Multi tier supplier selection for a sustainable global supply chain

N. Viswanadham and A. Samvedi

Abstract: **Using the green supply chain supply ecosystem consisting of the supply chain, resources involved, the government and social factors and the delivery mechanism, we formulate the risk and performance criteria as qualitative as well as quantitative measures. Then we solve the multi tier sustainable supplier selection problem using grey relational analysis approach.**

I. Introduction

The most often quoted definition of sustainability is "development that meets the needs of the present without compromising the ability of future generations to meet their needs." Organizations are implementing sustainable supply chain policies due to either reactive regulatory reasons or rising prices of energy and raw materials, to proactive strategic and competitive advantage reasons. Green supply chain emphasizes minimum consumption of resource and energy, and the minimum green house gas emissions. Green supply chain adds a role of recycler function, the reuse of products or parts, and the recycling of material and energy, which forms the closed-loop of material flow. The performance of the green supply chain is judged in terms of energy consumption, percentage of product that is recoverable and its cost and time, toxic and hazardous materials used or generated, Green House Gases (GHG) generated etc [1].

There is lot of literature on green supply chain networks including excellent survey papers by [1] and [9]. There are MIP formulations of selection of suppliers in green supply chain networks [5, 7 and 8]. There are also AHP and grey net work formulations [4]. Despite the clear motivation regarding green supply chain management, there is no established clear cut approach on how to do it [10]. This unstructured approach then brings in different kinds of new risk to the supply chain which are in addition to the risks the chain already faces. Thus deploying a green initiative is not risk-free and hence a good risk management is also needed [12].

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In this paper, our approach is first to present in section 2, the ecosystem map with four elements that completely describe all the features of a green supply chain. We present the performance measures and the risks that are relevant for green supply chain networks using the ecosystem framework. In section 3, we present the grey relational analysis approach and then show the applicability of the approach to such problems by solving a suitable example problem in section 4. Finally we conclude in section 5 giving few future research directions.

II. The Ecosystem

Figure 1 shows the ecosystem of a green supply chain comprising of a) forward-backward supply chains, b) resources, c) institutions, and d) delivery technologies and mechanism. The green supply chain has both forward and backward supply chains. The reverse features add additional complexity to the supply chain design. The delivery mechanisms include inbound, outbound and reverse logistics components. The reverse logistics is a new feature in green supply chains. The transport mode selection, outsourcing or owning the fleet, JIT or Inventory management are all decisions that affect the contribution of the green house gases. Institutions are playing a major role in enforcing and enabling the compliance of environmental regulations. There are three mechanisms to achieve the reduction in emissions: carbon pricing, clean development mechanism (CDM), and joint implementation (JI) [11]. Pricing carbon has become widely acknowledged as a significant catalyst in international efforts to reduce greenhouse gas emissions. There are two mechanisms for delivering carbon prices: carbon tax and carbon trading. While both are institutional enforcements, carbon trading is a market based approach that makes carbon a tradable utility and hence a vital resource in the ecosystem [2]. In addition to GHG emissions, industries significantly influence the environment in the use of raw materials, energy, water, and land. The carbon trading markets have made carbon also a resource though it is emission rather than consumption that is priced. In a global supply chain with many facilities, one can judiciously choose the facilities in different regions such that the emissions can be traded among subsidiaries by balancing carbon reductions with economic justifications.

Preprint submitted to 9th IEEE International Conference on Automation Science and Engineering. Received March 9, 2013.

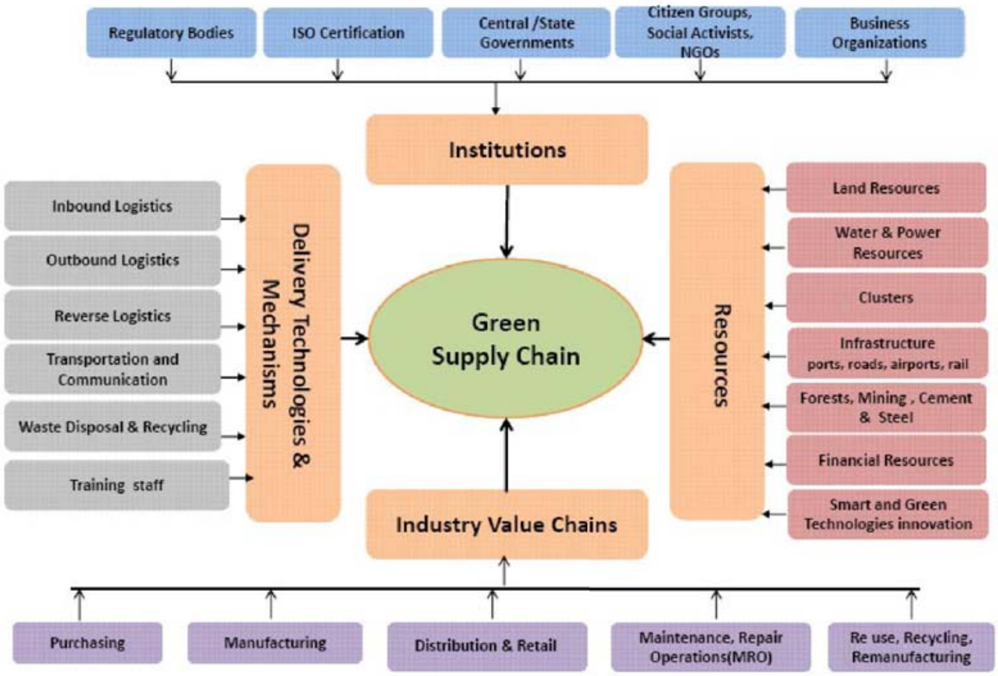

Figure 1: Green Supply Chain Ecosystem [11]

Performance and Risk

The commonly used metric of greenness is carbon footprint. A carbon footprint is the total set of greenhouse gas emissions caused directly and indirectly by an individual, organization, event or product, expressed as carbon dioxide equivalent. In general, the carbon footprint should be measured over the lifecycle of manufacturing, transportation, usage, and recycling or disposal [6]. In addition, green supply chains may include new processes related to repair, re-use, reverse logistics, re-manufacturing, and recycling. A green supply chain ensures greenness in all the three business processes: procurement, manufacturing, and distribution. Green supply chain is essentially taking into account factors like carbon footprint along with conventional drivers like cost, quality, and lead time in all the three business processes. A green supply chain also bring several risks due to market uncertainty, unclear government regulations such as green transportation or promoting electric cars and community campaigns as on nuclear energy [11]. Table 1 list out these risks.

Selection Criteria

The following criteria are chosen to be ones on which the alternatives will be evaluated. As can be seen, the last two criteria are specifically for the upstream subchains of the alternatives. This is because of the fact that the affect of any shortcomings in the upstream tier of the chain will propagate quickly and will have negative consequences. Thus it becomes important to test the upstream subchains of these alternatives than just these alternatives. Figure 2 shows in detail the supplier selection process.

C1) Cost: The cost of products that the company will have to bear if it chooses the particular supplier. This includes the purchase cost plus other life cycle costs such as maintenance costs, consultant expenses and other infrastructure costs.

C2) Lead time: How fast the particular supplier can deliver the order.

C3) Reverse logistics ready: This criterion tests the readiness of the supplier and its subchain for reverse logistics. That is do they use the parts of used products for further manufacturing.

C4) Carbon Foot Print: The full footprint of an organization encompasses a wide range of emissions sources, from direct use of fuels to indirect impacts such as employee travel or emissions from other organizations within the supply chain. The carbon footprint as the performance metric thus should be measured over the entire supply chain, from raw materials to final packing and delivery.

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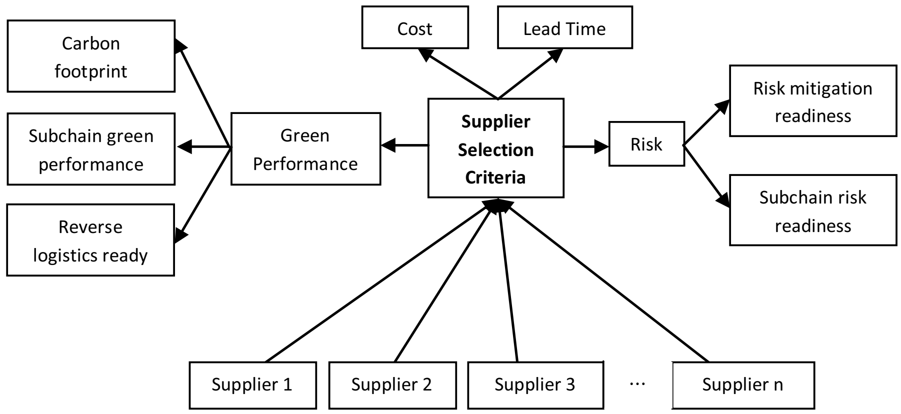

Figure 2: Combined performance risk based supplier selection hierarchy

Table 1: Risk classification by ecosystem approach [11]

Risk classification	Risk subclassification
Planning and product related risks	• Pollutants during the production • Waste disposal, hazardous waste liability, Recycling • Unstable governance structure: opportunistic behavior by partners • Community influence on buying patterns & legislative process • Perceived non-commitment by top management • Product recalls and after effects
Resources related risk	• Criminal / Insurance liability for violations and accidents • Inability to identify and remedy non-compliance or risk problems • Accidents due to a lack of training or awareness • Public pressures to Ban or restrict raw materials due to non-compliance penalties
Institutional risk	• Political/social pressures for regulations • Policy Changes • Changes during elections
Due to delivery infrastructure	• Reverse logistics and Waste disposal infrastructure • Operational readiness for accidents

C5) Risk mitigation readiness: How best this supplier can handle the situations when the normal operations of a supply chain has been disrupted and also how well it can help to mitigate such risks

C6) Subchain green performance: How green are the operations of the upstream subchain of that alternative.

C7) Subchain risk readiness: How risk prepared are the operations of the upstream subchain of that alternative.

Table 2 explains how does a supply chain perform under green criteria when influenced by enablers of a sustainable supply chain from all parts of ecosystem.

III. Proposed Method

The theory and applications of grey systems has been gaining increasing attention these days. This is in line with the growing recognition that the real life decisions involve uncertainty. The method of grey analysis is an approach to handle this uncertainty. The theory is based on the degree of information known. The advantage of grey theory over fuzzy theory is that grey theory takes into account the condition of the fuzziness; that is, grey theory can deal flexibly with the fuzziness situation [4]. It is used for the mathematical analysis of systems with discrete data and uncertain information. A MCDM methodology, based on grey relational analysis has been proposed here. The stepwise discussion on the proposed methodology is given below:

Table 2: Enablers and supply chain performance

	Product & Value chain	Trade Policies	Delivery Infrastructure	Resource Management
Enablers	Remanufacturing, Closed loop Supply Chains, GHG	Green Regulations, Carbon Trading, Gas Emission Limits, ISO Certification	Reverse Logistics, Carbon Efficient Transportation, Smart & Green Warehousing	Water, Green Power, Clusters, Carbon Trade
Cost	High	High	High initial investment, lower costs thereafter	High initial investment, lower costs thereafter
Lead time	High	High	High	High
GHG emissions	Low if product is refurbished or else high	Low	Low	Low
Green Performance	Less pollution per product	High SC motivation for greening	Green transportation like electric vehicles	Less polluting resources used like nuclear power

Step 1: Construct a committee of decision makers and determine the IS alternatives and selection criteria to be considered. The latter has been defined in Section 3.1 for this study.

Step 2: Obtain the decision matrix by identifying the criteria values as triangular fuzzy numbers or linguistic terms.

Step 3: Normalize the decision matrix as shown in Karsak (2002). The normalized values for fuzzy data denoted by triangular fuzzy numbers as (a_{ij}, b_{ij}, c_{ij}), for benefit-related criteria (B) and cost-related criteria (C) are given as:

$$r_{ij} = (r_{aij}, r_{bij}, r_{cij}) = \begin{cases} \left(\dfrac{a_{ij} - a_j^-}{c_j^* - a_j^-}, \dfrac{b_{ij} - a_j^-}{c_j^* - a_j^-}, \dfrac{c_{ij} - a_j^-}{c_j^* - a_j^-}\right), & j \in B \\ \left(\dfrac{c_j^* - c_{ij}}{c_j^* - a_j^-}, \dfrac{c_j^* - b_{ij}}{c_j^* - a_j^-}, \dfrac{c_j^* - a_{ij}}{c_j^* - a_j^-}\right), & j \in C \end{cases}$$

where $c_j^* = max_i c_{ij}$ and $a_j^- = min_i a_{ij}$

Step 4: Convert the fuzzy triangular numbers into interval numbers using the α-cut.

Step 5: The weighted interval data is calculated next. The priority weights of the criterion are multiplied to the performance values of alternatives under that criterion. The values are calculated by multiplying the minimum of the weight interval to the minimum of the performance interval to get the start value of the interval. Similarly the end value of the interval is calculated by multiplying the two maximum.

Step 6: The reference number vector is found by using the optimal values from the weighted interval values for every alternative. This can be explained as the maximum value of all the starting values of intervals under a given criterion and also the maximum of all the end values. The values obtained reflect the maximum weighted value obtained in the data set for that attribute.

Step 7: The next step is to find the relational coefficient between each alternative and the reference vector. Suppose there are two sequences denoted by $X_0(k)$ & $X_i(k)$. Then

$$RC_{0,i}(k) = \frac{\Delta_{min} + \tau\Delta_{max}}{\Delta_i(k) + \tau\Delta_{max}}$$

where

$$\Delta_i(k) = |X_0(k) - X_i(k)|$$

is the absolute difference between two comparing sequences.

$$\Delta_{max} = max_i max_k \Delta_j(k)$$
$$\Delta_{min} = min_i min_k \Delta_j(k)$$

are respectively the maximum and minimum values of the absolute differences of the comparing sequences, and τ ε [0,1] is a distinguishing coefficient, the purpose of which is to weaken the effect of Δ_{max} when it gets too big, and thus enlarges the difference significance of the relational coefficient, $RC_{0,i}(k)$ reflect the degree of closeness between the two comparing sequences at k. At Δ_{min}, $RC_{0,i} = 1$, that is, the relational coefficient attains its largest value. While at Δ_{max}, $RC_{0,i}$, attains the smallest value. Hence $0 < RC_{0,i} < 1$, for all i.

Step 8: Grey relational analysis compares relations of sequences in their appropriate metric spaces. If two sequences agree at each point then the grey relational coefficient is 1 everywhere and so their grey relational grade should be 1. Thus we can say that the relational grade between two sequences is the mean of relational coefficient values at different points. It is given as

$$RG_{0,i} = \frac{1}{p}\sum_{k=1}^{p} RC_{0,i}(k)$$

The RG being the relational grade between two sequences and 'p' being the length of the two sequences.

Step 9: The alternative with the highest relational grade is chosen as the best alternative.

The next section illustrates the proposed methodology numerically by applying it to a problem set suggested in a previous study.

IV. Numerical Illustration

After determining all the selection criteria and the methodology to be applied, the supplier alternatives which will be considered for evaluation are finalized. A total of seven alternatives are used here for the illustration of the proposed methodology. The criterion values that fill up the decision matrix have been picked up from [3]. The decision matrix is shown in the Table 3. The assessments for criterion cost and lead time have been given in fuzzy triangular numbers whereas for other criteria linguistic terms have been used. The fuzzy numbers gives us a range in which the value for the said criterion should fall, as well as the most likely value. The linguistic terms (poor, fair, good, very good) are represented such, as they make decision makers more comfortable in providing their assessments to these tangible criteria. They can be converted to fuzzy triangular numbers for the calculation purposes. The membership value graph shown in Figure 3 is used for this conversion. All the criteria used here do not carry equal importance to the selection and thus weights must be assigned to these criteria. This is done by asking the experts about what they feel the weights should be and they are asked to register their answers in linguistic forms (medium, high, very high). The membership value graphs for these have been shown in Figure 4.

Table 3: Data used to evaluate

Alternatives	C1 ($ millions)	C2 (days)	C3	C4	C5	C6	C7
S1	(3.3,3.8,4.3)	(40,42,45)	G	F	G	F	P
S2	(2.9,3.1,3.5)	(31,37,39)	G	G	F	VG	F
S3	(4.5,5.0,5.5)	(29,32,34)	VG	G	G	G	G
S4	(6.1,6.4,6.9)	(52,54,56)	G	F	F	G	VG
S5	(2.9,3.6,3.9)	(39,44,46)	P	G	G	P	G
S6	(6.1,6.7,7.0)	(57,59,64)	VG	VG	F	F	F
S7	(3.0,3.4,3.8)	(34,37,40)	F	P	P	G	VG

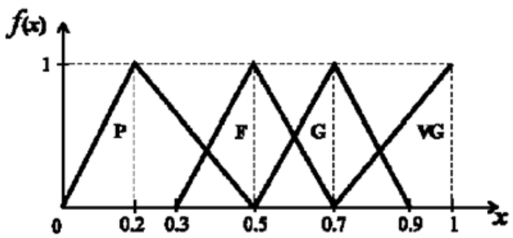

Figure 3: Membership functions for criteria values [3].

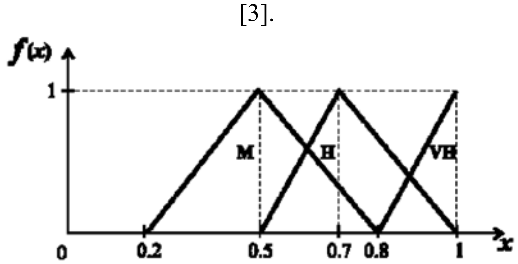

Figure 4: Membership functions for importance weights [3].

The values given by three experts from the decision making committee and the aggregated weights have been tabulated in Table 4. The problem set defined above has been now solved using the proposed methodology in the previous section. The values in the decision matrix are first normalized, before applying the grey relational analysis to it. The normalization process makes the criterion values unit free and comparable. The values in the normalized decision matrix are still in form of fuzzy triangular numbers. This should be converted to intervals so that we can apply GRA to it. This is done by applying α-cut method. The value of $\alpha = 0.5$ is used here.

Table 4: Importance weights and aggregate weights of the criteria [3].

Criteria	DM1	DM2	DM3	Aggregate weights
Cost	H	VH	H	(0.600,0.800,1.000)
Lead time	M	M	H	(0.300,0.567,0.867)
Risk mitigation readiness	H	VH	M	(0.500,0.733,0.933)
Reverse logistics ready	H	VH	M	(0.500,0.733,0.933)
Carbon footprint	M	M	VH	(0.400,0.667,0.867)
Subchain green performance	H	H	VH	(0.600,0.800,1.000)
Subchain risk readiness	H	VH	H	(0.600,0.800,1.000)

The interval numbers are then multiplied with the corresponding criterion weights to get the weighted normalized numbers. These numbers are then used to get the reference number sequence given in Table 5. Distances here are defined as the

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maximum between each interval value and the extremes generated. The maximum distance for each alternative to the ideal is identified as the largest distance calculation. The reference point is the minimum of all minima and maximum of all maxima distance for each alternative. The reference point is [0, 0.7805]. The maximum distance between the reference point and each of the weighted matrix values is given by the formula which gives us the relational coefficients. Here the value of resolving coefficient is 0.3. The average of these weighted values gives us the total score of the alternative and is used to rank the alternatives. The values are tabulated in the Table 6. It lists out the average weighted distances for the alternatives. The rankings based on these values are given as S3 > S2 > S7 > S5 > S1 > S4 > S6. The values also tell that there is not much of a difference in S3 and S2. Thus, if so required due to any reason, S2 can be chosen over S3 without much deterioration in performance. The rankings are also matched up with those given in the paper from where the data has been picked up. The rankings are almost similar and this validates the proposed methodology.

Table 5: Reference number vector

	C1	C2	C3	C4	C5	C6	C7
Max(Min)	0.3659	0.0000	0.2000	0.2000	0.0794	0.3000	0.3000
Max(Max)	1.0000	0.8100	0.9043	0.9043	0.8100	1.0000	1.0000

Table 6: Weighted distances to reference point

	C1	C2	C3	C4	C5	C6	C7	Average
S1	0.7059	0.4791	0.7214	0.4633	1.0000	0.4384	0.3189	0.5896
S2	1.0000	0.8349	0.7214	0.7214	0.5654	1.0000	0.4384	0.7545
S3	0.3750	1.0000	1.0000	0.7214	1.0000	0.7007	0.7007	0.7854
S4	0.2308	0.3055	0.7214	0.4633	0.5654	0.7007	1.0000	0.5696
S5	0.8485	0.5029	0.3412	0.7214	1.0000	0.3189	0.7007	0.6334
S6	0.2308	0.2654	1.0000	1.0000	0.5654	0.4384	0.4384	0.5626
S7	0.8819	0.6693	0.4633	0.3412	0.3941	0.7007	1.0000	0.6358

V. CONCLUSION

In this paper we use the ecosystem map for a green supply chain, to identify the risk and performance parameters in both qualitative and quantitative forms and use these for supplier section. The method can be extended to include more risk and performance measures. Our contribution is the methodology. Several optimization and machine learning techniques can be applied towards selecting the suppliers. This method is immensely useful in the current day scenario of supply chains being subjected to various pressures from governments, resource shortages and logistics issues.

Acknowledgement: The first author would like to thank INAE for all its support. Second author thanks Prof. Y. Narahari (Chairman CSA Dept., IISc) and DST for their support and funds, which helped in successful completion of this study.

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