*)} \tag{11}$$

Here ν means the weight of the strategy of the maximum group utility (Wu et al., 2009). When $v>0.5$, the decision tends toward the maximum majority rule; and if $v = 0.5$, the decision tends toward the individual regret of the opponent. Therefore, ν is introduced as weight of the strategy of ‘the majority of attributes’. Usually, the value of ν is taken as 0.5. However, ν can assume any value from 0 to 1. Rank and improve the alternatives, sort by the values *S, R,* and *Q*, in non-increasing order and reduce the gaps in the criteria and the best alternatives having the lowest value (Wu et al., 2009).

3. The results

The survey asks 10 experts' opinions in auto industry for filling the fuzzy Delphi questionnaire who were mostly highly educated. In addition, the study distributes the questionnaire among selected employees who worked for Saipa Group company for the second part of the survey. The survey considers seven criteria for green supply chain selection and 13 criteria for electronic green supplier selection. Table 1 and Table 2 demonstrate the summary of the description of these criteria.

Table 1

Description of the criteria associated with electronic green supply chain

Criteria	Description
(C1) Quality of product	To supply high quality products, the quality system must include: quality assurance, quality control procedures, quality control charts, documents, continuous quality improvement, etc.
(C2) Online quality information	Quality of information provided by suppliers must be appropriate and sufficient.
(C3) Precision of order information	All batches must include desirable product characteristics.
(C4) Delivery time	Appropriate times must be set in order to receive orders on planned scheduled.
(C5) Delivery based on schedule	All orders must be delivered on scheduled times.
(C6) Cost of order	Production cost is the most important part of order, which must be minimized.
(C7) Electronic catalog	When orders are placed, it must be possible to check details of orders online.
(C8) Website security	A secure online transaction facilities order policy.
(C9) e-business capability	e-business capabilities also help expedite the process of orders.
(C10) Online tracking	All orders must be traceable through internet.
(C11) IT facilities	There must be sufficient information technology facilities to help develop business.
(C12) Customer support	There must be a customer relationship management team to address any complains or concerns.
(C13) Website design	All websites must be designed properly such that customers could easily access required information.

Table 2

Description of the criteria associated with green supply chain

Criteria	Description
(C1) Corporate social responsibility	Corporate Responsibility in response to the outcome of the activities that affect the community.
(C2) Environmental Management System	This includes required structure, planning activities, responsibilities, procedures, processes and resources to develop, implement, review and maintain
(C3) Green production	Practical efforts to achieve sustainability, which is the practical implementation of principles formulated to achieve sustainability.
(C4) Green purchase	Green procurement and purchasing activities that aim to ensure the appropriateness of materials purchased with the environment.
(C5) Green design	This includes activities that aim to minimize the environmental impacts of a product throughout its life cycle.
(C6) Pollution	This includes changes in products or production methods to minimize the environmental pollution.
(C7) Green innovation	Innovations in hardware or software that is related to green product innovation in energy saving, reduction of material, technology innovation, etc.

We have asked decision makers to perform pairwise comparisons. Table 3 demonstrates the results of our findings on the comparison of green supply chain criteria.

Table 3

The summary of pairwise comparison of green supply chain criteria

	C1			C2			C3			C4			C5			C6			C7		
C1	1.00	1.00	1.00	0.90	1.22	1.53	1.53	1.83	2.13	1.15	1.57	2.02	1.41	1.89	2.35	1.89	2.51	3.12	2.59	3.41	4.26
C2	0.65	0.82	1.12	1.00	1.00	1.00	1.28	1.68	2.17	1.10	1.57	2.11	1.26	1.61	1.97	1.74	2.45	3.16	2.63	3.12	3.57
C3	0.47	0.55	0.65	0.46	0.60	0.78	1.00	1.00	1.00	0.55	0.75	1.07	0.92	1.16	1.47	0.88	1.12	1.45	1.58	2.22	2.81
C4	0.49	0.64	0.87	0.47	0.64	0.91	0.93	1.34	1.81	1.00	1.00	1.00	1.00	1.23	1.46	1.41	1.86	2.29	1.91	2.43	2.94
C5	0.43	0.53	0.71	0.51	0.62	0.79	0.68	0.92	1.21	0.68	0.81	1.00	1.00	1.00	1.00	0.93	1.13	1.41	1.64	2.02	2.35
C6	0.32	0.40	0.53	0.32	0.41	0.57	0.69	0.90	1.14	0.44	0.58	0.79	0.71	0.88	1.07	1.00	1.00	1.00	1.28	1.81	2.39
C7	0.23	0.29	0.39	0.28	0.32	0.38	0.40	0.48	0.63	0.34	0.41	0.52	0.43	0.49	0.61	0.42	0.55	0.78	1.00	1.00	1.00

As we can observe from the numbers of Table 3, all input numbers are in forms of triangular, which were shown after taking average using geometric mean. The implementation of fuzzy Delphi determines the ranking of criteria and Table 4 shows details of our findings.

Table 4
The summary of ranking seven criteria based on fuzzy Delphi for green supply chain criteria

$\widetilde{W}_j$	lw_j	mw_j	uw_j	Weight	Rank
$\widetilde{W}_1$	0.15	0.233	0.349	0.24	1
$\widetilde{W}_2$	0.135	0.209	0.321	0.22	2
$\widetilde{W}_3$	0.081	0.124	0.193	0.13	4
$\widetilde{W}_4$	0.098	0.153	0.238	0.16	3
$\widetilde{W}_5$	0.081	0.121	0.183	0.12	5
$\widetilde{W}_6$	0.064	0.098	0.155	0.1	6
$\widetilde{W}_7$	0.042	0.062	0.095	0.06	7

As we can observe from the results of Table 4, corporate social responsibility is number one priority followed by environmental management system, green purchase, green production, green design, pollution free and green innovation. Similarly, we have gathered the pair-wise comparisons for 13 criteria associated with electronic green supply chain using VIKOR method and Table 5 demonstrates the results of our survey. In Table 4 and Table 5, *Weight* is calculated as $(lw_j + 4mw_j + uw_j)/6$.

Table 5
The summary of ranking seven criteria based on VIKOR method for electronic green supply chain criteria

$\widetilde{W}_j$	lw_j	mw_j	uw_j	Rank
$\widetilde{W}_1$	0.118	0.185	0.28	1
$\widetilde{W}_2$	0.076	0.119	0.184	4
$\widetilde{W}_3$	0.046	0.07	0.11	6
$\widetilde{W}_4$	0.076	0.121	0.192	3
$\widetilde{W}_5$	0.045	0.07	0.11	7
$\widetilde{W}_6$	0.026	0.041	0.066	11
$\widetilde{W}_7$	0.032	0.048	0.076	8
$\widetilde{W}_8$	0.049	0.076	0.121	5
$\widetilde{W}_9$	0.03	0.046	0.072	9
$\widetilde{W}_{10}$	0.083	0.128	0.197	2
$\widetilde{W}_{11}$	0.02	0.03	0.49	12
$\widetilde{W}_{12}$	0.014	0.021	0.033	13
$\widetilde{W}_{13}$	0.027	0.042	0.068	10

4. Discussion and Conclusion

According to the results of Table 5, quality of products is the most important factor followed by the capability of online tracking, delivery time, online quality information, website security and precision of order information. In addition, delivery based on the schedule, availability of electronic catalog and e-business capability are among other important criteria, which must be considered when an electronic green supplier is chosen. Based on the criteria achieved using fuzzy Delphi and VIKOR techniques, the proposed study has ranked 12 suppliers. We have also presented the results of our survey to some expert and they have confirmed our findings.

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