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Using Integration of Fuzzy AHP – VIKOR for Selecting the Best Strategy in Green Supply Chain Management

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ABSTRACT

Increasingly, firms have recognized the significance of environmental issues in gaining competitive advantage. Many firms have searched for mechanisms that integrate environmental supply chain practices and performance objectives. This paper presents an integrated approach for selecting the best green supply chain management strategy. In this paper key performance indicator (KPI) are criteria and strategies are alternatives. Fuzzy AHP and VIKOR are used in the integrated approach. Fuzzy AHP is used to determine the fuzzy weights of criteria because it can effectively determine various criteria's weights in a hierarchical structure. VIKOR aims to rank strategies with respect to the criteria. We apply the integrated approach in real case to demonstrate the application of the proposed method.

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1. Introduction

Supply chains are value chains that extend from supplier to ultimate customer. Supply chain management requires integration and coordination of business processes throughout the supply chain for the purpose of satisfying and responding to changes in the demands of ultimate customers (Lambert & Cooper, 2000). Increasingly, companies are recognizing that environmental management is a key strategic issue with the potential for a lasting impact on organizational performance. For example, more than 40,000 companies have implemented ISO14001, the environmental management system standard (Zhu and Sarkis, 2006). Greening the supply chain is increasingly a concern for many business enterprises and a challenge for logistics management in the 21st century. Of particular concern is how to raise organizational environmental awareness incorporate environmental management practices into their logistics activities (Zhu et al., 2008). Green supply chain management (GSCM) lies at the confluence of elements of corporate environmental management and supply chain management which are both relatively new areas of study (Zhu and Sarkis, 2004). GSCM has emerged ''as an important new archetype for enterprises to achieve profit and market share objectives by lowering their environmental risks and impacts and while raising their ecological efficiency'' (Zhu et al., 2005). GSCM can be defined as integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life (Srivastava, 2007). Rettab and Ben Brik (2008) defined the green supply chain as a managerial approach that seeks to minimize a product or service's environmental and social impacts or footprint. Shang et al. (2010) identified taxonomies of green supply chain management capability from the perspective of a major Taiwan electronics-related manufacturing firm include green manufacturing and packaging, environmental participation, green marketing, green suppliers, green stock, and green eco-design. A variety of stakeholder and institutional pressures are major motivating forces that lead enterprises to pursue GSCM related practices (Tate et al., 2010). The implementation of GSCM practices is expected to result in improved environmental performance as measured by reductions in air emissions, effluent waste, solid waste, and the consumption of toxic materials. There is concern, however, whether such environmental sustainability efforts will ultimately translate into improved market share and profitability. Ultimately, manufacturing managers are responsible for the performance of the organizations for which they work (Green et al., 2008). To successfully adopt GSCM-related practices, such as green

purchasing, eco-design, and cooperation with customers, large manufacturers need not only good internal environmental management but also external cooperation and coordination with suppliers and customers in their supply chain. Industries pay attention to the "ecologically responsible design of new products" (Gonzalez-Benito, 2008).

2. Strategies of Green Supply Chain Management

GSCM is a remarkable concept to increase environmental performance and reduce environmental impacts (Srivastava, 2007). Organizations can adapt to emerging environmental policies by applying GSCM practices and thereby protect the environment globally (Chien and Shih, 2007). Increasing complexity of activities and environment has caused managers to understand the traditional planning will not be able to solve their problems and the smallest neglecting has a consequence. Hence strategic management in organizations has been proposed and managers with the help of strategic management want to find the proper orientation in order to lead their organizations. Strategic management can be understood as the collection of decisions and actions taken by business management, in consultation with all levels within the organization, to determine the long-term activities of the organization (Houben et al., 1999). Simpon and Samon (2008) proposed a broad range of strategies for GSCM. These strategies include risk-based strategy, efficiency-based strategy, innovation-based strategy, and closed-loop strategy.
Strategies of Green Supply Chain Management include (Simpon and Samson, 2008):

- Risk-based Strategies

The simplest strategy of GSCM with regard to inter-organizational investment resource development is one of risk minimization. Firms adopting this strategy are proposed to do so in response ostensibly to stakeholder requirements. Such a strategy is ideal for the organization that retains minimal internal environmental management resources or has only recently begun to consider the introduction of a supply chain greening program. It is based on minimal inter-organizational engagement ((Simpon and Samson, 2008).

- Efficiency-based Strategies

A more complex and developing strategy in recent years has been the 'eco-efficiency' or 'lean-and-green' approach to GSCM. This type of strategy derives environmental performance benefits for the supply chain beyond mere regulatory compliance through the requirement for suppliers to meet operations-based efficiency targets. Much of the environmental performance benefit arises from specific manufacturing practices that have been found to provide secondary environmental performance benefits (Simpon and Samson, 2008).

- Innovation-based Strategies

This strategy type guides companies to develop products from product life-cycles, enact stricter environmental requirements upon their suppliers, and even trains them to adjust operational processes to follow the newest environmental regulations. As a result, the innovation-based strategy forces companies to invest more resources and cultivate innovative capabilities for green management (Chen et al,. 2012).

- Closed-loop strategies

Closed-loop strategies are a more recent type of GSCM strategy and represent the most complex and collaborative form of this type of activity. Often referred to in its simplest form as 'reverse logistics,' closing the loop involves the capture and recovery of materials for either re-manufacture (high-value) or recycling (Simpon and Samson, 2008).

3. Evaluation Methods

3.1. Fuzzy AHP

A good decision-making model needs to tolerate vagueness or ambiguity because fuzziness and vagueness are common characteristics in many decision-making problems (Yu, 2002). Since decision- makers often provide uncertain answers rather than precise values, the transformation of qualitative preferences to point estimates may not be sensible. Conventional AHP that requires the selection of arbitrary values in pairwise comparison may not be sufficient and uncertainty should be considered in some or all pairwise comparison values (Yu, 2002). Since the fuzzy linguistic approach can take the optimism/pessimism rating attitude of decision- makers into account, linguistic values, whose membership functions are usually characterized by triangular fuzzy numbers, are recommended to assess preference ratings instead of conventional numerical equivalence method (Liang & Wang, 1994). As a result, the fuzzy-AHP should be more appropriate and effective than conventional AHP in real practice where an uncertain pairwise comparison environment exists (Lee, Chen, & Chang, 2008). There are many fuzzy-AHP methods proposed by various authors (Buckley, 1985; Chang, 1996; Cheng, 1997; Deng, 1999; Leung & Cao, 2000; Mikhailov, 2004;

Van Laarhoven & Pedrycz, 1983). These methods are systematic approaches to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis. Decision-makers usually find that it is more confident to give interval judgments than fixed value judgments. This is because usually he/she is unable to explicit about his/her preferences due to the fuzzy nature of the comparison process. In this study, we prefer Chang (1996) extent analysis method because the steps of this approach are easier than the other fuzzy-AHP approaches (Fuzzy sets and AHP are not detailed here because of being well-known applications). The steps of Chang (1996) extent analysis approach are as follows: Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set, and $U = \{u_1, u_2, \ldots, u_m\}$ be a goal set. According to the method of Chang (1996) extent analysis, each object is taken and extent analysis for each goal, g_i, is performed, respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs (Dag˘deviren, Yuksel, & Kurt, in press):
$\widetilde{M}_{g_i}^1, \widetilde{M}_{g_i}^2, \ldots, \widetilde{M}_{g_i}^m$, i=1, 2,…,n

Where $\widetilde{M}_{g_i}^j$(j=1,2,3,…, m) are all triangular fuzzy numbers. The membership function of the triangular fuzzy number is denoted by $M_{(x)}$. The steps of the Chang's extent analysis can be summarized as follows:

Step 1: The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} \widetilde{M}_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^j\right]^{-1} \quad (1)$$

Where $\otimes$ denotes the extended multiplication of two fuzzy numbers. In order to obtain $\sum_{j=1}^{m} \widetilde{M}_{g_i}^j$

We perform the addition of m extent analysis values for a particular matrix such that,

$$\sum_{j=1}^{m} \widetilde{M}_{g_i}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (2)$$

and to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^j\right]^{-1}$ we perform the fuzzy addition operation of

$\widetilde{M}_{g_i}^j$ (j =1,2,…,m) values such that,

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad (3)$$

Then, the inverse of the vector is computed as,

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (4)$$

Where u_i , m_i , $l_i > 0$

Finally, to obtain the S_j in Eq. (1), we perform the following multiplication:

$$S_i = \sum_{j=1}^{m} \widetilde{M}_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^j\right]^{-1}$$

$$= \left(\sum_{j=1}^{m} l_j \otimes \sum_{i=1}^{n} l_i, \sum_{j=1}^{m} m_j \otimes \sum_{i=1}^{n} m_i, \sum_{j=1}^{m} u_j \otimes \sum_{i=1}^{n} u_i\right) \quad (5)$$

Step 2: The degree of possibility of $\widetilde{M}_2 = (l_2, m_2, u_2) \geq \widetilde{M}_1 = (l_1, m_1, u_1)$ is defined as

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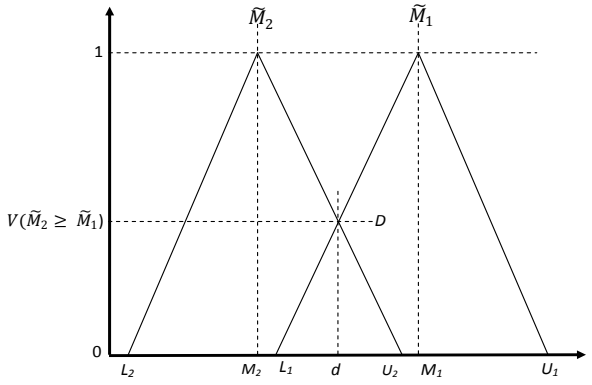


Figure 1. The degree of possibility of $\widetilde{M}_1 \geq \widetilde{M}_2$

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = sup[\min(\widetilde{M}_1(x), \widetilde{M}_2(y))] \quad (6)$$

This can be equivalently expressed as,

$$V(\widetilde{M}_2 \geq \widetilde{M}_1) = hgt(\widetilde{M}_1 \cap \widetilde{M}_2) = \widetilde{M}_2(d) = \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad (7)$$

Fig. 1 illustrates $V(\widetilde{M}_2 \geq \widetilde{M}_1)$ for the case d for the case $M_1 < L_1 < U_2 < M_1$, where d is the abscissa value corresponding to the highest crossover point D between $\widetilde{M}_1$ and $\widetilde{M}_2$,To compare $\widetilde{M}_1$ and $\widetilde{M}_2$, we need both of the values $V(\widetilde{M}_1 \geq \widetilde{M}_2)$ and $V(\widetilde{M}_2 \geq \widetilde{M}_1)$.

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i (i =1, 2… K) is defined as

$V(\widetilde{M} \geq \widetilde{M}_1, \widetilde{M}_2, \ldots, \widetilde{M}_k) = \min V(\widetilde{M} \geq \widetilde{M}_i)$, I =1,2,…,k

Step 4: Finally, $W = (\min V(s_1 \geq s_k) \min V(s_2 \geq s_k), \ldots, \min V(s_n \geq s_k))^T$, is the weight vector for k = 1,. . .,n.

3.2. VIKOR Method

The VIKOR method is a compromise MADM method, developed by Opricovic .S and Tzeng (Opricovic,1998; Opricovic, S. and Tzeng, G. H., 2002) started from the form of Lp-metric :

$$L_{pi} = \left\{ \sum_{j=1}^{n} \left[w_j \left(f_j^* - f_{ij} \right) / \left(f_j^* - f_j^- \right) \right]^p \right\}^{1/p} \quad 1 \leq p \leq +\infty ; i = 1,2, \ldots I$$

The VIKOR method can provide a maximum ‘‘group utility’’ for the “majority’’ and a minimum of an individual regret for the ‘‘opponent’’ (Opricovic,1998; Opricovic, S. and Tzeng, G. H., 2002 ; Serafim Opricovic and Gwo-Hshiung Tzeng,2004).

1) Calculate the normalized value

Assuming that there are m alternatives, and n attributes. The various I alternatives are denoted as xi. For alternative xj , the rating of the jth aspect is denoted as xij, i.e. xij is the value of jth attribute. For the process of normalized value, when xij is the original value of the ith option and the jth dimension, the formula is as follows:

$$f_{ij} = x_{ij} / \sqrt{\sum_{j=1}^{n} x_{ij}^2} \quad , i = 1,2,\dots,m \; ; j = 1,2,\dots,n \tag{8}$$

2) Determine the best and worst values

For all the attribute functions the best value was f_j^* and the worst value was f_j^-, that is, for attribute J=1-n, we get formulas (9) and (10)

$$f_j^* = \max \; f_{ij} \, , i = 1,2,\dots,m \tag{9}$$
$$f_j^- = \min \; f_{ij} \, , i = 1,2,\dots,m \tag{10}$$

Where f_j^* is the positive ideal solution for the jth criteria f_j^- is the negative ideal solution for the jth criteria. If one associates all f_j^*, one will have the optimal combination, which gets the highest scores, the same as f_j^-.

3) Determine the weights of attributes

The weights of attribute should be calculated to express their relative importance.

4) Compute the distance of alternatives to ideal solution

This step is to calculate the distance from each alternative to the positive ideal solution and then get the sum to obtain the final value according to formula (11) and (12).

$$S_i = \sum_{j=1}^{n} w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-) \tag{11}$$
$$R_i = \max_j \left[w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-) \right] \tag{12}$$

Where Si represents the distance rate of the ith alternative to the positive ideal solution (best combination), R_i represents the distance rate of the ith alternative to the negative ideal solution (worst combination). The excellence ranking will be based on S_i values and the worst rankings will be based on R_i values. In other words, S_i, R_i indicate L_{1i} and L_{*i} of L_p-metric respectively.

5) Calculate the VIKOR values Q_i for i=1,2, … ,m, which are defined as

$$Q_i = v \left[\frac{S_i - S^*}{S^- - S^*} \right] + (1 - v) \left[\frac{R_i - R^*}{R^- - R^*} \right] \tag{13}$$

Where $S^- = \max_i S_i \;\; S^* = \min_i S_i$, $R^- = \max_i R_i \;\; R^* = \min_i R_i$, and v is the weight of the strategy of "the majority of criteria'' (or ''the maximum group utility''). $[(S - S^*)/(S^- - S^*]$ represents the distance rate from the positive ideal solution of the ith alternative's achievements In other words, the majority agrees to use the rate of the ith. $[(R - R^*)/(R^- - R^*]$ represents the distance rate from the negative ideal solution of the ith alternative; this means the majority disagree with the rate of the ith alternative. Thus, when the v is larger (>0.5), the index of Q_i will tend to majority agreement; when v is less (<0.5), the index Q_i will indicate majority negative attitude; in general, v = 0.5, i.e. compromise attitude of evaluation experts.

6) Rank the alternatives by Q_i values

According to the Q_i values calculated by step (5), we can rank the alternatives and to make-decision.

4. Empirical Study and Discussions

This research has been conducted in supply chain of a tile manufacturer. The problem is the evaluation of green strategies and selection of the most appropriate one. For this reason, first of all, basic seven criteria are determined. These criteria are key performance indicator (KPI) in supply chain performance. Secondly, a two-step fuzzy AHP an VIKOR methodology is proposed to realize the evaluation. These criteria are Flexibility (C1), Financial (C2), Responsiveness (C3), Productivity (C4), Reliability (C5), Innovation (C6), and Information (C7). Four alternatives (strategies) include risk-based strategy (A1), efficiency-based strategy (A2), innovation-based strategy (A3), and closed-loop strategy (A4). The weights of criteria are calculated by using fuzzy-AHP, and these calculated weight values are used as VIKOR inputs. Then after VIKOR calculations, evaluation of the alternatives and selection of the most appropriate one is realized. The schematic structure established is shown in Fig 2.

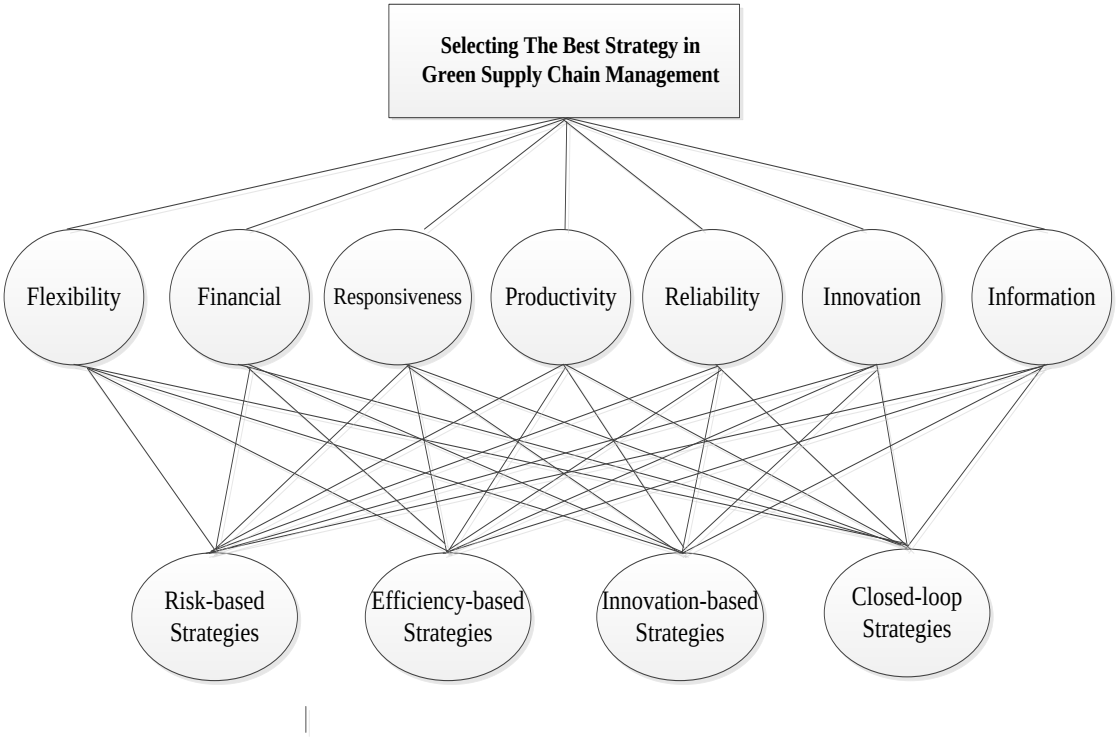


Figure 2. Research framework

Firstly, In fuzzy-AHP, there must be linguistic terms and their equivalent fuzzy numbers denoting comparison measures. The linguistic comparison terms and their equivalent fuzzy numbers considered in this paper are shown in Table 1.

Table 1. Fuzzy comparison measures

Linguistic terms	Triangular fuzzy numbers
Perfect	(8, 9,10)
Absolute	(7, 8, 9)
Very good	(6, 7, 8)
Fairly good	(5, 6, 7)
Good	(4, 5, 6)
Preferable	(3, 4, 5)
Not bad	(2, 3, 4)
Weak advantage	(1, 2, 3)
Equal	(1,1,1)

Then, the comparisons the criteria and the weight calculation need to be made. Thus, the evaluation of the criteria according to the main goal must be realized. After all these evaluation procedure, the weights of the criteria can be calculated. Pairwise comparison of criteria can be seen from Table 2.

Table 2. Pairwise comparison of criteria

criteria	C1	C2	…	C6	C7
C1	(1,1,1)	(0.20,0.25,0.33)	…	(1,2,3)	(0.25,0.33,0.50)
C2	(3, 4, 5)	(1,1,1)	…	(6, 7, 8)	(3, 4, 5)
⋮	⋮	⋮	⋮	⋮	⋮
C6	(0.33,0.5,1)	(0.125,0.142,0.166)	…	(1,1,1)	(0.33,0.5,1)
C7	(2, 3, 4)	(0.20,0.25,0.33)	…	(1, 2, 3)	(1,1,1)

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The criteria weights are calculated as:
W = (0.113, 0.204, 0.179, 0.154, 0.107, 0.97, 0.136)

The weights of the criteria are calculated by fuzzy AHP, and then these values can be used in VIKOR. By following VIKOR procedure steps and calculations, the ranking of strategies are gained. The results and final ranking are shown in Table 3.

Table 3. Final evaluation of the alternatives

i	Si=Σei	Ri=Max(ei)	Pi	Ranking
A1	0.475004	0.065245	0.5	2
A2	0.46334	0.07125	0.287065	1
A3	0.464694	0.075705	0.558042	3
A4	0.474687	0.069192	0.675065	4
Max	0.475004	0.075705		
Min	0.46334	0.065245		

5. Conclusion

Organizations to survive in today's rapid and turbulent environment need to develop coherent long term plans .The issues of environmental pollution accompanying industrial development must be addressed with supply chain management, and thereby contribute to a GSCM initiative (Sheu et al., 2005). Green supply chain management has emerged as an important organizational philosophy to reduce environmental risks. As pressures for environmental sustainability increase, industries need to adopt strategies to reduce environmental impact and improve products, services and environmental performance (Zhu et al., 2005). For selecting the optimal strategy, this study proposes a strategy decision making process. An appropriate and simple prioritization method for determining the best marketing strategy would be helpful to firms and strategists. A two-step fuzzy-AHP and VIKOR methodology is structured here that VIKOR uses fuzzy-AHP result weights as input weights. Then a real case study is presented to show applicability and performance of the methodology. The usage of fuzzy-AHP weights in VIKOR makes the application more realistic and reliable. The results of this study show that the most important strategy was efficiency-based strategy.

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