A novel hybrid MCDM approach based on DEMATEL, AHP and TOPSIS to evaluate green suppliers

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Abstract. This study presents a new hybrid strategic decision-making framework for multi-criteria assessment for Green Supply Chain supplier selection, which joins numerous green processes with order allocation for vibrant supply chains to deal with market differences. More precisely, the established approach replicates the knowledge attainment and manipulation in a way same to the decision makers who have congregated significant knowledge and expertise in procurement domain. DEMATEL is first applied to find the causal relationship between the criteria and to find out the most affecting criteria. AHP method is used for evaluation of green supplier criteria weights, which are qualitatively expressive. Thereafter, using TOPSIS method, the criteria application is quantitatively assessed for order allocation of suppliers. As a result, the approach produces decision-making knowledge, and thereafter, the established combination of rules for order allocation. To illustrate the applicability of the developed framework, a real-life study Indian electronics industry is developed, and the results are analysed accordingly.

1. Introduction
Awareness to safeguard environment in India and world is increasing due to which the green vogue to safeguard environment and conserve resources of earth is overwhelming, by that compelling industries in India and worldwide to adopt the same. As we know that industries are the backbone of a nation and industrialisation at highest possible rate would be the prime need of the time. Most of the underdeveloped countries focuses only on developments and forget about the environment protection concerned. Today, the world is heading towards greater environmental concern and awareness, keeping in view to the “Kyoto Protocol” which was adopted in the Kyoto City of Japan on December 11, 1997 and became operational on February 16, 2005. All the underdeveloped countries are adopting the anti-environmental policies which results in a great damage to the environment during the initial stages of industrialization and now it is not anymore, a feasible option for industrialization. No doubt, the aim of all the companies is to increase in production by enhancing its performance to its optimum level but its policies must be eco-friendly so that any loss to the environment can be alluded. With the advancement in different latest manufacturing techniques, in the era of modern industrialization, GSCM system may be described as guidelines for all supply chain stakeholders to attain optimum balance between industrialization and environmental protestation.

Keeping in view to the above cited facts, Multi Criteria Decision Making (MCDM) techniques may be proved to be a supportive tool in decision making, which extends greater flexibility. MCDM methods for selecting the best green chain suppliers among the rests, are implemented by GSCM, corresponding to a predefined set of criteria as per requirement. Technique for order preference based on similarity to ideal solution (TOPSIS) and analytical hierarchy process (AHP) methods are used to assess companies’
GSCM performance and for choosing the most effective green supplier in line with the economic and environmental criteria. “DEMATEL” technique is employed to grasp the correlation among criteria. The techniques are applied using MATLAB R2015a software.

The outstanding portion of this paper is organised as follows: Section 2 presents research significance while, Section 3 presents a brief review of the available literature on GSCM implementation and supplier selection. Section 4 describes the problem to be evaluated. Section 5 introduce the proposed methodology. Section 6 describes the proposed framework. Section 7 presents the proposed framework to a case of electronics industry and contains results. Section 8 discusses the results. In the section 9, analysis and results are presented. Finally, the section 10 concluded the case study.

2. Research Significance

Solitary cause of selection of supplier isn't constrained to get supply at least value and at suitable time. Selection of provider is a planned choice to perform purpose of the organization for lengthy period at low threat. Risks in SC are widely classified as internal threat that can be visible in ordinary operation and external risk that originate from exterior operations of the supply. Selecting specific suppliers could reduce external risks. The Supplier Selection Course is examined in the form of a mix of customer criteria and technical requirements. Many studies have shown the impact of customer satisfaction scores and technical characteristics on the vendor selection process, but no one has addressed an organized vendor evaluation based on the most significant criteria of the long-term listing. In addition, the literature on measuring the supplier's green performance is huge, a noteworthy gap compared to a methodical scrutiny of the green supplier is noticeable. To fill this gap, it is necessary to develop a framework to evaluate alternatives based on criteria that most influence selection. The proposed integrated framework aims to bridge this gap highlighted above. This study not only recognises a rich hierarchical structure for all pertinent sustainable factors and sub-factors, but also weight the decision criteria centred on the prominence of the client's requirements. Intentions to assimilate numerous techniques and express a significant logic to evaluate the performance of vendors are improving. Numerous contributions to the selection of green vendors were gotten using MCDM tools. However, developing vendor-based decision-making approaches by integrated methods can be synergistic since each detailed method includes generic functions that sanction stable solutions only if they integrate suitably. As this is a distinctive process for every MCDM problem, the selection of the best suppliers is highlighted by some key objectives, comprising the determination of the degree of importance (weighting) of the selection criteria and the estimation of the suppliers. According to these criteria. In this study, a case-based model is established where these goals are conquered through an integrated MCDM model.

3. Literature Review

Over the past few years, GSCM and green supplier selection has enticed attention of several researchers. A brief description of the work on green supplier selection associated issues is as follows:

Yu et al. (2018) proposed “a carbon footprint-based incentive green supplier selection model, which can urge the participants in the green supply chain to initiatively make greener decisions”. Chatterjee et al. (2018) evaluated green suppliers and the criteria based on which their performance can be evaluated, mostly in electronics sector. Yazdani et al. (2017) aimed to set forward an integrated DEMATEL-QFD-COPRAS approach for GSS by bearing in mind, numerous environmental performance necessities and criteria. Wang et al. (2017) developed “an integrated MCDM model based on the cloud model and QUALIFLEX approach for selecting the optimum green supplier and to assess the green performance of companies under economic and environmental criteria”. Hamdan et al. (2017) provided “a decision-making tool to solve a multi-period green supplier selection and order allocation problem. The tool contains three integrated components”. Mousakhani et al. (2017) presented “a new model centred on group decision-making methodology under novel compromise ranking method and interval type-2 fuzzy sets (IT2FSs) for the GSS problems and then a case study is considered to indicate the applicability of the proposed approach”. Awasthi et al. (2016) addressed the “problem of assessing green supplier improvement programs and suggested a fuzzy NGT (Nominal Group Technique)-VIKOR based solution
approach. Sensitivity analysis is accomplished to define the impact of modelling factors on ranking results of alternatives”. Gurel et al. (2015) had done a literature review for articulating what criteria consequence the decision environment to construct a better association with partners, and a criteria list for GSS for textile industry is offered in a hierarchical structure which is valuable to assimilate MCD scrutiny.

4. Problem Description
To demonstrate the application of the methodology, a real-life case of Indian Electronics Industry was carried out. The industry was established in 1990 and located in northern part of India (refer Table 1).

Table 1. Company Profile.

| Business Characteristics | Case Company |
|--------------------------|--------------|
| Year of Establishment    | 1983         |
| Turnover (in INR)        | 115430 Million |
| Employees                | More than 2000 |
| Products manufactured    | PCB Layout Design, Reverse Engineering, Gerber Editing, Data Conversion, Laser Photo Plotting, PCB fabrication |
| type/Specialisation      |              |
| Type of Business         | Manufacturer, Supplier |

Because of the government’s instruction, companies identify that proposing greener electronics not only reacts to customer demand, but also necessitates finding good green suppliers to advance their SCM. Based on this new baseline, the company Sustainability Manager is looking for an approach to recognize and select the vendors that will help the company adopt the GSCM practices.

5 potential suppliers have been diagnosed as candidates for company. An expert panel including three experts as decision maker (DM), denoted as DM1, DM2, and DM3 was established to rank five green suppliers (denoted S1, S2, S3, S4, and S5). The decision makers were one of the employees from the company, my supervisor and me. The criteria and sub criteria selected are shown table 2.

Table 2. Dimensions and related criteria for green vendor selection.

| Dimensions                  | Criteria                                      | References                                    |
|-----------------------------|-----------------------------------------------|-----------------------------------------------|
| Green Design (D1)           | Increasing Innovation Capabilities (C1)       | Chatterjee et al. (2018)                      |
|                             | Abstaining from toxic capabilities (C2)       | Chatterjee et al. (2018)                      |
|                             | Saving Energy (C3)                            | Chatterjee et al. (2018)                      |
|                             | Environmental performance (C4)                | Wang et al. (2017)                            |
|                             | Design products for recycling (C5)            | Sari et al. (2017)                            |
| Green Image (D2)            | Customer’s purchasing retention (C6)          | P.K Humphreys et al. (2003)                   |
|                             | Green market share (C7)                       | P.K Humphreys et al. (2003)                   |
|                             | Stakeholder’s relationship (C8)               | P.K Humphreys et al. (2003)                   |
| Green Production (D3)       | Green manufacturing (C9)                      | Wang et al. (2017)                            |
|                             | Environmental friendly packaging (C10)        | Azevado et al. (2011)                         |
|                             | Using Cleaner technology (C11)                | Sari et al. (2017)                            |
| Green Recycling (D4)        | Reducing activities (C12)                     | Wang et al. (2017)                            |
|                             | Remanufacturing (C13)                        | Wang et al. (2017)                            |
|                             | Reusing (C14)                                | Wang et al. (2017)                            |
|                             | Disposal (C15)                               | Wang et al. (2017)                            |
| Environmental Management Practices (D5) | Environmental policies (C16) | P.K Humphreys et al. (2003)                   |
|                             | Environmental planning (C17)                  | P.K Humphreys et al. (2003)                   |
|                             | ISO14001 Certification (C18)                 | Azevado et al. (2011)                         |
| Environmental Competencies (D6) | Use of environment friendly material (C19)   | P.K Humphreys et al. (2003)                   |
|                             | Pollution reduction capability (C20)          | P.K Humphreys et al. (2003)                   |
Returns handling Capabilities (C21) P.K. Humphreys et al. (2003)

Green network design (C22) Mallidis (2010)
Utilisation of fuel efficient transport fleets & equipment (C23) Mallidis (2010)
Reduction of empty vehicle returns (C24) Mallidis (2010)
Application of vehicle routing & scheduling software (C25) Mallidis (2010)

Green transportation and Distribution (D7)

5. Methodology

5.1. DEMATEL
"Decision-making trial and evaluation laboratory (DEMATEL)" method was originally established by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva.

Step 1: Build the Direct Answer Matrix:
Step 2: Compute the Original Average Matrix.
Step 3: Calculate the normalized Initial Direct Relation Matrix:
Step 4: Originate the Total Relation Matrix: Indirect effects between factors are measured by powers of 'D'.
Step 5: Calculate the Positions and Relations.
Step 7: Build Cause and Effect Relationship diagram.

5.2. AHP
The "Analytic Hierarchy Process (AHP)" is a multi-criteria decision making method and was presented by Saaty.

Step 1: Formation of a structural Hierarchy.
Step 2: Formation of comparative judgments.
Step 3: Synthesis of priorities and measurement of consistency.

5.3. TOPSIS
"TOPSIS is a multi-criteria decision making procedure" which controls solution alternatives from a finite set on the basis of maximizing the distance from the negative ideal point and lessening the distance from the positive ideal point. Steps are as follows:

Step 1: Normalization: Firstly the raw values \( D_{ij} \) are normalized \( N_{ij} \) using vector normalization.
Step 2: Weighted Normalization: Now estimate the weighted normalized decision matrix.
Step 3: Definition of Ideal Positive and Ideal Negative solutions.
Step 4: Calculation of \( D_i^+ \) and \( D_i^- \): Here \( D_i^+ \) presents the distance of each alternative from the best possible solution and it should be minimum, on the other side \( D_i^- \) signifies the distance of each alternative from the worst solution and it should be maximum.

\[
D_i^+ = \left( \sum_{j=1}^{n} (W_i N_{ij} - IS_j^+) \right)^{1/2} \quad (1)
\]

\[
D_i^- = \left( \sum_{j=1}^{n} (W_i N_{ij} - IS_j^-) \right)^{1/2} \quad (2)
\]
Step 5: Relative Closeness: It indicates the similarity to the worst solution in terms of ratio of distances. It is specified by the resulting formula and the larger value of this denotes the best alternative.

\[ C_i = \frac{D_i}{D_i^* + D_i} \]  

(3)

6. Proposed Integrated Framework for Green Supplier Selection (refer figure. 1)

Figure 1. Proposed Framework
7. Results

7.1. Results by DEMATEL
The first and foremost step of the approach is DEMATEL and it provides cause group criteria on the basis of \((r + c)\) and \((r - c)\) using equations (iv) and (v) respectively, which are further used to evaluate suppliers (refer table 3 and figure 2).

\[
r = [n]nX_1 = \left(\Sigma_{n=1}^n t_{ij}\right)nX_1 \tag{4}\]
\[
c = [n]nX_n = \left(\Sigma_{n=1}^n t_{ij}\right)nX_n \tag{5}\]

Table 3. The direct and indirect effects of criteria.

| Criteria | \(r + c\) | \(r - c\) |
|----------|-----------|-----------|
| C1       | 21.25     | -1.95     |
| C2       | 23.97     | 0.858     |
| C3       | 22.3      | -1.01     |
| C4       | 21.36     | -0.52     |
| C5       | 22.09     | -0.14     |
| C6       | 21.92     | -2.45     |
| C7       | 23.71     | 0.257     |
| C8       | 23.46     | 1.694     |
| C9       | 21.55     | -0.14     |
| C10      | 23.08     | -1.64     |
| C11      | 23.09     | 3.302     |
| C12      | 22.29     | -3.84     |
| C13      | 22.83     | -0.36     |
| C14      | 23.1      | 1.257     |
| C15      | 22.34     | -0.41     |
| C16      | 23.96     | 2.321     |
| C17      | 22.55     | -0.56     |
| C18      | 24.39     | 2.847     |
| C19      | 21.59     | -1.25     |
| C20      | 23.53     | -0.1      |
| C21      | 21.9      | -0.61     |
| C22      | 23.46     | 1.787     |
| C23      | 23.78     | 0.513     |
| C24      | 24.22     | 0.712     |
| C25      | 24.19     | -0.56     |
The criteria with positive \((r - c)\) value i.e. abstaining from toxic capabilities \((C2)\), green market share \((C7)\), stakeholder’s relationship \((C8)\), using cleaner technology \((C11)\), reusing \((C14)\), environmental policies \((C16)\), ISO 14001 Certification \((C18)\), green network design \((C22)\), Utilisation of fuel efficient transport fleets & equipment \((C23)\), reduction of empty vehicle returns \((C24)\) are the most important criteria as they belong to cause group.

After determining the criteria having direct influence on the system, five suppliers namely S1, S2, S3, S4 and S5 are evaluated on the basis of criteria obtained from DEMATEL.

### 7.2. Results by DEMATEL

Ten criteria that comes under cause group i.e. which have direct influence are then evaluated further and weights are given to them by AHP (refer table 4).

### Table 4. Weights of Criteria.

| Criteria | Weights |
|----------|---------|
| C2       | 0.012092|
| C7       | 0.069973|
| C8       | 0.095888|
| C11      | 0.22995 |
| C14      | 0.028091|
| C16      | 0.105444|
| C18      | 0.102579|
| C22      | 0.135581|
| C23      | 0.120603|
| C24      | 0.099799|

### 7.3. Results by TOPSIS

TOPSIS is applied to rank the green suppliers S1, S2, S3, S4, S5 and to find the best one on the basis of coefficient of closeness using equation (xiv), using weights by AHP (refer table 5).

### Table 5. Coefficient of Closeness and Rank.

| Supplier | CC     | Rank |
|----------|--------|------|
| S1       | 0.409325| 3    |
8. Discussions

A GSS framework for GSCM has been anticipated. An integrated method based AHP, DEMATEL, and TOPSIS has been proposed after evolving the GSS criteria and then it is authenticated in a case study of an electronics industry. This integrated method not only helps in finding the best supplier on the basis of criteria for vendor, but also aid to find the acute criteria upsetting the performance of GSS. Initially DEMATEL is applied to regulate the criteria prominence and discover the interrelationships among criteria. The study reveals that abstaining from toxic capabilities (C2), green market share (C7), stakeholder’s relationship (C8), using cleaner technology (C11), reusing (C14), environmental policies (C16), ISO14001 Certification (C18), green network design (C22), Utilisation of fuel efficient transport fleets & equipment (C23), reduction of empty vehicle returns (C24) are the most important criteria as they belong to cause group. They have prodigious influence on the GSS in industry. Decision makers should not only take into account the implication of assessment criteria as in previous supplier selection methodologies, but also deliberate the CER between vendor selection criteria to avoid the probable hazard of sustainable supplier selection. After determining the most important criteria, weights for the criteria are determined by AHP and then the alternatives are prioritised using TOPSIS approach. From the weights obtained it is noticed that the criteria using cleaner technology (C11) achieved higher priority weight 0.22995, which gives a signal about their prominence for effective GSS as shown in Figure 5. Then, alternatives are scrutinized on the behalf of criteria weights to compute the closeness coefficients as summarized in Table 13. Supplier ‘S2’ grips first rank with the highest closeness coefficient (0.870698), shown in Figure 6. Based on closeness coefficient, ranking of considered suppliers is decided as follows: S2 > S4 > S1 > S3 > S5. Hence, it concludes that cleaner technology is required to improve the green supply chain performance.

9. Managerial Implications

The usefulness of the projected tool for decision making is apparent, however the acceptance of the management might be cause for worry. Most decision makers can realize their reception in tools and templates simple to know. The AHP-TOPSIS-DEMATEL model employed in this analysis might not simply comprise the easy-to-understand class. This example is true for many mathematically advanced approaches. Using this tool as fragment of a decision support system will make it more adequate to management. This tool will be more adequate to managers who face a greater amount of uncertainty and inaccuracies in the vendor environment, as well as to those with prior information of supplier act. At that stretch, tables for ranking scheme are provided, but a graphical illustration of the criteria relationships can advance management reception. The objective of this case study is to select the finest green vendor for the extension of novel products that meet environmental guidelines and outmoded parameters.

10. Conclusion and Future Directions

In sum, the anticipated method makes numerous assistances to the green supplier selection:
- The proposed solution can find interdependencies among these criteria, the weakness and their strength. The proposed methodology integrates the merits of AHP, DEMATEL and TOPSIS. To our awareness, no former studies have inspected the subject of vendor selection with this type of assimilated technique.
- Subsequently, a solution is suggested for active management under environment friendly atmosphere. If these characteristics and criteria can be enhanced in the supply chain network, the existing SCM could be improved. This work also grants an example to illustrate the actual
lifetime applicability of the anticipated network model. The outcomes of this research can be predominantly valuable for the case of companies directing to become more proficient in scrutinising green suppliers. This effort may also help supervisory bodies, policy creators and managers to rank the acceptance of GSC and perform their work keeping in view the need of environment friendly operations.

Moreover, the study could be sustained with an expectation that the technique could be originate relevant to other alike vendor selection problems, such as low carbon vendor selection, strategic vendor selection, sustainable vendor selection, selection of 3PL service provider etc.

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