

AN INTEGRATED SUPPLIER SELECTION APPROACH IN SUPPLY CHAIN SYSTEM UNDER FUZZY ENVIRONMENT

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Received: December 2018 / Accepted: May 2019

Abstract: Due to the increasing awareness and government policies towards environmental sustainability, organizations are extending their efforts to enhance environmental practices in their Supply Chain (SC). At the same time, they are integrating their SC activities in such a way so as to reduce system cost while satisfying the needs of their consumers. Thus, organizations collaborate with the efficient suppliers in order to meet the quality level and customers requirements in terms of economic and environmental aspect. In this study, an optimization mathematical model is formulated for selecting suppliers with respect to interrelated criteria while taking care of ecological feature. An application is illustrated on an Indian manufacturing company of microwave oven. We propose an integrated supplier selection approach that consists of three stages. In the first stage, a dimension reduction method is utilized to group the variables as per interrelated criteria. An integrated methodology of mean and standard deviation along with Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is employed in the second stage for assessing the performance of suppliers in quantitative terms. The final stage comprises of a bi-objective

mathematical model. The model is formulated to minimize the system cost while simultaneously minimizing carbon emission. The model helps in efficient identification of the procurement amount of products and the appropriate distribution center (DC), which is based on customers demand and the DC capacity to deliver goods to the Retail Stores (RSs). A fuzzy goal programming approach is utilized further to create a trade-off between two contradictory goals of the optimization model. The results suggest that integrating environmental with economical aspect can improve the performance of the SC network.

Keywords: Multi-Criteria Decision Making, Supplier Selection, TOPSIS, Factor Analysis, Mean and Standard Deviation.

MSC: 90B85, 90C26.

1. INTRODUCTION

Supply Chain (SC) may be defined as the integration of business processes consisting of suppliers who provide products after sales services and information sharing to customers and other stakeholders. Thus, we can say, SC involves planning, control of materials, and information sharing internally or externally (Bowersox and Closs [8]). SC management has gained more focus in past two decades with rising global competition and expanding markets. Today, as never before, people are aware of the strong link between the economy and the environment for a robust SC design (You and Wang [76]). In the fields of business and management, organizations face greater responsibilities to minimize their impacts on environment. Environmental and economic trade-offs are commonplace in organizational decision making, whether it is based on the selection of right supplier or other management decisions such as cost, technology, and product selection (Kumar *et al.*[47]). The trade-offs are typically based on a variety of operational and strategic sustainability metrics that need careful integration, with or without management input (Eskandarpour *et al.* [29]).

Traditionally, purchasing activities have not been used to obtain the desired results. Thus, organizations are bringing purchasing activities into a strategic decisions that affect the efficiency of the whole SC. The trust level, sharing of appropriate information, commitment etc. were not up to the mark, mainly due to the suppliers competing on the price factor (Spekman [66]). However, assessing suppliers capability on only one factor is not enough to sustain in the market. Some other important dimensions are also needed to be considered for enhancing the competitiveness of the SC. Thus, strong long term association with right suppliers has a long-lasting effect on the whole SC (Chen *et al.* [19]).

The main aim of analysing the suppliers performance and their selection is to reduce purchase risk, maximize created value, and build long-term relationships (Trent and Monczka [69]). A typical supplier evaluation process consists of four phases: defining the problem, identifying criteria relevant to the decision, identifying suitable suppliers, and lastly, the final selection after assessing their performance on the significant criteria (de Boer *et al.* [25]). Identification of relevant criteria is significant for any study as it has direct impact on the evaluation

decision. Inclusion of intangible dimensions such as reputation, technical capability, service performance, material cost, capacitated distribution centres (DCs) and the increase of competitive advantage makes the decision problem more complex. The main cause of its complexity increase is mutually conflicting nature of these dimensions. Moreover, creating a trade-offs among criteria becomes more evident due to the addition of many dimensions in the decision process (Ting and Cho [67]). Hence, the evaluation of suppliers on many dimensions becomes a tedious and time-consuming task for any organization. However, there are chances of existence of interdependence among considered variables. Thus, it is necessary to transform the variables into lower number of unobserved variables, called factors or criteria (McDonald [53]). In other words, the assessment of the suppliers on significant independent variables reduces complexity of the decision process. Due to the increasing competition and customers requirements, organizations cannot rely on only one supplier. Burke *et al.* [9] discussed that risks associated with late delivery, higher cost, increased lead-time, etc., are the causes of excessive dependence on one supplier for the purchasing decisions. But, the decisions become more complicated when multiple suppliers and multiple conflicting criteria are considered. Due to vagueness in such decisions, there is a need to consider uncertainty in multiple criteria. Hence, supplier selection problem is considered as a multicriteria decision-making (MCDM) problem that create a trade-off among multiple vague criteria (Kannan *et al.* [44]).

Due to the changing situations and vagueness in the decision, decision makers (DMs) face difficulty in providing exact quantitative values for assessing suppliers performance. The reason is the ambiguous nature of human judgements that cannot be assessed in terms of numerical values. Also, there is a loss in objectivity and vagueness associated with the perception of the DM (Ordoobadi [58]). Thus, assessing the preference values in terms of linguistic variables reduces the complexity of decision process rather than using numerical values (Bellman and Zadeh [4]; Chen [17]). Most of the authors have used the same linguistic term set to deal with qualitative data for solving the MCDM problems. However, in real life scenarios, the DMs considered are from different backgrounds, have diverse experience and knowledge. There are possibilities of using different cardinalities by DMs according to their convenience to provide their preferences that must be possible in multi-granularity linguistic assessment information. Incorporating multi-granularity assessment approach in MCDM has improved the solution from various outlooks (Liu *et al.* [52]). In earlier studies, authors did not consider the weight of DMs or assume them having equal importance (Liu *et al.* [51]). But in practical situations, different educational backgrounds and experiences of DMs forced to compute importance weights rather than to assume equal weights. This will help in achieving important decisions for the whole SC network.

Generally, SC planning comprises of three decision levels: strategic, tactical, and operational. At strategic level, SC design includes decisions such as facility location, number of facilities to be open, and evaluation of suppliers performance and strategies for building long-term relationships while optimizing the total cost (Chopra and Meindl [22]). Due to the awareness of environmental aspect among

consumers, selection of an appropriate vehicle helps in optimizing the total costs and emissions considered as a tactical decision. Measurement of carbon footprint is an accurate and robust method to identify the environmental impact. Thus, there is a need to pay attention towards procurement and distribution planning. Organizations implement successful environmental SC practices that reduces the logistics costs as well as energy to gain the competitive edge. The operational decisions taken by organizations is to maintain inventory in such a way so as to minimize the total cost. In this study, an integrated mathematical model is developed for the evaluation and selection of suppliers while minimizing the carbon emission level.

The rest of the paper is organized as follows. Literature review is given in section 2 followed by the problem description in section 3. Section 4 shows the solution methodology. Numerical illustration is given in Section 5. Results and implications are discussed in section 6 and followed by conclusion in section 7.

2. LITERATURE REVIEW

In this paper, a bi-objective optimization model is developed which integrates decisions such as assessment of suppliers performance, based on independent criteria, and consideration of environmental issues while transporting the goods by minimizing the systems cost. Fuzzy goal programming approach is employed in order to handle the vagueness in both the objectives and to achieve their aspiration values. In sub-sections 2.1 and 2.2, the literature review provides the essence of the recent work done by many authors. This includes identification of criteria for supplier evaluation, approaches for supplier selection and optimization model combining environmental and economic aspects. Sub-section 2.3 addresses the research gap and our contribution.

2.1 Supplier evaluation criteria and models

With the growing needs of customers demand, decisions related to purchasing have become more vital for an organization. Due to globalization, technological advancement and change in customers needs, purchasing decisions are gaining more importance (Chen *et al.* [19]; Sarache Castro *et al.* [61]). One of the most important activity in purchasing function is the selection of the appropriate supplier. The reason of its importance is the huge impact on the performance of SC (Haq and Kannan [36]). Thus, organizations are relying more on suppliers performance and these decisions appear to be more serious (de Boer *et al.* [25]). A selection of appropriate suppliers leads to success of a firm in terms of cost, sales, and satisfaction of customers needs (Zhang *et al.* [77]). The evaluation process starts with identifying the criteria relevant for the study, some of which are conflicting and interrelated. In other words, there exist some variables in which relationships and patterns can be construed simply. Thus, factor analysis is utilized to regroup those variables into a set of factors which usually share variances (Yong and Pearce [75]; Bhayana *et al.* [5]). The main aim of the approach is that the sets of formed factors are independent from each other and no relationship exists among them

(Ghahramani and Hinton [33]). Extant literature shows that the approach is used in various environments. Kannan and Tan [41] developed an empirical study which identified the importance of supplier selection and performance criteria by taking a case study of American manufacturing companies. Ramanathan and Gunasekaran [60] developed the impact of collaborative planning, collaboration with SC partners and collaborative execution of processes empirically using factor analysis and structural equation modelling.

Many researchers (Dickson [28]; Busch [10]) have discussed that quality, delivery lead time, and flexibility are some vital criteria for supplier selection. Traditionally, suppliers were evaluated mostly on quantitative data but after 1990s its been shifted to qualitative assessment because of the ease in providing preferences by DMs, but there are some factors which cannot be quantified. Further, due to the change in processes and customers awareness, new evaluation criteria such as trade restrictions, quality management systems, tariffs or taxes and environmental factors started gaining importance (Narsimhan *et al.* [57]; Sarkis and Talluri [62]). After the boom of information technology, some criteria such as quality management system and e-transaction capabilities were introduced into the supplier selection process (Bottani and Rizzi [7]; Chen and Huang [20]). Different studies by many authors highlighted several criteria by taking a case study specific to country or an industry (Muralidharan *et al.* [56]; Xia and Wu [74]). Hence, identification of numerous significant criteria for the selection of supplier in several studies proved it to be an important aspect of the selection process (Kumar Kar and Pani [48]). However, the research work done in this area is very limited. Variables identified for this study are provided in Table 6 in appendix.

Supplier selection process is considered as a group decision-making process with respect to multiple criteria. de Boer *et al.* [24] and Choi and Hartley [21] argued that some properties must be considered while solving the supplier selection problem. These are related to the type of criteria considered, opinions given by multiple DMs, vagueness in decision opinions and lastly, the type of the used decision model. Liu *et al.* [51] discussed inclusion of relative importance of DMs opinions into the process. Due to variations in DMs background, knowledge, experience and cultural work there may be chances of having different cardinalities to express their opinions. Thus, it is significant to incorporate the importance weights of DMs opinions into the process using 2-tuple multi-granularity linguistic assessment approach. Hence, developing an appropriate methodology for the selection of supplier is another important aspect of the decision process. A variety of approaches have been utilized by the authors to build an effective selection process. These includes: Analytic Hierarchy Process (AHP) (Ramanathan [59]; Deng *et al.* [26]), Analytic Network Process (ANP) (Gencer and Grpinar [32]; Dargi *et al.* [23]), Decision Making Trial and Evaluation Laboratory (DEMATEL) (Chang *et al.* [16]; Hsu *et al.* [39]), Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) (Boran *et al.* [6]; Zouggari and Benyoucef [79]), Data Envelopment Analysis (DEA) (Ramanathan [59]; Toloo and Nalchigar [68]), Grey System Theory (Bai and Sarkis [2]; Wu [73]), and many more. A detailed literature review for supplier selection approaches can be found in Ho *et al.* [37] and Chai

et al. [14]. Due to the vagueness in DMs preferences, many authors utilized fuzzy set theory (Wang *et al.* [71]; Shemshadi *et al.* [65]) to deal with such scenarios. Thus, research on MCDM problems have broad application area. Liu *et al.* [51] proposed a novel approach in which mean and standard deviations are used for identifying the importance weights of unknown criteria and an improved TOPSIS is applied to find the relative weights of DMs. Further, authors aggregated the DMs preferences by using Linguistic Weighted Arithmetic Averaging (LWAA) operator into comprehension evaluation scores for each alternative. Scott *et al.* [63] developed a methodology to deal with the problem of selecting appropriate supplier and allocating orders optimally by using AHP-QFD (Quality Function Deployment) approach. They integrated stakeholders necessity into stochastic multi-criteria problems and constructed scenarios for the decision support system, and validated their model by implementing it into the energy industry.

Many authors have discussed the problem of an efficient supplier selection in various studies. Authors identified the relative scores of suppliers in different scenarios. But, the identification of these relative scores is not sufficient as organizations are also keen in optimizing the cost, profits and sales in order to be competitive in market.

2.2 Optimization model

In early 90s, due to ozone depletion, global warming and hazardous resources, environmental issues have gained huge attention in the optimization models of SC management. So, organizations shifted their focus towards effective procurement and distribution planning. Traditionally, the organizations focus was either on minimizing the cost or maximizing the profit, and environmental objectives were almost excluded. In today's business environment, DMs are incorporating environmental aspects in the decision process to make themselves environment friendly organizations in order to satisfy customers needs and sustain in market (Ilgin and Gupta [40]). Their concerns are not only related to the reduction in carbon footprints in product design or the utilized processes but also to transporting goods from source to destination, selecting an appropriate vehicle (Eskandarpour *et al.* [29]). Various authors discussed environmental issues in their studies. Fahimnia *et al.* [30] obtained a trade-off between the systems cost and environmental issues such as carbon emission, consumption of energy, and waste generation. They also incorporated the issues related to multiple transport lot sizing and capacity of keeping inventory at warehouses flexibly. Zhao *et al.* [78] developed a multi-objective mathematical model considering environmental and economic aspects that minimizes the threat arises due to the harmful materials, related carbon footprints, and total cost.

In the current study, we formulated an optimization model by obtaining a trade-off between total systems cost and carbon emission while selecting an efficient supplier by utilizing fuzzy goal programming approach to deal with the inherent vagueness in SC cost and carbon emission of the proposed mathematical model.

2.3 Research Contribution

The integrating supplier selection model with procurement and distribution decisions improves the performance of SC. This forms the basis of the following research contribution:

- (i) An integrated approach, developed in this study, combines mean and standard deviations along with improved TOPSIS, considering multi-granularity linguistic assessment data in order to identify relative weights of suppliers. To the best of our knowledge, the proposed approach has not been utilized by many authors for solving the problem of supplier selection while identifying DMs weights in an electronic industry.
- (ii) Afterwards, we utilized fuzzy goal programming to solve a bi-objective optimization problem. Two objective functions are formulated in this study; minimizing the systems cost and keeping amount of carbon emission minimum while transporting goods from suppliers to selected DCs and then to RSs. Developing a practical method is limited. In this study, we have filled that gap by developing a bi-objective optimization model which is solved by using fuzzy goal programming approach in order to optimally identify the procurement quantity while identifying an appropriate DC, based on the demand and its own capacity.

3. PROBLEM DESCRIPTION

In this section, we discuss SC system of an Indian electronic manufacturing company that manufactures microwave oven, having different variants. The main objective of the firm is to enhance the SC performance of two variants of the product. In the current SC network, three echelon system has been followed in which variants are transported from suppliers to RSs through DCs. Firstly, the products are delivered from suppliers to DCs, the designated space for keeping stock of RSs, and then transported to the RSs. The sole responsibility of RSs is to increase the demand of the products. Due to the risk factors such as delivery time, flexibility in orders, service quality, etc., the company requires multiple suppliers. The performance of each and every supplier varies according to their capacities, demand of RS, and procurement quantity. Figure 1 shows SC system of the firm, which involves many suppliers transporting goods to the identified DCs using appropriate vehicle, and further, to several RSs who sell their products to consumers. All the suppliers can supply both variants of the products in all time periods.

Firms should not focus only on minimizing of their costs but also on the issue of increased carbon emission amount. As the objective of firms should not only be their cost, they have to include the expending of their target market, customers that can buy the good quality product at a reasonable price, minimizing carbon emission caused by transporting goods from sources to the destinations, and designing an efficient network so that performance of SC could be improved

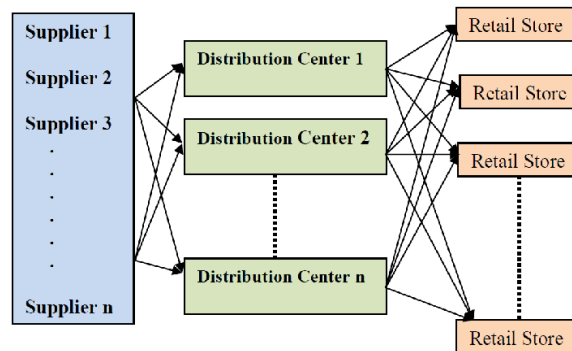


Figure 1: SC Framework

while fulfilling customers demand. These objectives can be achieved by selecting priority suppliers and applying appropriate strategy for selecting the appropriate vehicle for transporting products from suppliers to the appropriate DCs, and further to RSs. So, in order to enhance the performance of the SC, DMs come across with the following decisions.

- (i) At strategic level, the efficient supplier with respect to the significant criteria is evaluated and selected while identifying the appropriate DC on the basis of demand and capacity for supplying the goods to RSs in order to gain the competitive advantage.
- (ii) At tactical level, optimal number of products to be purchased to optimize the total cost of the system is identified, and lastly, the decision of reducing the amount of carbon emission is considered so as to reduce the environmental risks.

The objective of the current study is to accomplish the efficient SC network. For achieving the objective, the assessment of the suppliers performance is done while transporting goods from suppliers to RSs through appropriate DC by integrating the tactical decisions into the decision process.

4. METHODOLOGY

We developed a methodology based on the following framework.

1. Evaluation and selection of efficient supplier, based on importance of DMs decision and priority weights of alternatives. The process includes:

- (a.) Identification of important variables for the evaluation of supplier.
- (b.) Transformation of interrelated variables into meaningful independent factors using factor analysis.

- (c.) Computation of suppliers weights based on independent factors using standard and mean deviations along with improved TOPSIS method.

2. A bi-objective mathematical model is formulated with following fuzzy objectives, which is then solved using fuzzy approach:

- (a.) Minimization of total cost of the system includes procurement, holding, and transportation costs;
- (b.) Minimization of carbon emission that can be accomplished by selecting the appropriate vehicle for distribution of goods;
- (c.) Utilization of Fuzzy Goal Programming (FGP) approach to solve the bi-objective optimization problem for fulfilling the goals of the decision process.

4.1. Supplier Selection Process

4.1.1. Identification of important variables (criteria)

A group of DMs is formed for the assessment of suppliers, which comprises of managers from operations, procurement and production departments having experience of 3-5 years. Five potential suppliers are selected based upon their previous performances. Thirty variables are extracted from the literature and consensus with DMs as given in Table 6 (appendix).

4.1.2. Factor Analysis Process

After extracting the variables, it is recognized that there exists some interdependence among the observed variables. Moreover, evaluating the performance of suppliers on 30 variables increases complexity in a decision process and also takes lot of time. Hence, factor analysis has been used to reduce the observed variables into independent latent variables called factors. The main objective of factor analysis is to find the latent factors that show a commonality without any loss of information. For factor analysis, a sample from 50 DMs is collected (involves senior managers from various departments) through questionnaire using a 7 point scale (1- very low to 7-very high). They were asked to indicate the degree of agreement using a 7-point scale with the statements such as How important is the particular criterion for assessing the suppliers performance? Moreover, there is a vast discussion by many authors about the effect of sample size in order to get the significant results while solving the problem by factor analysis (Mac Callum *et al.* [54]; Hogarty *et al.* [38]). However, de Winter *et al.* [27] discussed that the sample size 50 is appropriate to get the desired results providing high commonalities, low model error, and large number of variables. The details of factor analysis are found in Malhotra [55].

4.1.3. Assessment of suppliers performance using mean and standard deviation with TOPSIS method

Let A_1, A_2, \dots, A_n represent feasible alternatives; F_1, F_2, \dots, F_n be n factors; d_1, d_2, \dots, d_k be k DMs; w_1, w_2, \dots, w_n represent weights of n factors where $w_n \in [0, 1]$; w_n^k denotes n^{th} factors weight provided by k^{th} DM; $\lambda = (\lambda_1, \lambda_2, \dots, \lambda_k)^T$ represents the weights of DMs where $\lambda_k \geq 0, \sum_k \lambda_k = 1$. Let $S = \{s_i | i = -t, \dots, -1, 0, 1, \dots, t\}$ represent a finite set of ordered discrete terms, where s_i denotes assessment value for a linguistic variable given by DMs. s_i can take any value such as: a set of 7 terms $S = \{s_{-3} = \text{very poor}, s_{-2} = \text{poor}, s_{-1} = \text{slightly poor}, s_0 = \text{fair}, s_1 = \text{slightly good}, s_2 = \text{good}, s_3 = \text{very good}\}$ provided by a DM. The step by step procedure of assessing the suppliers performance is mentioned in Liu *et al.* [51].

4.2. Mathematical Model Formulation

In this section, a mathematical model is developed for the selection of a performing supplier in order to enhance the performance of the SC network. The objective of the model is to minimize the total cost and carbon emission value while transporting products from supplier to RSs through DCs. The proposed bi-objective optimization problem is formulated under the following assumptions:

Assumptions:

- ∅ Parameters are known.
- ∅ Initial inventory at all DCs and RSs are zero.
- ∅ Shortages are not allowed.
- ∅ Single product having two variants is considered.
- ∅ Each supplier can supply both models.
- ∅ Supply is instantaneous.
- ∅ Multi-period is considered.
- ∅ Demand is known with certainty and is divisible.
- ∅ Three types of vehicles (γ_1, γ_2 and γ_3) are considered based on capacity and carbon emission amount.

The considered sets, parameters, decision variables, objective function, and constraints are given below:

Sets:

- $i \in I$ Set of products
- $a \in A$ Set of suppliers
- $j \in J$ Set of DCs
- $r \in R$ Set of RSs
- $t \in T$ Set of time periods
- $\gamma \in \Gamma$ Set of vehicle type according to capacity and carbon emission amount

Parameters:

- ∅ H_{ijt}^1 : Per unit inventory holding cost of i^{th} product at j^{th} DC in time period t ;
- ∅ H_{irt}^2 : Per unit inventory holding cost of i^{th} product at r^{th} RS in time period t ;
- ∅ P_{iajt} : Procurement cost of i^{th} product supplied by a^{th} supplier at j^{th} DC in time period t ;

- ¢ T_{ajt}^1 : Transportation cost per kg transporting products from a^{th} supplier to j^{th} DC in time period t ;
 - ¢ T_{jrt}^2 : Transportation cost per kg transporting products from j^{th} DC to r^{th} RS in time period t ;
 - ¢ $C_{aj\gamma t}^1$: Carbon emission of γ^{th} vehicle while transporting goods from a^{th} supplier to j^{th} DC in time period t ;
 - ¢ $C_{jr\gamma t}^2$: Carbon emission of γ^{th} vehicle while transporting goods from j^{th} DC to r^{th} RS in time period t ;
 - ¢ CC_{iajt} : Relative weights obtained of a^{th} supplier for i^{th} product at j^{th} DC during time period t using methodology given in section 4.1.3;
 - ¢ S_w : Acceptable supplier weight provided by the company;
 - ¢ IO: Initial inventory at DC;
 - ¢ INI: Initial inventory at RS;
 - ¢ D_{ijrt}^1 : Demand of i^{th} product at j^{th} DC from r^{th} RS during time period t ;
 - ¢ D_{irt}^2 : Demand of i^{th} product at r^{th} RS during time period t ;
 - ¢ Cap_{ijt}^1 : Capacity of i^{th} product at j^{th} DC during time period t ;
 - ¢ Cap_{irt}^2 : Capacity of i^{th} product at r^{th} RS during time period t ;
 - ¢ ω_i : Weight of i^{th} product in kg;
 - ¢ $E_{aj\gamma t}^1$: Threshold for γ^{th} vehicle load for transporting goods from a^{th} supplier to j^{th} DC in time period t ;
 - ¢ $E_{jr\gamma t}^2$: Threshold for γ^{th} vehicle load for transporting goods from j^{th} DC to r^{th} RS in time period t ;
 - ¢ \tilde{C} is fuzzy total cost;
 - ¢ \tilde{CB} is fuzzy total carbon emission;
 - ¢ C_o and C^* are the aspiration and tolerance level of fuzzy total cost;
 - ¢ CB_o and CB^* are the aspiration and tolerance level of fuzzy carbon emission.
- Decision Variables:**
- ¢ I_{ijt}^1 : Ending inventory of i^{th} product at j^{th} DC during t^{th} time period;
 - ¢ I_{irt}^2 : Ending inventory of i^{th} product at r^{th} RS during t^{th} time period;
 - ¢ X_{iajt} : Quantity procured of i^{th} product from a^{th} supplier at j^{th} DC during t^{th} time period;
 - ¢ V_{iajt} : Binary variable i.e. 1 if a^{th} supplier is selected for i^{th} product at j^{th} DC during t^{th} time period, or 0 otherwise;
 - ¢ L_{ajt}^1 : Quantity in kg transported from a^{th} supplier to j^{th} DC during t^{th} time period;
 - ¢ L_{jrt}^2 : Quantity in kg transported from j^{th} DC to r^{th} RS during t^{th} time period;
 - ¢ $CO_{aj\gamma t}^1$: Binary variable i.e. 1, if total load falls in γ^{th} vehicle break while transporting goods from a^{th} supplier to j^{th} DC in t^{th} time period, or 0 otherwise;
 - ¢ $CO_{jr\gamma t}^2$: Binary variable i.e. 1, if total load falls in γ^{th} vehicle break while transporting goods from j^{th} DC to r^{th} RS in t^{th} time period, or 0 otherwise;
 - ¢ β_j : Binary variable i.e. 1, if j^{th} DC is operational, or 0 otherwise.

Objective Functions

The first objective function comprises inventory holding cost at DCs and RSs, cost of procuring goods, and transportation cost while transporting goods from suppliers to DCs and further to RSs, and cost of opening of DC.

$$\begin{aligned}
 \text{Min } \tilde{C} = & \sum_{i=1}^I \sum_{j=1}^J \sum_{t=1}^T H_{ijt}^1 I_{ijt}^1 + \sum_{i=1}^I \sum_{r=1}^R \sum_{t=1}^T H_{irt}^2 I_{irt}^2 \quad (1) \\
 & + \sum_{i=1}^I \sum_{a=1}^A \sum_{j=1}^J \sum_{t=1}^T P_{iajt} X_{iajt} V_{iajt} + \sum_{a=1}^A \sum_{j=1}^J \sum_{t=1}^T T_{ajt}^1 L_{ajt}^1 V_{iajt} + \sum_{j=1}^J \sum_{r=1}^R \sum_{t=1}^T T_{jrt}^2 L_{jrt}^2 \beta_j
 \end{aligned}$$

The second objective function minimizes total carbon emission value while transporting goods from suppliers to DCs and further to RSs. It is measured on the basis of the carbon emission produced due to the movement of trucks.

$$\text{Min } \tilde{C}B = \sum_{a=1}^A \sum_{j=1}^J \sum_{\gamma=1}^{\Gamma} \sum_{t=1}^T C_{aj\gamma t}^1 CO_{aj\gamma t}^1 + \sum_{j=1}^J \sum_{r=1}^R \sum_{\gamma=1}^{\Gamma} \sum_{t=1}^T C_{jr\gamma t}^2 CO_{jr\gamma t}^2 \quad (2)$$

Constraints

Here, equations (3) and (4) are utilized for the selection of best performing supplier based upon the weights determined using mean and standard deviations along with TOPSIS.

$$CC_{iajt} \geq S_w V_{iajt} \quad \forall i, a, j, t \quad (3)$$

$$\sum_{a=1}^A V_{iajt} = 1 \quad \forall i, j, t \quad (4)$$

Equations (5) and (6) are inventory balancing equations at DC.

$$I_{ijt}^1 = IO + \sum_{a=1}^A X_{iajt} V_{iajt} - \sum_{r=1}^R D_{ijrt}^1 \beta_j \quad \forall i, r, t = 1 \quad (5)$$

$$I_{ijt}^1 = I_{ij,t-1}^1 + \sum_{a=1}^A X_{iajt} V_{iajt} - \sum_{r=1}^R D_{ijrt}^1 \beta_j \quad \forall i, r, t > 1 \quad (6)$$

Equation (7) ensures that the demand should be satisfied at DC.

$$\sum_{j=1}^J \sum_{t=1}^T I_{ijt}^1 + \sum_{a=1}^A \sum_{j=1}^J \sum_{t=1}^T X_{iajt} V_{iajt} \geq \sum_{j=1}^J \sum_{r=1}^R \sum_{t=1}^T D_{ijrt}^1 \beta_j \quad \forall i \quad (7)$$

Equation (8) restricts the capacity at DC.

$$I_{ijt}^1 + \sum_{a=1}^A X_{iajt} V_{iajt} \leq Cap_{ijt}^1 \quad \forall i, j, t \quad (8)$$

Equations (9) and (10) are inventory balancing equations at RSs.

$$I_{irt}^2 = INI + \sum_{j=1}^J D_{ijrt}^1 * \beta_j - D_{irt}^2 \quad \forall i, r, t = 1 \tag{9}$$

$$I_{irt}^2 = I_{irt-1}^2 + \sum_{j=1}^J D_{ijrt}^1 * \beta_j - D_{irt}^2 \quad \forall i, r, t > 1 \tag{10}$$

Equation (11) gives guaranty that the demand is satisfied at RSs.

$$\sum_{r=1}^R \sum_{t=1}^T I_{irt}^2 + \sum_{j=1}^J \sum_{r=1}^R \sum_{t=1}^T D_{ijrt}^1 * \beta_j \geq \sum_{r=1}^R \sum_{t=1}^T D_{irt}^2 \quad \forall i \tag{11}$$

Equation (12) limits the capacity at RSs.

$$I_{irt}^2 + \sum_{j=1}^J D_{ijrt}^1 * \beta_j \leq Cap_{irt}^2 \quad \forall i, r, t \tag{12}$$

Equations (13) and (14) are the connector between procurement and transportation, which converts the number of products into kg at DC and RS.

$$L_{ajt}^1 = \sum_{i=1}^I \omega_i X_{iajt} V_{iajt} \quad \forall a, j, t \tag{13}$$

$$L_{jrt}^2 = \sum_{i=1}^I \omega_i D_{ijrt}^1 \quad \forall j, r, t \tag{14}$$

Equations (15)-(18) discusses carbon emission level while transporting goods from suppliers to DCs and from DCs to RSs.

$$L_{ajt}^1 \geq E_{aj\gamma t}^1 CO_{aj\gamma t}^1 \quad \forall a, j, \gamma, t \tag{15}$$

$$\sum_{\gamma=1}^{\Gamma} CO_{aj\gamma t}^1 = 1 \quad \forall a, j, t \tag{16}$$

$$L_{jrt}^2 \geq E_{jr\gamma t}^2 CO_{jr\gamma t}^2 \quad \forall j, r, \gamma, t \tag{17}$$

$$\sum_{\gamma=1}^{\Gamma} CO_{jr\gamma t}^2 = 1 \quad \forall j, r, t \tag{18}$$

Equations (19) and (20) identify an appropriate DC on the basis of its capacity and customers demand.

$$\sum_{i=1}^I \sum_{t=1}^T Cap_{ijt}^1 \geq 0.60 * \sum_{i=1}^I \sum_{r=1}^R \sum_{t=1}^T D_{ijrt}^1 * \beta_j \quad \forall j \tag{19}$$

$$\sum_{j=1}^J \beta_j \geq 1 \quad (20)$$

Equation (21) restricts the demand at DC.

$$D_{irt}^2 \leq \sum_{j=1}^J D_{ijrt}^1 * \beta_j \quad \forall i, r, t \quad (21)$$

The following two equations, (22) and (23), are non-negativity and binary constraints.

$$X_{iajt}, I_{ijt}^1, I_{irt}^2 \geq 0; \quad (22)$$

$$\beta_j, CO_{ajt}^1, CO_{jrt}^2, V_{iajt} \in [0, 1] \quad (23)$$

Above mentioned mathematical model is a fuzzy non-linear bi-objective programming problem with non-linear constraints. These kinds of problem cannot be solved by simple mathematical programming model. So, we employed a goal programming method with fixed priorities for conflicting objectives to solve the problems.

4.3. Fuzzy Goal Programming Approach (Bellman and Zadeh [4]; Zimmermann [80])

In a multi-objective optimization problem (MOOP), it is difficult to optimize the objectives having conflicting nature with respect to the constraints. Multi-objective optimization solution approach involves identifying the best feasible solution among all. In the current problem, a trade-off has to be obtained for the two objectives because of their contradictory nature. But, in the absence of deterministic conditions, it is more accurate to use flexible fuzzy objectives. Vague aspirations in DMs preferences lead to the consideration of fuzzy objectives. The reason of using fuzzy programming is to stabilize the ambiguity in DMs opinion and to adjust the degree of agreement for each goal (Tsai and Hung [70]). Weighted max-min approach is utilized here to solve the above optimization problem. The steps of fuzzy goal programming are given in Bhayana *et al.* [5].

The optimal solution obtained signifies the optimal compromised solution based on the DMs preferred weights. The model is solved by Lingo 11.0 to get the desired results.

5. NUMERICAL ILLUSTRATION

The current study emphasizes on the establishment of optimum SC network of a microwave oven manufacturer by optimally utilizing the resources. In this chain, the demand at RSs directly affects the demand of suppliers. So, products must be inventoried not to affect the total cost and capacity of the system while satisfying the demand of the RSs.

In this section, data are provided for the problem developed in section 3 for four planning periods. The company is concerned about promoting their three models (M1, M2 and M3) of microwave oven so to maximize their sales. Five suppliers are considered, based on their past performance to efficiently supply all the models as per customers requirements. However, the efficiency of each and every supplier varies because of different factor. Hence, suppliers must be selected based on their performance on identified factors. The assessment process of identifying suppliers performance is explained below in order to determine relative weights of suppliers with respect to the independent factors.

Firstly, Factor Analysis is utilized to find the independent factors out of 30 interrelated variables, as mentioned in Table 6 (in appendix). The results are given below.

1. In this study, the null hypothesis that the population correlation matrix is an identity matrix is rejected by the Bartlett's test of sphericity.
2. Value of KMO statistic, i.e. 0.662, confirms the use of apt size of the sample.
3. The results of Principal Component Analysis show the presence of five factors that account for approximately 79% of total variance. The variance value of each factor tells us the priority of each factor. Priority of first factor is higher than the priority of other four factors. Similarly, the second factor is more important than the third factor, and so on.
4. Afterwards, five factors have been determined after rotating the variables using Varimax rotation.
5. The factors are renamed as: Management (F1), Cost (F2), Delivery (F3), Flexibility (F4), and Quality (F5). The factors and their criteria are given in Table 1.

Factors	Variables
F1	B1,B3,B5,B14,B17,B18,B19,B20,B25
F2	B9,B10,B13,B22,B23,B26
F3	B2,B4,B16,B21,B24,B28
F4	B6,B11,B15,B29,B30
F5	B7,B8,B12,B27

Table 1: Factors and their criteria

Subsequently, priority weights of suppliers, based on above extracted five factors, are computed. The step by step approach is given below:

In the first step, DMs have provided their opinions in terms of multi-granularity linguistic variables using 9-point, 7-point, and 5-point scales, as mentioned below.

$S_i^9 = \{S_{-4}^9 = \text{extremely poor}, S_{-3}^9 = \text{verypoor}, S_{-2}^9 = \text{poor}, S_{-1}^9 = \text{slightly poor}$
 and $S_0^9 = \text{fair}, S_1^9 = \text{slightly good}, S_2^9 = \text{good}, S_3^9 = \text{very good}, S_4^9 = \text{extremely good}\}$

$S_i^7 = \{S_{-3}^7 = \text{verypoor}, \dots, S_3^7 = \text{very good}\}$

$S_i^5 = \{S_{-2}^5 = \text{verypoor}, \dots, S_2^5 = \text{very good}\}$

The performance scores given by DM1 for five suppliers based on the five factors (Table 1) are given in Table 2. Similarly, the decision opinions for each

supplier can be provided by other DMs also.

Suppliers	F1	F2	F3	F4	F5
A1	S_0^5	S_2^5	S_1^5	S_2^5	S_0^5
A2	S_2^5	S_1^5	S_0^5	S_2^5	S_{-1}^5
A3	S_{-1}^5	S_1^5	S_2^5	S_1^5	S_2^5
A4	S_1^5	S_0^5	S_2^5	S_2^5	S_1^5
A5	S_2^5	S_1^5	S_{-1}^5	S_1^5	S_2^5

Table 2: The 5 granularity decision table for all alternatives with respect to factors given by DM1

Afterwards, the decision matrices are transformed into 9 granularity evaluation matrices. In the next step, the mean and standard deviations are calculated for all DMs. Subsequently, attribute weights with respect to each DM are calculated by taking both standard deviation and mean deviation in the process, i.e. by taking $u = v = 0.5$, as given below:

$$w_n^{(1)} = (0.2559, 0.1198, 0.2559, 0.1125, 0.2559)$$

$$w_n^{(2)} = (0.2621, 0.1392, 0.1905, 0.1035, 0.3048)$$

$$w_n^{(3)} = (0.1854, 0.0868, 0.2333, 0.2769, 0.2176)$$

Further, the weights of the DMs are calculated.

$$\lambda_k = (0.3257, 0.3393, 0.3350)$$

Lastly, the evaluation scores of five suppliers with respect to five factors are given in Table 3, below:

Suppliers	A1	A2	A3	A4	A5
RelativeScores	0.2271	0.0996	0.1951	0.2557	0.2225

Table 3: Relative Scores of Suppliers

Afterwards, the numerical data are provided by the company for optimization model. Procurement cost per unit of model M1 ranges from INR 15400 to INR 21970, M2 between INR 14500 and INR 20410, and M3 ranges from INR 12700 to INR 17329 along with shipping cost per kg from supplier to DCs and further to RSs ranges between INR 3 to INR 5. The weights of models M1, M2, and M3 are 17.5 kg, 21 kg, and 13.5 kg, respectively. The company is also concerned about shipping the products from DCs to the RSs. Thus, identifying an appropriate DC for operations also reduces the cost. In addition, the company is concerned about minimizing the total carbon emission while shipping from one level to another, which is based upon the selection of appropriate vehicle type. Hence, the level of carbon emission of all three trucks per trip while delivering goods from suppliers to DCs and further to RSs according to the vehicle capacity is provided by the company. The capacity level of a vehicle for delivering the goods while going

from suppliers to DC is 6000 units and 100 units while moving to RSs. The range varies for each time period.

The cost of keeping stock at DCs and RSs ranges between INR 2 to INR 5 along with RSs demands, which ranges between 23 units to 40 units. The demanded quantity at DC is depended upon the demand at RSs. Hence, demand at DC is calculated by the mathematical model directly. Moreover, keeping too much stock of the final product increases the total cost of the system. Hence, restricting the capacity level at DC and at RSs helps to optimize the cost. The data related to capacities of DCs and RSs are provided by the company. So the procurement amount along with the inventory should not exceed the capacity of suppliers and the capacity of DCs in a given time. Fulfilling the demand of the customers leads to the customers satisfaction level. Thus, the procurement quantity along with inventory must be greater than the demand of customer.

The information given above will be used to solve the mathematical model developed in section 4.2. In the next section, results and implications are provided.

6. RESULT AND IMPLICATION

6.1. Results

The optimization software Lingo 11.0 solves the proposed mathematical model. Based on the steps of fuzzy goal programming and using the numerical information provided in section 5, optimal solutions with respect to the constraints of SC network is obtained. The optimal solution is provided in the Table 4, given below.

<i>Objective</i>	<i>Cost</i>	<i>Carbon Emission Level</i>
<i>Minimization of Cost</i>	INR 71143320	24738
<i>Minimization of Carbon Emission</i>	INR 72171120	58468

Table 4: Aspiration levels

Initially, thirty variables are identified, some are interrelated and some show independent behaviour. The interrelated variables are transformed into five independent factors using factor analysis. The suppliers are assessed based on those five factors by utilizing mean and standard deviation method along with improved TOPSIS. The integrated approach identifies the relative weights of suppliers, which are further used in the optimization model for the selection of performing suppliers while minimizing the total cost of the system and carbon emission level of the vehicles.

In the next stage, weighted max-min approach is employed to transform the bi-objective optimization problem into a single objective problem. The approach considers all goals simultaneously by assigning the relative weights to all the goals based on the DMs preference. In the above problem, equal importance is given to both objectives, i.e., $\tau_1 = \tau_2 = 0.5$ is considered. Since minimizing the carbon emission is also an important aspect for the company in order to be

sustainable, the compromised solution obtained for the proposed model as cost = INR 71143320 and carbon emission = 24738.

Procurement quantities of all three models from the selected suppliers are given in Table 5. The suppliers selected for procuring the products are A1, A4, and A5. It is evident that selecting an operational DC on the basis of capacity and demand is more beneficial as it makes direct impact on the total cost. If the capacity of a DC is more than the demand, then only that DC would be operational. According to demand, all five DCs get activated for delivering the goods to RSs in four planning horizons. Carbon emission equations help to determine the selection of appropriate vehicles while transporting the goods from supplier to DCs and to RSs. Three trucks having different carbon emission level were hired with varying capacities. The truck with minimum carbon emission is selected for transporting the goods from one level to another in different time periods.

	J1,T1	J4,T1	J1,T2	J2,T2	J4,T2	J1,T3	J2,T4
I1,A1	439	0	373	87	0	309	20
I1,A4	0	228	0	0	118	0	0
I2,A1	366	0	311	72	0	258	17
I2,A4	0	190	0	0	98	0	0
I3,A1	570	0	484	113	0	401	26
I3,A4	0	295	0	0	153	0	0

Table 5: Procurement quantity of all models from suppliers to DCs for time period T1 to T4

6.2. Implications

The main aim of this study is to help managers about sustaining in the market by making critical decisions.

¢ The proposed methodology helps DMs to optimize the total cost while selecting the best performing supplier. In order to conduct the environmental and economic conscious activities, supplier-buyer relationship is considered as an important aspect of the SC. Thus, a good supplier helps in attaining the environmentally sound SC network at minimum cost.

¢ The objective of minimizing carbon emission in a mathematical problem ensures the company to be environmentally conscious. Results show that the incorporation of carbon emission into the decision process leads to effective and environmentally friendly system. Hence, including carbon emission into the process can prove to be an effective strategy for the DMs to sustain in the market.

7. CONCLUSION

The current study focuses on the integration of strategic, tactical, and operational decisions in the SC network while minimizing the total cost and carbon emission by selecting the appropriate vehicle under fuzzy environment. The significant aspects of the proposed fuzzy bi-objective optimization problem are: (1)

Integrating the strategic decisions, such as identifying an appropriate DC and evaluating and selecting the efficient supplier strategically on the basis of five interrelated factors with the tactical decision for maintaining the inventory well, and selecting the vehicle as per the carbon emission and capacity at operational level; (2) obtaining a trade-off between the two conflicting goals of minimizing carbon emission and systems cost. Mean and standard deviation method along with improved TOPSIS is integrated for assessing the performance of suppliers in terms of relative scores, which are further utilized in the mathematical model to optimize the decisions. Fuzzy goal programming (FGP) approach is used to find the compromised solutions of the bi-objective model by considering an Indian manufacturing company of microwave oven to illustrate the model. Results show that the model efficiently and effectively identifies the best performing supplier based on its priority weights. The proposed mathematical model proves to be an effective tool for three level network for enhancing the image of an organization towards ecological aspects. The mathematical model developed in this paper can be aptly utilized by other industries with the suitable adjustments.

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Appendix

S.No.	Variables	References
1	Management Capability (B1)	Sevkli <i>et al.</i> [64]; Kannan <i>et al.</i> [43]; Awasthi <i>et al.</i> [1]
2	Order Fulfil Rate (B2)	Celebi and Bayraktar <i>et al.</i> [13]
3	Financial Position (B3)	Gencer and Gurpinar [32]; Keskin <i>et al.</i> [45]
4	Order Lead Time (B4)	Sevkli <i>et al.</i> [64]; Kannan <i>et al.</i> [43]
5	Information System (B5)	Kannan <i>et al.</i> [43]; Celebi and Bayraktar [13]
6	Response Flexibility (B6)	Chen [18]; Bai and Sarkis [2]
7	Response to Claims (B7)	Ha and Krishnan [35]; Weber <i>et al.</i> [72]
8	Service Quality Credence (B8)	Gencer and Gurpinar [32]; Bai and Sarkis [2]
9	Product Price (B9)	Cebi and Otay [12]; Sevkli <i>et al.</i> [64]
10	Logistic Cost (B10)	Kannan <i>et al.</i> [43]; Govindan <i>et al.</i> [34]
11	Service Flexibility (B11)	Buyukozkan and Cifci [11]; Kannan <i>et al.</i> [43]
12	Skills of Workers (B12)	Weber <i>et al.</i> [72]; Ha and Krishnan [35]
13	Discount for Early Payment (B13)	Banos-Caballero <i>et al.</i> [3]
14	Technology Oriented Operations (B14)	Cebi and Otay [12]; Sarkis and Talluri [62]
15	Inventory Position (B15)	Gary Teng and Jaramillo [31]; Ku <i>et al.</i> [46]
16	On-time Delivery (B16)	Cebi and Otay [12]; Sevkli <i>et al.</i> [64]
17	Past Business Records (B17)	Liu and Hai [50]; Ku <i>et al.</i> [46]
18	Infrastructure (B18)	Liu and Hai [50]; Chan <i>et al.</i> [15]
19	Honesty (B19)	Liu and Hai [50]; Kannan and Choon [42]
20	Procedural Compliance (B20)	Gencer and Gurpinar [32]; Liu and Hai [50]
21	Trade Restriction (B21)	Gary Teng and Jaramillo [31]; Ku <i>et al.</i> [46]
22	Tariff and Taxes (B22)	Chan <i>et al.</i> [15]; Ku <i>et al.</i> [46]
23	Discount for Bulk Order (B23)	Xia and Wu [74]; Lee <i>et al.</i> [49]
24	Reliable Delivery Method (B24)	Gencer and Gurpinar [32]; Keskin <i>et al.</i> [45]
25	Service Performance (B25)	Sarkis and Talluri [62]; Kannan <i>et al.</i> [43]
26	Ordering Cost (B26)	Govindan <i>et al.</i> [34]; Gary Teng and Jaramillo [31]
27	Extent of Information Standardization (B27)	Gencer and Gurpinar [32]; Kannan <i>et al.</i> [43]
28	Modes of Transportation Facility (B28)	Haq and Kannan [36]
29	Negotiability (B29)	Gary Teng and Jaramillo [31]; Ku <i>et al.</i> [46]
30	Conflict Resolution (B30)	Sarkis and Talluri [62]; Bai and Sarkis [2]

Table 6: List of variables (criteria) for the evaluation of supplier