Integrated Fuzzy Criteria Evaluation with Metaheuristic Optimization for Green Supplier Selection and Order Allocation

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Abstract. In the present growing competitive environment, it’s essential for a company to select the best supplier because company performance not only depends on its internal efforts but also on supplier’s performance. Due to growing environmental issues & increased awareness among public, and stricter environmental laws imposed by the government made the companies consider environmental sustainability matters while selecting suppliers. If in case suppliers have any capacity constraint or any other constraints, then complexity in selecting suppliers who fulfill both company’s demand and standards increases. Information from the literature review and through the opinion of experts, the effort has been made to find essential criteria for the evaluation and at the same time for the selection of a green supplier. For the same an integrated decision-making tool, on the basis of fuzzy TOPSIS and fuzzy DEMATEL has been presented to show the procedure for the selection of the best supplier. Due to vagueness in human judgment fuzzy concept has been used. A MILP (Mixed Integer Linear Programming) has been proposed which shows how order can be allocated in multiple sourcing environments. Modeling a supply chain network for multi product flow in different demand scenarios and solving the problem using a novel meta-heuristic algorithm like Teacher-learner-based-optimization (TLBO) is the major contribution of this work.

Keywords: Green, supplier selection, fuzzy, MILP and TLBO

1. Introduction

We are in the midst of a competitive environment and here finding the best suppliers is the major critical issues that manufacturing firms are confronting. In such firms, the final cost of a product essentially relies upon the initial cost of raw material, and to reduce purchasing price selection of the best supplier is necessary [1]. Due to expanding awareness between people for the security of the environment and governmental legislation, the firm has to incorporate environmental sustainability into supply chain exercises to keep up its edge in this global market which pave way for the development of green supply chain management (GSCM) [2]. Also, companies convey enthusiastically several regulatory programs to ensure that the suppliers should supply their products and their services both having higher quality and along with that it must satisfy the environmental standards [3]. GSCM for the most part intends to watch suppliers and to have coordinated effort only with that supplier who satisfies environmental standards. There are two ways by which we can select suppliers, first one is Single sourcing, a single
supplier who can satisfy the whole customer’s necessities and at the same time the customer has to choose only one: that one will be the best supplier. The second one is Multiple sourcing, where more than one supplier must be chosen why because no single supplier is able to fulfill every customer’s orders. Subsequently, firms have to choose both the best and good suppliers and must have an idea about quantity the that should be allocated among them for fabricating a healthy competition [4]. According a research conducted, about 64 percent of the industries in India have good amount of lean with green awareness and 34 percent of industries have low level of awareness [5]. Lack of updating the latest technology in Indian SMEs and low financial capabilities of the industries are the barriers to implementing green methodologies [6].

There is a need to coordinate the accessible decision making techniques into a powerful framework that can help industries confronted with multi-green supplier, multi-criteria choices under instability. While the current work incorporates strategies to deal with different mixes of numerous green suppliers, various plants and different criteria supplier determination, there is no accessible decision-making system that can completely address these issues together for making an interpretation of manufacturer prerequisites into a stochastic multi-criteria and multi-supplier choice to handle. This circumstance is confronted by industries and such an approach would permit an all the more comprehensively effective choice on green supplier selection and subsequently a more supportable order allocation can be made by the supplier network partner.

2. Literature review

2.1. Decision making techniques

Selection of supplier is an MCDM problem which contains both qualitative and quantitative criteria both, together, are now discussion. over the last couple of years, several researchers have formed along the selection of supplier as a problem to create reasonable decision-making methods which will dish out with the problem efficiently and effectively [7]. Decision Making techniques are categorized into three groups 1) Mathematical programming 2) AI techniques 3) MCDM techniques [8]. AHP was popular MCDM technique developed by Thomas L. Saaty in the year 1970 used pairwise comparisons and in view of human judgment to rank distinctive alternative in light of defined goal while ANP is an extension of AHP which also includes interdependence among criteria and alternative. AHP is broadly used approach because of its simplicity, easiness and flexibility [9]. Many researchers utilized AHP and ANP independently for decision making like AHP was utilized in quickly changing apparel industry [10], ranking of potential suppliers in manufacturing firms [11] and in machining parameter decision making in turning operation [12]. ANP was applied for supplier selection [13]. Fuzzy DEMATEL is used as a tool to calculate the weights of factors in their respective works. This research paper served as a basis for use of fuzzy DEMATEL to identify weights of 15 critical success factors considered [14].

2.2. Criteria for the supplier selection

Identification of the criteria for the selection of supplier and evaluation has been major research area since the 1960s. Going back in history during 1970s cost was considered as primary criteria for SS while slowly focus shifted towards cycle time, customer responsiveness during the 1980s whereas flexibility is also being considered during 1990s. It is mentioned that business practices should adopt following preventive measures for environmental protection: Green design, life cycle analysis (LCA), TQM, and ISO 14000 certification by [15]. Green design, green purchasing, environmental management systems, legal-compliance competency, inventory and management of hazardous substances included in their research [16]. While environment management, technology capability, pollution control, green competencies and quality were used in their research for green supplier selection [17].

3. Methodology

The proposed coordinated way to handle green supplier evaluation incorporates fuzzy DEMATEL, fuzzy TOPSIS, and MOLP for solving problem of supplier choice and along with that allocation of order. Initially utilized a fuzzy DEMATEL for the calculation of the comparative weights of supplier selection criteria, then, in order to assign rank for the suppliers we utilized fuzzy TOPSIS method according to the chosen criteria. At the end, the weights assigned to the standards and also ranks assigned
to the suppliers were planned to incorporate into the MILP model to define the optimal order quantity from each and every supplier while being exposed to some resource constraints.

3.1. Fuzzy concept
To pinpoint the fuzziness which encircle the decision-makers when they organise a pairwise comparison matrix. Instead of crisp numbers, TFN is expressed with boundaries. Membership function which is having a triangular fuzzy numeric value of triangular form, having $B^\ast = (r, s, t)$, is shown below,

$$
\begin{cases}
0 & y < r, y > t \\
\frac{y - r}{s - r} & r \leq y \leq s \\
\frac{t - y}{t - s} & s \leq y \leq t
\end{cases}
$$

3.2. Fuzzy DEMATEL concept
In fuzzy DEMATEL concept, importance can be specified by assigning a weightage to each and every factor under consideration. This Weightage is evaluated and analysed by using fuzzy DEMATEL. Even though DEMATEL is an appropriate technique for the evaluation of problems, the relationships are commonly given by binary values in generating a conceptual model. However, considering this crisp numbers are always inadequate for practical scenario. Therefore, fuzzy concept is used to the DEMATEL technique in order to solve a MCDM problem [18]. Also, many researchers agreed that human decision regarding preferences is often ambiguous and difficult to rate by accurate crisp numbers [19].

Fuzzy DEMATEL steps are expressed below:
Step 1: Derive a fuzzy direct relationship matrix and make a pairwise classification about the relative relevance of the SS factor i.e. a $n \times n$ matrix in which $\hat{A}$, $\hat{a}(l_{ij}, m_{ij}, u_{ij})$ denotes the degree to which the factor $i$ influence the factor $j$.
Step 2: Derive a normalized direct relationship matrix called $X$
Step 3: Derive fuzzy total relationship matrix $T$
Step 4: Calculating the sum of row and column from each of matrix $T$.

Consider $R$ as the summation of an $i^{th}$ row in the “$T$” matrix, at the same time consider $C$ as the summation of column $j$ in “$T$” matrix. The columns “$R+C$” and “$R-C$” can be called as prominence value and relation value. Note that the “$R-C$” of positive signed represents the factor is associated with group of the cause relation. On the other side, minus signed value displays the factor associated with group of the effect relation.

3.3. Fuzzy TOPSIS concept
Fuzzy TOPSIS methodology, which requires all the preliminarily data about the relative relevance of the criteria, obtained from fuzzy DEMATEL. We can find numerous TOPSIS and fuzzy TOPSIS studies and analysis in numerous areas as selection of supplier and turning parameters in machining [20], [21] and [22].

The following steps are a part TOPSIS solution method:
Step1: Normalization of devised fuzzy decision criteria(factor) matrix
Step 2: Calculate the weighted matrix $p_{ij}$ by the multiplying weigh $e_{i}$ of the criteria with the matrix obtained in step 1, calculating the weight associated normalized decision criteria matrix with.
Step 3: Calculate the positively signed ideal solution (PIS, $B^*$) and negatively signed ideal solution (NIS, $B$)
Step 4: Calculate the distance of each alternative from both NIS and PIS.
Step 5: For each alternative evaluate the coefficient of closeness ($DD_i$).
Step 6: At the final stage of the analysis, by comparing $DD_i$ values, the rank assigning of alternatives is done.
Alternative A is farther from FNIS (B) and closer to the FPIS (B*) as DD having tendency for approaching to 1. The rank giving order of every alternatives determined on the basis of the reducing order of DD.

3.4. Teacher-learner-based-optimization

The Teacher-learner-based-optimization technique (TLBO) has been developed in 2011 by Rao et al. [23]. The core idea of the algorithm is the effect of a teacher’s influence on knowledge of learners (students) in a class. TLBO technique is also population based optimization (like other evolutionary and swarm based optimizations such as GA, ABC, PSO etc.) in which learners are considered as members of the population (or class). The variables are used in the place of the subjects and the learner’s result in that of figure of merit. The TLBO approach has the phases of two. The phase one is the phase of the teacher, where the learners are getting the input and second phase is the learner’s phase when learners will try to enhance their knowledge through interacting with other. Suppose that there are l learners in number (i.e size of population is given by i=1,2……l) and s number of different subjects offered (i.e decision variables are denoted by j=1,2……s). The performance of i th learner in jth subject is denoted as A_{i,j} and the the best learner’s performance in the jth subject in the class is represented as A_{best,j}.

3.4.1. The Teacher phase

The main activity in this phase is to improve the mean value in the subject that she/he handles. The difference between the previously existing mean and the new mean in the kth iteration is given

Δm(k)=rand(A_{best,j,k}-tff * m_{j,k})

Where A_{best,j,k} refers to the result obtained by the best learner at the kth iteration in the jth subject. Rand is a random value between 0 and 1. tff is the teacher factor which takes a value of either 1 or 2 as suggested by Rao et.al. m_{j,k} is the mean of subject j at the kth iteration.

AN_{i,j,k} = Δm(k)+ A_{i,j,k}

The above equation gives the value of new A based the mean difference obtained. where AN_{i,j,k} is the new value of the A_{i,j,k} at kth iteration. F(A_{i,j,k}) represents the objective function value for the corresponding A_{i,j,k}.

\[
B_{i,j,k} = \begin{cases} 
A_{i,j,k} & \text{if } F(AN_{i,j,k}) > F(A_{i,j,k}) \\
A_{i,j,k} & \text{if } F(AN_{i,j,k}) < F(A_{i,j,k}) 
\end{cases}
\]

The above equation helps in getting the value of B_{i,j,k}.

3.4.2. Learner phase

The learning process happens through two ways. The learning process is happening through teacher and through interaction. The B_{i,j,k} from the teacher phase acts as the input for the first type. The input for the “learning through interaction” is chosen randomly. Two students e and f are taken randomly. It is to be ensured that e and f are not the same student.

\[
C_{e,j,k} = \begin{cases} 
B_{e,j,k}+ran1( B_{e,j,k} - B_{f,j,k}) & \text{if } F( B_{e,j,k}) < F( B_{q,j,k}) \\
B_{f,j,k}+ran2( B_{f,j,k} - B_{e,j,k}) & \text{if } F( B_{f,j,k}) < F( B_{e,j,k}) 
\end{cases}
\]

Where, C_{e,f,k} - solution obtained in the learners phase F(B_{e,j,k}) , F(B_{f,j,k}) – Objective function values. ran1, ran2 - random values in the interval [0,1].

4. Problem formulation
A model network is considered with four suppliers, two distribution centers and three customers only one plant is manufacturing the products. There are two products, namely S1 and S2 being produced by the plant. There are two raw materials used to produce the products namely R1 and R2. All the four suppliers are producing R1 and R2 but their capacities vary. These raw materials are transferred to the plant. After manufacturing products S1 and S2, these products are transported to the customers through Distribution centers DC1 and DC2.

4.1. Mathematical model

Sets
- N: Set of supplier plants i
- P: Set of manufacturing plants j
- D: Set of Distribution Centers k
- C: Set of customers c
- R: Set of raw materials r
- S: Set of products s

Parameters
- Cijr: Cost of production and transportation of rth raw material from ith supplier to jth plant
- Cjks: Cost of production and transportation of sth product from jth plant to kth DC
- CDkcs: Distribution cost of sth product from kth DC to cth customer
- Tijr: Delivery time for rth raw material from ith supplier to jth plant
- Tjks: Delivery time for sth product from jth plant to kth DC
- Tkcs: Delivery time for sth product from kth DC to cth customer
- Qir: Average defect rate for the production of rth raw material in ith supplier
- Qjs: Average defect rate for the production of sth product in jth plant
- Pj: Invariable cost for opening manufacturing plant j
- Dk: Invariable cost for opening a DC k
- DDcs: Demand ofcth customer for ssth product
- DRSir: Permissible defect number of ith supplier for rth raw material
- DRPjs: Permissible defect number of jth plant for sth product
- DLs: Distribution limit for sth product
- CASir: Capacity of ith supplier for rth raw material
- CAPjs: Capacity of jth plant for sth product
- CADks: Capacity of kth DC for sth product
- Lij: Distance in km from ith Supplier to jth plant
- Ljk: Distance in km from jth plant to kth DC
- Lkc: Distance in km from kth DC to cth Customer
- W1: Weighting for cost objective
- W2: Weighting for delivery time objective
- W3: Weighting for defect rate objective

Decision variables
- Xijr: Quantity of raw material r from supplier plant i to manufacturing plant j
- Sjks: Quantity of product S from manufacturing plant j to DC k
- Ykcs: Quantity of product S from DC k to the customer of c type
- Aj: Binary variable equals to 1 if jth plant is open, 0 otherwise
- Bk: Binary valued variable equals to 1 if kth DC is open, 0 otherwise
- Gi: Binary valued variable equal to 1 if ith supplier is open, 0 otherwise

Objective function
Minimizing
Cost, \( P \)
\[
= \sum_{i=1}^{N} \sum_{j=1}^{P} \sum_{r=1}^{R} C_{ijr} \times X_{ijr} \\
\sum_{j=1}^{P} \sum_{k=1}^{D} \sum_{s=1}^{S} C_{jks} + \sum_{k=1}^{D} \sum_{c=1}^{C} \sum_{s=1}^{S} C_{Dkc} \times S_{kc} + P_{ij} \times A_{ij} + D_{jk} \times B_{jk} 
\]

Delivery time, \( DT \)
\[
= \sum_{i=1}^{N} \sum_{j=1}^{P} \sum_{r=1}^{R} T_{ijr} \times X_{ijr} \\
\sum_{j=1}^{P} \sum_{k=1}^{D} \sum_{c=1}^{C} \sum_{s=1}^{S} S_{jks} + \sum_{k=1}^{D} \sum_{c=1}^{C} \sum_{s=1}^{S} T_{jks} \times S_{jks} 
\]

Defect rate, \( DR \)
\[
= \sum_{i=1}^{N} \sum_{j=1}^{P} \sum_{r=1}^{R} Q_{ri} \times X_{ijr} \\
\sum_{j=1}^{P} \sum_{k=1}^{D} \sum_{c=1}^{C} \sum_{s=1}^{S} Q_{js} \times S_{jks} + P_{ij} \times A_{ij} + D_{jk} \times B_{jk} 
\]

Constraints:

Material balance: quantity of raw materials required to produce product 1 and product 2
\[
2 \times \sum_{i=1}^{N} \sum_{j=1}^{P} X_{ij1} + 3 \times \sum_{i=1}^{N} \sum_{j=1}^{P} X_{ij2} = \sum_{j=1}^{P} \sum_{k=1}^{D} S_{jk1} \\
1 \times \sum_{i=1}^{N} \sum_{j=1}^{P} X_{ij1} + 3 \times \sum_{i=1}^{N} \sum_{j=1}^{P} X_{ij2} = \sum_{j=1}^{P} \sum_{k=1}^{D} S_{jk2} 
\]

Capacity constraints: capacity of suppliers, plant and DCs
\[
\sum_{j=1}^{P} X_{ijr} \leq CAS_{ir} \\
\sum_{k=1}^{D} S_{jks} \leq CAP_{js} \\
\sum_{c=1}^{C} Y_{kcs} \leq CAD_{ks} 
\]

Distribution limit: Quantity of products that the distribution network can handle should be more than the quantity transferred to the customers
\[
\sum_{k=1}^{D} \sum_{c=1}^{C} Y_{kcs} \leq DL_{cs} 
\]

Demand Constraint: supply to the customer should always satisfy the demand
\[
\sum_{k=1}^{D} Y_{kcs} \geq DD_{cs} 
\]

Distribution center constraint: quantity transferred from plant should be equal to the quantity transferred to the customer from DC
\[
\sum_{j=1}^{P} \sum_{k=1}^{D} S_{jks} = \sum_{k=1}^{D} \sum_{c=1}^{C} Y_{kcs} 
\]

Defect rate constraint: number of defective raw materials from respective suppliers and number of defective products from plant should be less than the permissible number
\[
Q_{ri} \times \sum_{j=1}^{P} X_{ijr} \leq DRS_{ir} \\
Q_{js} \times \sum_{k=1}^{D} S_{jks} \leq DRP_{js} 
\]

Non negative constraints
\[
X_{ijr}, S_{jks}, Y_{kcs} \geq 0 
\]
Three sets of demand conditions for both the products are been considered, like high, medium and low. It is given in the Table 1.

| Customer | Demand 1 | Demand 2 | Demand 3 |
|----------|----------|----------|----------|
| Product 1 |          |          |          |
| C1       | 380      | 38       | 1000     |
| C2       | 480      | 50       | 3000     |
| C3       | 880      | 40       | 1000     |
| Product 2 |          |          |          |
| C1       | 850      | 100      | 1800     |
| C2       | 950      | 50       | 1500     |
| C3       | 1050     | 80       | 3200     |

5. **Results**

The criteria weights obtained from fuzzy DEMATEL are shown in the Table 2.

| Criteria                  | Weights | Rank |
|---------------------------|---------|------|
| Cost                      | 0.190   | 3    |
| Quality                   | 0.224   | 2    |
| Delivery                  | 0.151   | 5    |
| Technological Capability  | 0.180   | 4    |
| Environmental Competency  | 0.254   | 1    |

Similarly, supplier has been ranked on the basis of the outcomes of fuzzy TOPSIS method.

Supplier’s weights and ranking obtained from Fuzzy TOPSIS are given in Table 3.

| Supplier | Weights | Ranking |
|----------|---------|---------|
| Supplier C | 0.42   | 1       |
| Supplier B | 0.38   | 2       |
| Supplier A | 0.20   | 3       |

The order allocation for the suppliers and quantity flowing between different entities of supply chain is shown in figure 1.
6. Conclusions
For a green supply chain network cost, delivery time, defect rate of products, environmental criteria like carbon footprint, are considered as key objectives and by optimizing them selection of supply chain partners and their quantity allocation is done. This research provides an example of the selection of sourcing of raw material under green concepts with the application of integrated fuzzy decision making tools with TLBO optimization. The main aim of the present work is to analyse the performance in terms of criteria and tools required for the evaluation for the prioritising and allocating the order to the suppliers considering environmental criteria.

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