A Fuzzy Based Green Supply Chain Performance Appraisement Platform

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Abstract

Green Supply Chain Management (GSCM) is increasingly becoming a necessity for industries to compete globally, and is now a part of the majority of large organization's structure. GSCM can be defined as '*Integrating environment thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers, and end-of-life management of the product after its useful life*' (Srivastava, 2007). While implementing green practices in the organizational supply chain management, evaluation of green performance metric is indeed necessary. Such an assessment would help the industries to assess their existing status of green performance practices, to compare different industries those are adapting green practices and also to identify areas which require future improvement towards successful 'green implementation'. In this context, the present work introduces an appraisement platform to evaluate green supply chain performance extent, in fuzzy environment. In order to deal with subjective qualitative green performance attributes; the concept of fuzzy numbers has been utilized. Theory of generalized positive triangular fuzzy numbers has been explored to facilitate such an appraisement module. Apart from estimating overall performance index; the proposed appraisement platform helps in identifying ill-performing areas which necessarily require future attention to prosper. A case study has also been presented.

Keywords: Green Supply Chain Management (GSCM); Fuzzy numbers

1. Introduction

Green supply Chain Management (GSCM) is an approach to improve performance of the process and products according to the requirements of the environmental regulations (Hsu and Hu, 2008). Green supply chain management (GSCM) is a strategy for enhancing productivity and environmental performance for overall socio-economic development. It is the application of appropriate techniques, technologies, and management systems to produce environmentally compatible goods and services. GSCM philosophy focuses on how firms utilize the supplier's processes and technologies, as well as the supplier's ability to integrate environmental concerns and enhance the firm's competitive advantage (Vachon and Klassen, 2008). Now-a-days, many organizations are incorporating environmental issues in their negotiation with suppliers. Organizations are realizing that they can use their purchasing power to influence the suppliers.

Rao (2005) represented beneficiary in implementing 'greening' in South East Asian region and identified initiatives taken by companies in their greening endeavors and clusters the companies with respect to the type of initiatives taken and the major driving forces considered by them and revealed the major driving forces that are responsible for the increasing endeavors in the greening of the suppliers. Hu and Hsu (2006) developed a tentative list of critical factors of GSCM and the Statistical tests demonstrated that four critical factors was valid, namely supplier management, product recycling, organization involvement and life cycle management. Additionally, they also validated critical factors of GSCM practices which can help enterprises in identifying those areas of GSCM where acceptance and improvements was to be made, and in prioritizing GSCM efforts. Wu et al.

(2007) proposed a multi-objective decision making process for GSC management (GSCM) to help the supply chain manager in measuring and evaluating suppliers' performance based on an analytical hierarchy process (AHP) decision-making method and fuzzy logic process. Xu and He (2007) proposed that an enterprise should evaluate and select green suppliers on the basis of product life cycle assessment, and control them according to the strategy of grading. Lee et al. (2009) proposed an integrated model that adopts environmental and non-environmental criteria for selecting green supplier in high-tech industry, including the criteria of quality, technology capability, pollution control, environmental management, green product, and green competencies. Peng (2012) presented Optimization of Green Suppliers Based on Analytical Hierarchy Process (AHP) and Grey Relational Analysis (GRA) and provided green supply chain management model supplier evaluation index system, combined with the characteristics of the indicator system, proposed the concept of green adjustment factors.

In the context of implementing green practices in supply chain management, performance evaluation is an important issue that infers the extent that an organization is cooperating 'greenly' to the environment. An integrated structured evaluation model followed by an appraisement platform (methodological hierarchy) is seemed essential to quantify an equivalent green performance index. The factors that enhance green supply chain performance can be categorized as green enablers/capabilities, green attributes followed by green criterions. Elements of this hierarchical order are assumed to be correlated, thereby, influencing overall supply chain performance towards green revolution. In general, most of the green capabilities-attributes as well as criterions are subjective in nature and therefore, appropriateness rating (performance extent) and corresponding priority weights cannot be evaluated by exact numeric score. Therefore, assignment of priority weight as well as appropriateness rating seeks expert opinion of decision-makers (DMs). The situation may be viewed as a Multi-Criteria Group Decision-Making (MCGDM); linguistic variables are to be utilized to represent DMs subjective judgment towards qualitative evaluation criteria along with associated importance weights. Fuzzy logic has been found efficient in dealing with such types of subjective evaluation by representing linguistic variables into fuzzy numbers. Therefore, fuzzy numbers theory has been adapted here to facilitate such a decision-modeling. The fuzzy based appraisement platform presented here yields an overall performance index towards green implementation in supply chain; ascertains ranking order of green attributes and indentifies week performing areas for future improvement. The proposed appraisement index system has been implemented in an Indian manufacturing sector, and results obtained thereof, analyzed as a case study.

2. Proposed Appraisement Platform: Implementation

The green supply chain performance evaluation index platform adapted in this paper has been shown in Table 1 (Wang et al., 2011). The 2-level hierarchical model consists of various indices. Business process, financial value, cost, customer service and environmental performance have been considered as the 1st level indices followed by 2nd level indices which encompass a number of attributes. An approach based on fuzzy numbers set has been used to evaluate an overall performance index. This method has been found fruitful for solving the group decision-making problem under uncertain environment due to vagueness, inconsistency and incompleteness associated with decision-makers' subjective evaluation. The proposed evaluation index platform has been explored by the supply chain of an Indian automobile part manufacturing company at eastern part of India. The analysis has been carried out using numerical illustrations on a case study presented as follows. In this paper, the attribute weights and corresponding appropriateness ratings (performance estimates) have been considered as linguistic variables which have been further transformed into fuzzy numbers. Here, these linguistic variables corresponding to weight assignment has been expressed in fuzzy numbers by 1-9 scale as shown in Table 2. Similarly, the fuzzy performance ratings of individual attributes have also been expressed in fuzzy numbers by 1-9 scale shown in Table 2. The procedural steps and its implementation results have been summarized as follows.

Step 1: Measurement of performance ratings and importance weights of attributes using linguistic terms

For evaluating importance weights of various attributes, a committee of five decision-makers (DMs), $DM_1, DM_2, DM_3, DM_4, DM_5$ has been formed to express their subjective preferences (priority importance) in linguistic terms (Tables 2) which have been further transformed into fuzzy numbers. After the linguistic variables for assessing the performance ratings and importance weights of various attributes has been accepted by the decision-makers (DMs), the decision-makers have been asked to use aforesaid linguistic scales to assign fuzzy priority weight of these attributes (both at 1st and 2nd level) as furnished in Tables 3-4. Similarly fuzzy appropriateness ratings of 2nd level indices have been assessed by the DMs as shown in Table 5.

Step 2: Approximation of the linguistic terms by triangular fuzzy numbers

Using the concept of generalized positive triangular fuzzy numbers in fuzzy set theory, the linguistic variables have been be approximated by fuzzy numbers (as shown in Table 2). Next, the aggregated decision-making cum evaluation matrix has been constructed. The aggregated fuzzy appropriateness rating against individual 2nd level indices with corresponding importance weight have been computed. Similarly, aggregated fuzzy priority weight of various 1st level indices has also been obtained.

Step 3: Estimation of appraisement index

FPI represents the *Fuzzy Performance Index*. The fuzzy performance index has been calculated at the 2nd level indices and then extended to 1st level indices.

The fuzzy performance index of 1st level can be calculated as follows:

$$U_i = \frac{\sum_{j=1}^{n} \left(w_{ij} \otimes U_{ij} \right)}{\sum_{j=1}^{n} w_{ij}} \tag{1}$$

Here U_{ij} represent aggregated performance measure (rating) and w_{ij} represent aggregated fuzzy weight for priority importance corresponding to 2nd level index C_{ij} which is under i_{th} 1st level index.

$$U\left(FPI\right) = \frac{\sum_{i=1}^{n} \left(w_i \otimes U_i \right)}{\sum_{i=1}^{n} w_i} \tag{2}$$

Thus, overall fuzzy performance index $U\left(FPI\right)$ can be obtained as given in Eq. 2.

Here U_i =Rating of i^{th} 1st level index C_i; w_i =Weight of i^{th} 1st level index, and $i = 1, 2, 3, ... n$.

The FPI thus becomes **(3.29, 6.98, 14.59)**. FPI can be compared with predefined performance estimate fuzzy scale set by the management to check the existing performance level for the said green supply chain and to seek for week performing areas which need future improvement.

Step 4: Identification of week areas which need future improvement

After evaluating FPI, simultaneously it is also felt indeed necessary to identify and analyze the week areas towards performance improvement. *Fuzzy Performance Importance Index (FPII)* may be used to identify these ill-performing areas. FPII combines the performance rating and importance weight of various 2nd level indices. The higher the FPII of a factor, the higher is the contribution. The FPII can be calculated as follows in Eqs. 3-4. The concept of FPII was introduced by (Lin et al., 2006) for agility extent measurement in supply chain.

$$FPII_{ij} = w'_{ij} \otimes U_{ij} \quad (3)$$

Here, $w'_{ij} = \left[(1,1,1) - w_{ijk}\right]$ (4)

w_{ij} is the fuzzy importance weight of j_{th} 2nd level index which is under i_{th} 1st level index.

If used directly to calculate the FPII, the importance weights w_{ij} will neutralize the performance ratings in computing FPII; in this case it will become impossible to identify the actual weak areas (low performance rating and high importance). If w_{ij} is high, then the transformation $\left[(1,1,1) - w_{ijk}\right]$ is low. Consequently, to elicit a factor with low performance rating and high importance, for each 2nd level index C_{ij} (j_{th} 2nd level index under i_{th} 1st level index), the fuzzy performance importance index $FPII_{ij}$, indicating the effect of each 2nd level index that contributes to FPI, has been defined as:

$$FPII_{ij} = w'_{ijk} \otimes U_{ij} \quad (5)$$

FPII need to be ranked to identify individual attribute's performance level. Based on that 2nd level indices have been ranked accordingly and ill-performing attributes have been sorted out. In future, the particular industry should pay attention towards improving those attribute aspects in order to boost up overall green supply chain performance extent.
Computed FPII against each 2nd level index has been obtained. Ranking scores based on u_T^{α} (of FPIIs) have been evaluated next. In this computation, three types of DMs risk-bearing attitude (optimistic, neutral and pessimistic: $\alpha = 1, 0.5, 0$) have been considered for the decision-making process. The revised ranking method proposed by (Chou et al., 2011) has been explored in this computation. Ranking provides necessary information about comparative performance picture of existing attributes. By this way, 2nd level indices have been ranked accordingly and thus, improvement opportunities have been verified.

3. Conclusions

Around the world, interest in protecting the environment and in purchasing green products is becoming more and more popular. In addition, governments continue to pass more comprehensive laws designed to protect the environment. Manufacturers are realizing how important it is to provide green products made using green practices. The first steps were to improve environment management, Hazardous Substance Management, Waste Control and Recycling. Of course, the benefits of adopting the *Green Supply Chain Management* are tremendous to everyone. The processes that are implied by this environmental friendly management help businesses to reduce the environmental load of the atmosphere, low production prices, reduce ownership's expenses, minimize the amount of resources for consumption and many others. In addition, the *green management* helps business owners to increase their performances, get competitive advantages, obtain more profits, reduce production risks, and gain a great reputation and ethical image. The aforesaid study aimed to develop an appraisement index system to evaluate green supply chain performance extent in fuzzy environment. The model adapted here can be extended to evaluate ill-performing areas in order to prosper in future by incorporating special managerial attention and strategies.

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Table 1: Green supply chain performance appraisement platform

Targeted Goal (C)	Primary Indices (C_i)	Secondary Indices (C_{ij})
Green supply chain performance index	Business process (C_1)	Raised production capacity rates (C_{11})
		Waiting order ratio (C_{12})
		Supply chain information sharing rate (C_{13})
		Product qualification rate (C_{14})
	Financial value (C_2)	Profit growth rate (C_{21})
		Asset liability ratio (C_{22})
		Return on equity (C_{23})
		Sales profit margins (C_{24})

		Total asset turnover (C_{25})
	Cost (C_3)	Human resource cost (C_{31})
		Logistics lost (C_{32})
		Information cost (C_{33})
		Waste processing cost (C_{34})
		Asset costs (C_{35})
	Customer Service (C_4)	Market share (C_{41})
		Shortage frequency (C_{42})
		Response time against complaint (C_{43})
	Environmental performance (C_5)	Raw material and resource utilization (C_{51})
		Emissions (C_{52})
		Waste recycling (C_{53})

Table 2: Definitions of linguistic variables for criteria ratings
(A-7 member interval linguistic term set)

Linguistic Variables (Attribute ratings)	Fuzzy Numbers (Ratings)	Linguistic Variables (Attribute/capability weights)	Fuzzy Numbers (Priority weights)
Worst (W)	(0, 0.5, 1.5)	Very Low (VL)	(0, 0.05, 0.15)
Very Poor (VP)	(1, 2, 3)	Low (L)	(0.1, 0.2, 0.3)
Poor (P)	(2, 3.5, 5)	Fairly Low (FL)	(0.2, 0.35, 0.5)
Fair (F)	(3, 5, 7)	Medium (M)	(0.3, 0.5, 0.7)
Good (G)	(5, 6.5, 8)	Fairly High (FH)	(0.5, 0.65, 0.8)
Very Good (VG)	(7, 8, 9)	High (H)	(0.7, 0.8, 0.9)
Excellent (E)	(8.5, 9.5, 10)	Very High (VH)	(0.85, 0.95, 1.0)

Table 3: Importance weight of primary indices collected the group of decision-makers (DMs)

Criteria (C_i)	Importance of each primary indices				
	DM_1	DM_2	DM_3	DM_4	DM_5
Business Process (C_1)	H	H	FH	FH	FH
Financial Value (C_2)	H	VH	VH	H	H
Cost (C_3)	VH	VH	H	VH	VH
Customer Service (C_4)	FH	M	FH	FH	FH
Environmental Performance (C_5)	H	VH	H	VH	VH

Table 4: Importance weight of secondary indices collected the group of DMs

Secondary Indices (C_{ij})	Importance of each secondary indices				
	DM_1	DM_2	DM_3	DM_4	DM_5
Raised production capacity rates (C_{11})	H	H	H	H	H
Waiting order ratio (C_{12})	H	VH	VH	H	VH
Supply chain information sharing rate (C_{13})	FH	M	M	FH	FH
Product qualification rate (C_{14})	FH	H	H	FH	H
Profit growth rate (C_{21})	VH	VH	H	VH	VH
Asset liability ratio (C_{22})	FH	M	M	FH	M
Return on equity (C_{23})	H	H	FH	H	H

Sales profit margins (C_{24})	VH	VH	VH	H	VH
Total asset turnover (C_{25})	H	H	FH	H	H
Human resource cost (C_{31})	FH	H	H	FH	H
Logistics lost (C_{32})	VH	VH	VH	VH	VH
Information cost (C_{33})	VH	H	VH	H	H
Waste processing cost (C_{34})	H	VH	H	H	H
Asset costs (C_{35})	H	H	H	H	VH
Market share (C_{41})	FH	H	FH	FH	FH
Shortage frequency (C_{42})	M	FH	M	FH	FH
Response time against complaint (C_{43})	FH	H	FH	FH	FH
Raw material and resource utilization (C_{51})	H	VH	H	VH	VH
Emissions (C_{52})	H	H	VH	VH	VH
Waste recycling (C_{53})	H	VH	VH	VH	VH

Table 5: Appropriateness rating of secondary indices collected the group of DMs

Secondary Indices (C_{ij})	Rating of each secondary indices				
	DM_1	DM_2	DM_3	DM_4	DM_5
Raised production capacity rates (C_{11})	G	G	G	G	VG
Waiting order ratio (C_{12})	F	F	G	F	G
Supply chain information sharing rate (C_{13})	VG	G	E	G	VG
Product qualification rate (C_{14})	F	G	F	G	F
Profit growth rate (C_{21})	G	F	G	G	G
Asset liability ratio (C_{22})	F	F	F	F	F
Return on equity (C_{23})	G	G	G	G	G
Sales profit margins (C_{24})	E	VG	E	E	E
Total asset turnover (C_{25})	VG	G	G	VG	VG
Human resource cost (C_{31})	G	VG	G	G	G
Logistics lost (C_{32})	VG	E	VG	VG	VG
Information cost (C_{33})	VG	G	G	G	VG
Waste processing cost (C_{34})	VG	E	E	E	E
Asset costs (C_{35})	G	G	G	G	G
Market share (C_{41})	F	G	F	F	F
Shortage frequency (C_{42})	G	VG	G	G	G
Response time against complaint (C_{43})	F	P	F	F	F
Raw material and resource utilization (C_{51})	VG	E	G	G	G
Emissions (C_{52})	G	VG	VG	G	G
Waste recycling (C_{53})	E	E	VG	E	VG