Evaluating Supplier Appraisement Index in Green Supply Chain using grey numbers

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Abstract
With growing worldwide awareness of environmental protection, green production has become an important issue for almost every manufacturer sector which will influence the sustainability of a manufacturer in the long term. A performance evaluation system for green suppliers is indeed necessary in order to determine the suitability of suppliers to cooperate with the firm effectively. Related research on performance evaluation and/or selection of suppliers are seemed abundant for traditional supply chain management, however, those that concern environmental issues thereby incorporating environmental performance criteria are rather limited. To this end, the present research aims to develop an efficient measurement index evaluation system towards assessing suppliers' green performance practices. In order to tackle incompleteness and imprecision arising from assigning appropriateness rating as well as priority weights against subjective performance criteria, use of grey numbers has been proposed in this reporting. A case study reflects effectiveness of exploring grey relation theory in the context of green supplier evaluation.
Keywords: green supplier; green performance; grey relation theory

1. Introduction and Prior Sate of Art

In a today's highly competitive marketplace, consumers are demanding high quality products, with quicker delivery, economic price and excellent services. In addition to that, environmental challenges, such as global warming, acid rain etc have resulted greater concern of the organizations regarding their environmental management. The global movement towards green and more eco-sustainable business strategies plays an important role in today's global supply chain management. In the last few years, lawmakers and regulatory agencies, such as the Environmental Protection Agency (EPA), Governments etc are focusing towards environmental concern and have already passed strict rules and regulation against companies to improve their greening activities i.e., environmental performance. Appropriate supplier selection is one of the major key success factors for supply chains. Therefore, while selecting best supplier on the basis of cost, quality, delivery, reliability, performance, etc may not be enough, however, industries should also incorporate environmental aspects in relation to green performance of the candidate suppliers. Extent of green performance is recently being viewed as one of the potential supplier selection criterion, as it plays a major role in improving organizational environmental performance against environmental challenges. Hence, the concept of green supplier selection arises in supply chain management, so as to make any organization 'green', as environmental responsibility has become a business imperative.

As the pace of market globalization quickens, the number of potential suppliers and the number of factors to be considered increases in potential suppliers selection, which in turn results in enhancement of supplier selection decisions, by the fact that various criteria must be considered in the decision making process. Green supplier selection criteria arise from an organization inclination to respond to any existing trends in environmental issues related to business management and allied processes. Green supplier selection criteria may be developed with intent of focusing on meeting government regulations, focusing on process improvement, and focusing on buying company's environmental policy.

Noci (1997) designed a conceptual approach that first identified measures for assessing a supplier's environmental performance and, secondly, suggested effective techniques for developing the supplier selection procedure according to an environmental viewpoint.

Angell and Klassen (1999) presented a report on the research that was done in the field of environmental operations management. The authors developed an integrated and extended perspective of environmental operations management that could be a guidepost for future research. This perspective was structured along two dimensions: process of environmental improvement and level of analysis. Manufacturing strategy, supply chain management, technology management and quality were found areas where strong opportunities for gaining better understanding of environmental issues and enhancing practice could be seen.

Jabbour and Jabbour (2009) attempted to verify if Brazilian companies were adopting environmental requirements in the supplier selection process. Further, this paper intended to analyze whether there was a relation between the level of environmental management maturity and the inclusion of environmental criteria in the companies' selection of suppliers.

Wen and Chi (2010) considered a criteria set including green, traditional, and partnership issues for the green supplier selection problem. The criteria set took carbon footprint into account, because the international regulations had paid much attention on the carbon footprint exposure in recent years. This study introduced Data Envelopment Analysis (DEA) into assessment, and combined with AHP to establish an integrated model.

Kumar and Jain (2010) proposed a comprehensive approach for suppliers' selection, which aimed to cut across a huge variety of supplier base, cater to almost all businesses, was environment-friendly and robust. The approach encouraged suppliers to go green and cut down their carbon footprints in order to survive the competition.

Thongchattu and Siripokapirom (2010) contributed a green supply chain supplier selection model by using an Analytical Hierarchy Process (AHP) which allowed the decision maker to structure complex problems. The framework involved a number of difference criteria based on Company Reliability, Material Quality, Material Price, Environmental Project and standard for environmental management systems (ISO14000). This paper proposed the consensus final decision by neural network technique by minimizing a limitation error set.

Peng (2012) applied Analytical Hierarchy Process (AHP) and Grey Relational Analysis (GRA) to model supplier evaluation index system in green supply chain management. Based on the complexity of the evaluation index for supplier selection in green supply chain, Li et al. (2012) attempted to develop an evaluation index system in green supply chain using BP neural network to select potential supplier with evaluation indexes as BP neural network's input and the outcome of DEA/AHP model as BP neural networks expected output. Lee et al. (2009) proposed a model for evaluating green suppliers. The Delphi method was applied first to differentiate the criteria for evaluating traditional suppliers and green suppliers. A hierarchy was then constructed using fuzzy extended analytic hierarchy process to help evaluate the importance of the selected criteria and the performance of green suppliers. Wang et al. (2011) proposed a supplier selection system of pharmaceutical green supplier by combining fuzzy set theory and TOPSIS methods. The validity and practicality of the research were demonstrated through a case.

The supplier selection problem involves analyzing and measuring the performance of a set of candidate suppliers towards ranking and selecting the appropriate one for improving the competitiveness of the whole supply system. As many conflicting factors should be taken into account in the analysis, this problem is usually tackled using Multi-Criteria Group Decision Making (MCGDM) models. In recent years, an increasing environmental awareness has favored the emergence of the green supply chain paradigm; therefore, in the supplier selection problem, green criteria have to be incorporated (Genovese et al., 2010).

Most of the supplier selection criteria being subjective in nature, it is difficult to assign numeric score against criteria performance. Moreover, priority weights of the criterions may vary according to the individual perception of the decision-makers (DM). Due to uncertainty in subjective judgment of the decision-makers, fuzziness arises in the decision-making problem. Literature depicts that such kind of inconsistency, imprecision can be overcome by representing appropriateness rating as well as weight against each criterion by grey or fuzzy numbers (Li et al., 2007; 2008; Ordoobadi, 2009). In this context, the present study highlights application of grey theory [Deng, 1982; Xia, 2000, Shi et al., 2005] and fuzzy logic towards estimating an equivalent single performance index in relation to suppliers' green practices. A green supplier evaluation carried out in an Indian automobile sector has been presented here as a case study.

2. Proposed Appraisement Index Evaluation Platform

The green suppler evaluation index platform adapted in this paper has been shown in Table 1. The 2-level hierarchical model consists of various green enablers as well as green criteria. Enterprise ability, service level, cooperation degree and environmental factors have been considered as green capabilities at the 1st layer followed by 2nd layer which encompasses a number of green attributes. An approach based on grey numbers as well as grey possibility degree has been used to evaluate an overall performance index of suppliers. This method is very suitable for solving the group decision-making problem under uncertainty environment. Assume that $Q = \{Q_1, Q_2, ..., Q_n\}$ is a set of n attributes of suppliers. The attributes are additively independent. $\otimes w = \{\otimes w_1, \otimes w_2, ..., \otimes w_n\}$ is the vector of attribute weights. In this paper, the attribute weights and corresponding appropriateness ratings (performance) of individual candidate supplier are considered as linguistic variables (Xu and Sasaki, 2004). Here, these linguistic variables corresponding to weight assignment can be expressed in grey numbers by 1-7 scale as shown in Table 2. The attribute ratings $\otimes G$ can be also expressed in grey numbers by 1-7 scale shown in Table 3. The procedural steps are summarized as follows:

Step 1: Form a committee of decision-maker and identify attribute weights of suppliers. Assume that a decision-making group has K persons, then the attribute weight of attribute Q_j can be calculated as:

$$\otimes w_j = \frac{1}{K}\left[\otimes w_j^1 + \otimes w_j^2 + ... + \otimes w_j^K\right] \tag{1}$$

Here, $\otimes w_j^K \left(j = 1, 2, ..., n\right)$ is the attribute weight of k_{th} DM and can be described by grey number $\otimes w_j^K = \left[\underline{w}_j^K, \overline{w}_j^K\right]$

Step 2: Using linguistic variables for the ratings to make attribute rating value. Then the rating value can be calculated as:

$$\otimes G_{ij} = \frac{1}{K}\left[\otimes G_{ij}^1 + \otimes G_{ij}^2 + ... + \otimes G_{ij}^K\right] \tag{2}$$

Here $\otimes G_{ij}^K \left(i = 1, 2, ..., m; j = 1, 2, ..., n\right)$ is the attribute rating value of K_{th} DM and can be described by grey number $\otimes G_{ij}^K = \left[\underline{G}_{ij}^K, \overline{G}_{ij}^K\right]$.

Step 3: Estimation of appraisement index is carried out as follows:
GOPI represents the grey overall performance index. The grey index has been calculated at the attribute level and then extended to enabler (capabler) level. Grey index system at 1st level encompasses several green enablers/ capablers.
The grey index of 1st level green capability can be calculated as follows:

$$U_i = \frac{\sum_{j=1}^{n} \left(w_{ij} \otimes U_{ij}\right)}{\sum_{j=1}^{n} w_{ij}} \tag{3}$$

Here U_{ij} represent aggregated performance measure (rating) and w_{ij} represent aggregated grey weight for priority importance corresponding to green attribute C_j.
Thus, grey overall performance index $U(GOPI)$ can be obtained as follows:

$$U(GOPI) = \frac{\sum_{i=1}^{n} \left(w_i \otimes U_i\right)}{\sum_{i=1}^{n} w_i} \tag{4}$$

Here U_i =Rating of i^{th} green capability C_i; w_i =Weight of i^{th} green capability, and $i = 1, 2, 3, \ldots n$.

Step 4: Identification of week areas which need future improvement
After evaluating GOPI, simultaneously it is also felt indeed necessary to identify and analyze the week areas towards green performance improvement. Grey Performance Importance Index (GPII) may be used to identify these obstacles. GPII combines the performance rating and importance weight of various green attributes. The higher the GPII of a factor, the higher is the contribution. The GPII can be calculated as follows in Eqs. 5-6. The concept of GPII is similar to the FPII (Fuzzy Performance Importance Index) that was introduced by (Lin et al., 2006; Vinodh and Devadarsan, 2011) for agility extent measurement in supply chain.

$$GPII_{ij} = w_{ij}' \otimes U_{ij} \tag{5}$$

Here, $w_{ij}' = \left[(1,1) - w_{ijk}\right]$ (6)

w_{ij} is the grey importance weight of j_{th} green attribute under i_{th} green capability.
If used directly to calculate the GPII, the importance weights w_{ij} will neutralize the performance ratings in computing GPII; 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 $\left[(1,1) - w_{ij}\right]$ is low. Consequently, to elicit a factor with low performance rating and high importance, for each green-enable-attribute ij (j_{th} attribute under i_{th} green capability), the grey performance importance index $GPII_{ij}$, indicating the effect of each green-enable-attribute that contributes to GOPI, is defined as:

$$GPII_{ij} = \left[(1,1) - w_{ij}\right] \otimes U_{ij} \tag{7}$$

GPII need to be ranked to identify individual attribute's performance level. Based on that poorly performing attributes can be sorted out and in future, the particular supplier should pay attention towards improving those attribute aspects in order to boost up overall green performance extent.

3. Case Study

The proposed evaluation index platform has been explored by an Indian automobile part manufacturing company at eastern part of India. A particular supplier has been evaluated to check its performance level with respect to green attributes. As shown in Table 1 there are eleven green attributes (where, $C_{ij} \approx j_{th}$ attribute under i_{th} green enabler) considered to assess the said evaluation metric (Peng, 2012). The analysis has been carried out using the following steps already discussed above. Numerical illustrations have been furnished below.

Step 1: For evaluating the importance weights of green capabilities as well as 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 in linguistic terms (Tables 4-5) which have been further transformed into grey numbers.

Step 2: Similarly, the decision-making group has been instructed to assign appropriateness rating against performance of various green attributes using linguistic evaluation score (Table 6).

Step 3: Using Eqs. 13-14 group decision has been combined to compute aggregated grey performance rating of green attributes. Similarly aggregated grey priority weights have also been computed for green capabilities as well as green attributes. Results of computations have been furnished in Tables 7-10. Eq. 15 has been used to evaluate performance rating of each green capability at level 1. Finally, grey overall performance index (GOPI) has been computed using Eq. 16. The GOPI thus becomes [3.228, 11.78] which can be compared with predefined grey measurement scale set by the management to check the existing green performance level for the said supplier and to seek for week performing areas which need future improvement.

Step 4: Grey Performance Importance Index (GPII) has been computed against each of the green attribute and furnished in Table 11. The concept of 'grey possibility' degree has been explored to identify poorly performing areas of the candidate supplier considered. Grey possibility degree between GPII (of individual green attributes) has thus been computed. Lesser value of grey possibility degree corresponds to higher degree of performance. In other word, the attribute whose GPII's grey possibility degree is less; is said to be contributing more to the overall grey performance estimate. By this way, green attributes (under each green capability) have been ranked accordingly (Table 12) and thus, improvement opportunities have been verified.

4. Conclusions

Over the last two decades, growing concerns about ecosystem quality have stimulated to a renewed interest in environmentalism. Purchasing professionals should also be concerned and need to rethink purchasing strategies which have traditionally neglected environmental impacts. The 'green' purchasing-packaging in reducing and eliminating waste is a major concern in recent days. In order to help foster environmentally concerned purchasing strategies, this article presents the findings of supplier evaluation strategy in an enterprise with enhanced degree of awareness and frequent applications of 'green' purchasing. Environmental factors are identified that may reshape supplier evaluation decisions. The concept of grey numbers set has been adopted in this work.

The major contributions of this work have been summarized as follows:

1. Development and implementation of an efficient decision-making tool to support green supplier evaluation.
2. An overall green performance index evaluation platform has been introduced.
3. Concept of grey numbers has been efficiently explored to facilitate this decision-making.

4. The appraisement index system has been extended with the capability to search ill-performing areas which require future progress.

5. References

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Table 1: Green supplier evaluation index system

Target Layer (C)	Rule Layer (C_i) (green capabler)	Project Hierarchy (C_{ij}) (green attributes)
Evaluation of green supplier	Enterprise ability (C_1)	Volume flexibility (C_{11})
		Scale of production (C_{12})
		Information level (C_{13})
	Service level (C_2)	Price rate (C_{21})
		Delivery time (C_{22})
		Delivery-check qualified rate (C_{23})
	Cooperation degree (C_3)	On-time delivery rate (C_{31})
		Average order completion ratio (C_{32})
	Environmental factors (C_4)	Content of hazardous substances (C_{41})
		Energy consumption (C_{42})
		Harmless rate (C_{43})

Table 2: The scale of attribute weights $\otimes w$

Scale	$\otimes w$
Very Low (VL)	[0.0, 0.1]
Low (L)	[0.1, 0.3]
Medium Low (ML)	[0.3, 0.4]
Medium (M)	[0.4, 0.5]
Medium High (MH)	[0.5, 0.6]
High (H)	[0.6, 0.9]
Very High (VH)	[0.9, 1.0]

Table 3: The scale of attribute ratings $\otimes G$

Scale	$\otimes w$
Very Poor (VP)	[0, 1]
Poor (P)	[1, 3]
Medium Poor (MP)	[3, 4]
Fair (F)	[4, 5]
Medium Good (MG)	[5, 6]
Good (G)	[6, 9]
Very Good (VG)	[9, 10]

Table 4: Priority weight of green attributes given by decision-makers

Green attributes C_{ij}	Weight w_{ij}	Priority weight expressed in grey numbers				
		DM1	DM2	DM3	DM4	DM5
C_{11}	w_{11}	VH	H	H	H	VH
C_{12}	w_{12}	MH	MH	H	H	H
C_{13}	w_{13}	VH	VH	VH	H	VH
C_{21}	w_{21}	M	MH	MH	MH	MH
C_{22}	w_{22}	H	MH	VH	VH	VH
C_{23}	w_{23}	H	H	H	H	H
C_{31}	w_{31}	VH	VH	H	VH	VH
C_{32}	w_{32}	H	H	H	H	H
C_{41}	w_{41}	H	VH	H	VH	H
C_{42}	w_{42}	MH	H	VH	MH	H
C_{43}	w_{43}	VH	VH	VH	H	H

Table 5: Priority weight of green capablers given by decision-makers

Green capablers C_i	Weight w_i	Priority weight expressed in grey numbers				
		DM1	DM2	DM3	DM4	DM5
C_1	w_1	VH	H	VH	VH	VH
C_2	w_2	H	VH	VH	H	H
C_3	w_3	H	H	MH	H	H
C_4	w_4	VH	VH	H	H	H

Table 6: Appropriateness rating on green attributes given by decision-makers

Green attributes C_i	Rating U_i	Appropriateness rating expressed by grey numbers				
		DM1	DM2	DM3	DM4	DM5
C_{11}	U_{11}	VG	G	MG	MG	VG
C_{12}	U_{12}	G	G	G	MG	MG
C_{13}	U_{13}	F	F	MG	F	F
C_{21}	U_{21}	MP	F	MG	MG	MG
C_{22}	U_{22}	F	MG	F	F	F
C_{23}	U_{23}	G	G	VG	VG	VG
C_{31}	U_{31}	G	G	G	G	G
C_{32}	U_{32}	MG	MG	F	MG	MG
C_{41}	U_{41}	MP	F	MP	MP	MP
C_{42}	U_{42}	G	VG	G	VG	G
C_{43}	U_{43}	MG	F	G	G	G

Table 7: Grey aggregated appropriateness rating on green attributes

Green attributes $C_{i,j}$	Rating $U_{i,j}$	Grey aggregated appropriateness rating (values) $U_{i,j}$	Grey aggregated weighted appropriateness rating (values) $U_{i,j} \otimes w_{ij}$
C_{11}	U_{11}	[6.80, 8.20]	[4.90, 7.71]
C_{12}	U_{12}	[5.60, 7.80]	[3.14, 6.08]
C_{13}	U_{13}	[4.20, 5.20]	[3.53, 5.10]
C_{21}	U_{21}	[4.40, 5.40]	[2.29, 3.56]
C_{22}	U_{22}	[4.20, 5.20]	[3.19, 4.68]
C_{23}	U_{23}	[7.80, 9.60]	[4.68, 8.64]
C_{31}	U_{31}	[6.00, 9.00]	[5.04, 8.82]
C_{32}	U_{32}	[4.80, 5.80]	[2.88, 5.22]
C_{41}	U_{41}	[3.20, 4.20]	[2.30, 3.95]
C_{42}	U_{42}	[7.20, 9.40]	[4.46, 7.52]
C_{43}	U_{43}	[5.40, 7.60]	[4.21, 7.30]

Table 8: Grey aggregated priority weight of green attributes

Green attributes C_{ij}	Weight w_{ij}	Grey aggregated priority weight (values) w_{ij}
C_{11}	w_{11}	[0.72, 0.94]
C_{12}	w_{12}	[0.56, 0.78]
C_{13}	w_{13}	[0.84, 0.98]
C_{21}	w_{21}	[0.52, 0.66]
C_{22}	w_{22}	[0.76, 0.90]
C_{23}	w_{23}	[0.60, 0.90]
C_{31}	w_{31}	[0.84, 0.98]
C_{32}	w_{32}	[0.60, 0.90]
C_{41}	w_{41}	[0.72, 0.94]
C_{42}	w_{42}	[0.62, 0.80]
C_{43}	w_{43}	[0.78, 0.96]

Table 9: Aggregated grey priority weight of green capablers

Green capablers C_i	Weight w_i	Aggregated grey priority weight w_i
C_1	w_1	[0.84, 0.98]
C_2	w_2	[0.72, 0.94]
C_3	w_3	[0.58, 0.84]
C_4	w_4	[0.72, 0.94]

Table 10: Grey performance rating of green capablers (Supplier A)

Green capablers C_i	Weight U_i	Grey performance rating U_i	Weighted grey performance rating $U_i \otimes w_i$
C_1	U_1	[4.29, 8.91]	[3.60, 8.73]
C_2	U_2	[4.13, 8.98]	[2.97, 8.44]
C_3	U_3	[4.21, 9.75]	[2.44, 8.19]
C_4	U_4	[4.06, 8.85]	[2.93, 8.32]

$$U(GOPI) = W1 \times U1 + W2 \times U2 + W3 \times U3 + W4 \times U4 / W1 + W2 + W3 + W4$$
$$= [3.228, 11.78]$$

Table 11: Computation of grey performance importance index (GPII) of green attributes

Green attributes $C_{i,j}$	Grey aggregated appropriateness rating (values) $U_{i,j}$	Grey aggregated weights w_{ij}	Grey performance Importance index (GPII) $\lfloor 1 - w_{ij} \rfloor \otimes U_{i,j}$
C_{11}	[6.80, 8.20]	[0.72, 0.94]	[0.408, 2.296]
C_{12}	[5.60, 7.80]	[0.56, 0.78]	[1.232, 3.432]
C_{13}	[4.20, 5.20]	[0.84, 0.98]	[0.084, 0.832]
C_{21}	[4.40, 5.40]	[0.52, 0.66]	[1.496, 2.592]
C_{22}	[4.20, 5.20]	[0.76, 0.90]	[0.420, 1.248]
C_{23}	[7.80, 9.60]	[0.60, 0.90]	[0.780, 3.840]
C_{31}	[6.00, 9.00]	[0.84, 0.98]	[0.120, 1.440]
C_{32}	[4.80, 5.80]	[0.60, 0.90]	[0.480, 2.320]
C_{41}	[3.20, 4.20]	[0.72, 0.94]	[0.192, 1.176]
C_{42}	[7.20, 9.40]	[0.62, 0.80]	[1.440, 3.572]
C_{43}	[5.40, 7.60]	[0.78, 0.96]	[0.216, 1.672]

Table 12: Attribute performance ranking (under each green capability) by comparing GPII

Green attributes $C_{,ij}$	Grey performance Important Index (GPII) $[1-w_{ij}]\otimes U_{i,j}$	Grey Possibility degree	Attribute ranking Under Enterprise ability (C_1)
C_{11}	[0.408, 2.296]	0.740	2
C_{12}	[1.232, 3.432]	0.500	1
C_{13}	[0.084, 0.832]	1.000	3

Green attributes $C_{,ij}$	Grey performance Important Index (GPII) $[1-w_{ij}]\otimes U_{i,j}$	Grey Possibility degree	Attribute ranking Under of Service level (C_2)
C_{21}	[1.496, 2.592]	0.681	2
C_{22}	[0.420, 1.248]	1.000	3
C_{23}	[0.780, 3.840]	0.566	1

Green attributes $C_{,ij}$	Grey performance Important Index (GPII) $[1-w_{ij}]\otimes U_{i,j}$	Grey Possibility degree	Attribute ranking Under Cooperation degree (C_3)
C_{31}	[0.120, 1.440]	0.696	2
C_{32}	[0.480, 2.320]	0.500	1

Green attributes $C_{,ij}$	Grey performance Important Index (GPII) $[1\text{-}w_{ij}]\otimes U_{i,j}$	Grey Possibility degree	Attribute ranking Under Environmental factors (C_4)
C_{41}	[0.192, 1.176]	1.000	3
C_{42}	[1.440, 3.572]	0.500	1
C_{43}	[0.216, 1.672]	0.935	2