A Fuzzy Multi-Criteria Optimization Model for Allocating SKU and Suppliers in SC System

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Abstract

Supply chain stakeholders are increasingly paying attention to the optimal design of their supply chains because of several reasons like increasing production cost, reducing product life cycles, shrinking resources, and environmental sustainability. There has been greater emphasis on environmental concerns whilst designing the supply chains because of emerging government legislations in this domain and pressure from society. As a result, supply chain partners need to analyse their operations more critically. This study proposes a strategic decision-making model considering the operational costs caused by coordination and optimization of the sustainable supply chain design to satisfy the demand at retailers. In the study, an integrated supplier selection, procurement, inventory control and transportation model is discussed that helps in evaluating the suppliers, determining optimum quantity to procure, choosing transportation vehicle type along with managing environmental issues, obtaining optimal stock keeping units (SKU) and safety stock for each product category to fulfil a specified service level for retailers at minimum cost for the next planning horizon. The model demonstrates that how demand at retailer drives the full supply chain coordination and selection of distribution centre. The model has been validated through a case study.

Keywords

Credibility, Fuzzy analytical network process, Travelling salesman models, Stock keeping units; service level

1. Introduction

Effective supply chains must be flexible and responsive to the changing dynamics in the market place, in manufacturing and technology, and in consumer expectations. But, change must be planned and based on today's demands and tomorrow's opportunities and risks (USAID, 2014). Supply chain optimization is a powerful, practical tool that can improve performance now and position supply chains for the future. The supply chain performance of any organization is affected by its suppliers' environmental, economical and their credibility performance. Selecting green suppliers is a strategic decision in order to be more competitive in today's global market. Environmental

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sustainability of a supply chain depends on the purchasing strategy of the supply chain members. Selecting and evaluating suppliers involves several quantitative and qualitative criteria. Mostly the literature have focused on cost, quality, lead time, etc. issues but not enough importance have been given to carbon emission, operational cost for supplier evaluation in forward supply chain management (Shaw *et al.,* 2012). On the other side, integration of many partners in supply chain network can also help in optimizing the supply chain performance. In the globalized world, supply chain can be extremely complex. For example, it may have an intricate network structure involving an arbitrary number of firms, each firm may have private information about its own cost and demand forecast, and the actions taken by firms may not be observable or verifiable. Therefore, integration and collaboration of supply chain entities for common objectives and constraints becomes an important area of research. Specially, collaboration between retailers and supply chain for a common objective can help in improving performance in terms of sales, stocks and future demand etc. When retailers shares the plan with their suppliers, the suppliers are able to manage their supplies in a better way which helps in reducing the risk of rejection and provides more consistency to the retailers. Though collaboration between these two important entities is still a new concept, as many are cautious for sharing sentitive information like demand data and with competition, paranoia about confidential data getting into the public domain makes a lot of sense for the retailers.

Supply Chain Management (SCM) and integration are issues which have encouraged great amount of research in recent years. (Diabat *et al.* 2009) formulated a mixed integer programming (MIP) for an organization to design their optimal supply chain network whilst meeting their carbon cap. Abdallah *et al.* (2012) analysed the impact of carbon emissions on supply chain network design and supplier selection using Life Cycle Assessment approach. Chaabane *et al.* (2012) considered the impact of carbon emissions on sustainable closed loop supply chain (CLSC) network by evaluating the tradeoffs between economic and environmental objectives. Diabat *et al.* (2013) considered the issues of facility location problem in CLSC with trading of carbon emission and procurement cost. Fahimnia *et al.* (2013) proposed a MIP model for a CLSC in which impact of carbon emission is measured based on the influence of forward and reverse supply chain. During the SCM coordination, organizations select suitable suppliers based on many criteria to offer more competitive products with lessening internal costs. Each organization has a large number of suppliers and each supplier has its own product strategy to remain competitive with contrast customer demands and preferences. Most of these research studies have concentrated on finding out the best supplier on the basis of many attributes to supply all required products. Multi-attribute decision making (MADM) is a methodology of finding the most favourable alternative from the given set of alternatives. Numerous multi-criteria decision-making methods have been proposed to select suppliers such as Data Envelopment Analysis (DEA), Analytical Hierarchy Process (AHP), Analytic Network Process (ANP) etc. Golmohammadi and Mellat-Parast (2012) applied an integrated fuzzy pair-wise comparison matrix and Grey Relational Analysis (GRA) to develop a supplier selection model by taking criteria such as price, quality, delivery, transportation cost and technology. Azadi *et al.* (2015) proposed a fuzzy DEA model for the evaluation of efficiency and effectiveness of suppliers in sustainable supply chain management context. Hashemi *et al.* (2015) integrated green supplier selection approach with analytic network process and improved Grey relational analysis. Hussain *et al.* (2016)

applied an ISM-ANP integrated framework for evaluating alternatives for sustainable supply chain management.

Transportation is undoubtedly one of the most important issues in the scientific logistics because of the generation of high costs. Thus, this issue should be cautiously considered because it is directly related to the economic development of the nation. Many researchers have addressed this issue in the literature. Jha *et al.* (2012) proposed a model of minimizing transportation cost of a joint inventory location model using modified adaptive differential evolution algorithm. Jha and Shanker (2013) proposed single vendor multi-buyer integrated production inventory model with controllable lead time and service level constraints. Optimal distribution of products from one stage to another is a critical factor to manage environmental concerns like carbon emission. Travelling salesman problem (TSP) is considered appropriate for the distribution of products optimally. In TSP, salesmen find the shortest tour in such a way that all retail stores are visited exactly once to minimize the total cost and carbon emission of the vehicle. TSP is perhaps the most well-known and broadly studied problem in the area of combinatorial optimization. A number of researchers have studied the problem of TSP. Li (2014) proposed to solve a 2-objectives and 3-objectives dynamic multi-objective TSP using a parallel search system. Luo *et al.* (2014) proposed a new variant of the NSGA II algorithm (INSGA-II-MOTSP) for the solution of the multi-objective TSP. This algorithm used a layer strategy in order to avoid the production of unnecessary Pareto fronts.

Supply chain optimization problems have extensively been studied during the past decade. In addition to other problems such as uncertain demands, multi-objective problems etc., quantity discounts are also studied regarding the case of supplier selection problem. Quantity discounts are a general and helpful policy for suppliers in order to promote their products. If quantity discounts are offered by the suppliers, retailers can acquire products at a lower unit price by ordering the quantity which is more than a certain value. Mansini *et al.* (2012) proposed an integer programming based heuristic to solve the model with quantity discount and truckload shipping problem. In order to fulfil service level to meet customer's order and delivery needs, safety stock is required throughout the supply chain network. An organization's safety stock is highly influenced by demand and lead time. So to determine safety stock, there must be a significant body of knowledge. Humair *et al.* (2013) improved upon existing models by accounting for lead-time variability, particularly in multi-echelon supply chain networks. Boute *et al.* (2014) discussed an analytical approach for safety stock calculation when correlation between demand and lead time is a consequence of auto-correlated demand.

This study proposes a strategic decision-making model considering the operational costs due to coordination and optimization of the sustainable supply chain management. In this paper, an integrated supplier selection, procurement, inventory control and transportation model is discussed to evaluate performing suppliers, procured quantity, choosing transportation vehicle type along with managing environmental issues, obtain optimal stock keeping units (SKU) and safety stock for each product category to fulfil a specified service level as well as each of the locations at minimum cost for the next planning horizon. Demand from retailers is an important component that changes the decision of full supply chain. In the study, information on retailer's demand disturbs the requirement at warehouse and distribution centres, therefore, deviation takes place in the demand data at retailer's side, that affects important decisions like procurement quantity, inventory and transportation. Further, at the end of each period, the current solution is put to evaluate possible deviations from previous fixed target and a modified solution is obtained. A data set from a realistic situation is presented to demonstrate the effectiveness of the proposed model. The proposed approach can handle a realistic situation when there is information vagueness related to inputs. The model is executed on Optimization Software Lingo, version 11.0 and provided us a compromized solution for minimizing cost and carbon emission. Before executing the model, Fuzzy Analytical Network Process (FANP) is used to select suppliers on the basis of their environmental, economical and credibility performance.

2. Model Description and Methodology

In the current article, we present coordination strategy among multi-echelon supply chain for three product category, i.e. I – non-perishable consumable, II – perishable consumable and III – usable among suppliers, distribution centres, warehouses to fill the requirements of adjoined retails stores.

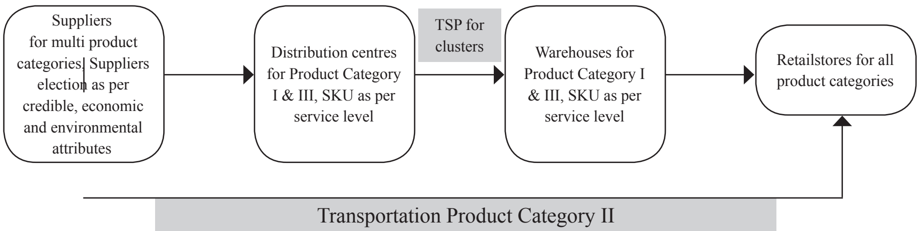

Figure 1: Flow Diagram of Supply Chain Network

For each product category, many suppliers are available who can transfer goods to distribution centres. However as, product category II, i.e. perishable consumable products cannot be stored at distribution centre; hence ordered quantity of this category is to be transported to retail stores directly. The distribution centres have capacity to store product category I and III in big size, therefore it can be considered as main warehouse for the warehouses connected to them. These warehouses are further adjoined with many retail stores. Here, warehouses and a distribution centre (DC) are grouped on the basis of minimum distance to be covered among them. In the coordination process, supply chain partners need to analyse their operations such as supplier selection, procurement, inventory management, transportation, and warehousing activities. We consider the scenario in which there are multiple suppliers in the market for each product category and best supplier is to be evaluated on the basis of many attributes. For each supplier, we have their credibility data that include past delivery time data, the quality they have offered, capacity, consistency, competency and a price per product. On the environmental side, supplier's carbon emission and carbon credits are key areas to look after. In the study, FANP is applied for selecting the appropriate supplier, addressing carbon emission, credibility and economic aspects. The calculated weight for each supplier is used in the mathematical model to select a supplier with weight more than the pre-specified threshold. At the core of inventory management is stocking control, which ensures that the right amount of stock is available to support the company's targeted fill rate in the market at minimum cost. 98% service level is specified by the companies so that customers across the supply chain are served in time. The service level percentage specified by the company is taking care of the demand deviations at retail stores. Transportation activities play a vital role in the effective management of a supply chain. In addition to being major contributor for accomplishment of service level, it has an immense impact on overall carbon emission of the supply chain. But finding the optimal balance among these factors is not easy, especially because of the vast global market size. In the course of model discussion, the transportation took place at many stages like, from suppliers to distribution centres, distribution centres to warehouses and further to retail stores. At each stage, transportation cost is involved and has to be borne by the company. Hence, analysing and optimizing the transportation process becomes extremely crucial. At the time of transportation from distribution centre to warehouses, distribution centre is selected on the basis of demand from the clustered warehouse group and one distribution centre can be connected with more than one warehouse cluster. This shows that each distribution centre has capacity to fulfil the demand of connected clusters. Further, to route the quantity in each cluster, TSP is used.

2.1 Assumptions, Sets, Parameters and Decision Variables

Initial inventory at all the distribution centres and the warehouses is zero; shortages are not allowed; safety stock has been considered at the distribution centres and warehouses.

Sets: *i=product i=1...P; j=supplier j=1,..J; t=time period t=1,...,T; m=distribution centre m=1,...,M; y=warehouse y=1,...,Y; r=retail store r=1,..,R; s=cluster s=1,...,S; f= vehicle load level f=1,..,F; u=carbon emission break u=1,..,U; c=product category c=1,...,C.*

Parameters: h_{cimt}: per unit inventory holding cost of the *i*th product of product category *c* at the *m*th distribution centre (DC) during the *t*th time period; PC_{cijt}: procurement cost of the *i*th product of product category *c* at the *j*th DC during the *t*th time period; d_{cijt}: discount factor on procured quantity as per the shelf life; η_{ct}: binary variable if the product category is consumable or usable; β_{ct}: binary variable if the product category is perishable consumable or non-perishable consumable; h'_{cimt}: per unit inventory holding cost of safety stock of the *i*th product of product category *c* at the *m*th DC during the *t*th time period; $z_{(1-\alpha)}$: service level or fill rate; TC_{jmt}: transportation cost per weight from the selected suppliers to DC; OC_{m}: operating cost of *m*th distribution centre; H_{ciyt} and H'_{ciyt}: per unit holding and safety stock costs of the *i*th product of product category *c* at the *r*th retail store during the *t*th time period; DT_{abms} and T_{ms}: distance and transportation cost per km between the nodes a and b belonging to the *s*th cluster connected to the *m*th distribution centre resp.; D_{ciyrt}: demand of the *i*th product of product category *c* at the *r*th retail store during from warehouse *y* the *t*th time period; D_{cijrt}: demand of the *i*th product of product category *c* at the *r*th retail store from warehouse *y* during the *t*th time period; TC_{cijrt} and TC_{ciyrt}: transportation cost per weight from supplier to retail store or warehouse to retail store respectively; Co_{jmt}: carbon emission value from supplier to distribution centre; Co_{fumst}: carbon emission value of *f*th vehicle load level for *s*th cluster connected to the *m*th distribution centre in *t*th time period. SL_{cijt}: Shelf life of the product; TL_{cijt}: total life of the product; WE_{cijt}: normalized weight obtained from FANP of each supplier; Cap_{cijt}: Capacity at supplier *j*; w_{ci}: weight per product per category; LT_{cimyt}: Lead time to deliver from distribution centre to warehouse and $\sigma_{LTcimyt}$ is its standard deviation; σ_{Qcimyt}: standard deviation in demand from warehouse to distribution centre; CAP_{m}: capacity at distribution centre; *Ps*: total number of nodes in the *s*th cluster; B_{fumst}: load threshold beyond which a particular vehicle type is used; LT_{ciyrt}: lead time to deliver from warehouse to retail store and $\sigma_{LTciyrt}$ is its standard deviation; σ_{Dciyrt}: standard deviation in demand from retail store to warehouse; Cap_{cirt}: capacity at retail store.

Decision Variables: X_{cijt}: Quantity procured from supplier *j*; V_{cijt}: binary variable if *j*th supplier is chosen; R_{cijt}: binary variable if shelf life of the product is less than by total life; I_{cimt}: inventory level at DC; SS_{cimt}: safety stock at DC; ϕ_{jmt}: weighted quantity to be transported from supplier to DC; α_m: binary variable if *m*th DC gets operational; G_{abms}: 1, If vehicle travels from node *a* to node *b* belonging to *s*th cluster connected to *m*th DC and otherwise zero; G_{ms}: 1, if *m*th DC is connected to *s*th cluster, or 0 otherwise; IS_{ciyt}: inventory level at warehouse; SY_{ciyt}: safety stock at warehouse; Z_{fumst}: 1, if *f*th vehicle as per load gets activated for transporting weighted quantity from DC *m* to cluster *s* in time period *t* or 0 otherwise; K_{fumst}: 1, if *u*th carbon emission break gets activated out of *f*th activated vehicle or 0 otherwise; e_a and e_b are positive values that ensures no sub-routing in travelling salesman; A: number of nodes.

3. Model Formulation

The model in the article develops a green supply chain design that incorporates the cost of procurement, safety stock cost at 98% service level, inventory carrying cost and carbon emissions value, transportation cost into the objective function. The goal of the model is to simultaneously minimize procurement, inventory and logistics costs along with the environmental concerns of carbon emissions by strategically connecting DC with the clusters of warehouses.

The first objective function is the combination of procurement cost for all the three product categories, holding and safety stock costs at DC and warehouses, and transportation cost from one stage to another.

$$Min\, Z_1 = \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{i=1}^{P}\sum_{c=1}^{C} PC_{cijt} X_{cijt} V_{cijt} \left\{\eta_{ct} + \left(1-\eta_{ct}\right)\left[\beta_{ct} + \left(1+\beta_{ct}\right) d_{cijt} R_{cijt}\right]\right\}$$

$$+\sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{i=1}^{P}\sum_{\substack{c=1\\ c\neq 2}}^{C} h_{cimt} I_{cimt} + \sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{i=1}^{P}\sum_{\substack{c=1\\ c\neq 2}}^{C} h'_{cimt} SS_{cimt} Z_{(1-\alpha)\mathrm{cimt}} + \sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{j=1}^{J} TC_{jmt}\phi_{jmt}$$

$$+\sum_{m=1}^{M} OC_m \alpha_m + T * \sum_{s=1}^{S}\sum_{m=1}^{M}\sum_{b=0}^{A}\sum_{a=0}^{A} DT_{abms} G_{abms} G_{ms} T_{ms} + \sum_{t=1}^{T}\sum_{y=1}^{Y}\sum_{i=1}^{P}\sum_{\substack{c=1\\ c\neq 2}}^{C} H_{ciyt} IS_{ciyt}$$

$$+\sum_{t=1}^{T}\sum_{y=1}^{Y}\sum_{i=1}^{P}\sum_{\substack{c=1\\ c\neq 2}}^{C} H'_{ciyt} SY_{ciyt} Z_{(1-\alpha)\mathrm{ci}\,y\,\mathrm{t}} + \sum_{t=1}^{T}\sum_{\square=1}^{R}\sum_{y=1}^{Y}\sum_{i=1}^{P}\sum_{\substack{c=1\\ c\neq 2}}^{C} D_{ciy\square t}\, \square_{ci} TC_{ciy\square t}$$

$$+\sum_{t=1}^{T}\sum_{\square=1}^{R}\sum_{j=1}^{J}\sum_{i=1}^{P}\sum_{c=2} D_{cij\square t} V_{cijt}\, \square_{ci}\, TC_{cij\square t} \tag{1}$$

Second objective minimizes total carbon emission on the basis of vehicle load and carbon emission value

$$Min\, Z_2 = \sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{j=1}^{J} Co_{jmt}\phi_{jmt} + \sum_{f=1}^{F}\sum_{u=1}^{U}\sum_{m=1}^{M}\sum_{s=1}^{S}\sum_{t=1}^{T} Co_{fumst} Z_{fumst} K_{fumst} \tag{2}$$

Following two equations helps in selecting supplier on the basis of weights obtained from FANP and ensure that only one supplier will be selected.

$$WE_{cijt} \geq Vol * V_{cijt} \quad \forall c \neq 2, i, j, t \tag{3}$$

$$\sum_{j=1}^{J} V_{cijt} = 1 \quad \forall c \neq 2, i, t \tag{4}$$

The next equation activates discount factor as per the shelf life and total life of the product.

$$SL_{cijt} \geq 0.8TL_{cijt} R_{cijt} \quad \forall c \neq 2, i, j, t \tag{5}$$

Following three equations explain about capacity at supplier and calculation of weighted quantity.

$$Cap_{cijt} \geq X_{cijt} V_{cijt} \quad \forall c \neq 2, i, j, t \tag{6}$$

$$X_{cijt} = \sum_{m=1}^{M} X_{cijmt} \quad \forall c \neq 2, i, j, t \tag{7}$$

$$\phi_{jmt} = \sum_{i=1}^{I} \sum_{\substack{c=1 \\ c\neq 2}}^{C} w_{ci} X_{cijmt} \quad \forall j, m, t \tag{8}$$

The two equations show inventory balancing with zero inventory level in first period.

$$I_{cimt} = I_{cim(t-1)} + \sum_{j=1}^{J} X_{cijmt} - \sum_{y=1}^{Y} Q_{cimyt} \quad \forall c \neq 2, i, m, t > 1 \tag{9}$$

$$\sum_{t=1}^{T} I_{cimt} + \sum_{j=1}^{J} \sum_{t=1}^{T} X_{cijmt} \geq \sum_{y=1}^{Y} \sum_{t=1}^{T} Q_{cimyt} \quad \forall c \neq 2, i, m \tag{10}$$

Safety stock calculation is shown by next equation.

$$SS_{cimt} = \sqrt{\sum_{y=1}^{Y} \left(LT_{cimyt} \sigma^2_{Q\,cimyt} + Q^2_{cimyt} \sigma^2_{LT\,cimyt} \right)} \quad \forall c \neq 2, i, m, t \tag{11}$$

Following equation helps in taking decision to open a DC as per demand and capacity.

$$CAP_m \geq 0.7 \sum_{\substack{c=1 \\ c\neq 2}}^{C} \sum_{i=1}^{P} \sum_{y=1}^{Y} \sum_{t=1}^{T} Q_{cimyt}\, \alpha_m \quad \forall m \tag{12}$$

$$\sum_{\substack{m=1 \\ y\in s}}^{M} \alpha_m = 1 \tag{13}$$

Equation (14) calculates weighted quantity to be transported from DC to clustered suppliers.

$$WQ_{mst} = \sum_{\substack{y=1 \\ y\in S}}^{Y} w_{ci} Q_{cimyt} G_{ms} \quad \forall c \neq 2, i, m, s, t \tag{14}$$

Next, set of equations are the travelling salesman problem equations which directly create the shortest distance path among warehouses in a particular cluster and also connects it to a particular DC.

$$\sum_{a=1}^{A} G_{abms} = 1 \quad \forall b < P_s, m, s, a \neq b \tag{15}$$

$$\sum_{b=1}^{A} G_{abms} = 1 \quad \forall b < P_s, m, s, a \neq b \tag{16}$$

$$\sum_{a=1}^{A} G_{abms} = \sum_{a=1}^{A} G_{bams} \quad \forall b < P_s, m, s, a \neq b \tag{17}$$

$$\sum_{m=1}^{M} G_{ms} \sum_{a=1}^{A} G_{abms} = 1 \quad \forall s, b, a \neq b \tag{18}$$

$$e_a - e_b + P_s G_{abms} \leq P_s - 1 \quad \forall m, s, a \neq 1, a, b < P_s, b \neq 1, a \neq b \tag{19}$$

Following three equations check on choosing a vehicle with optimum load and minimum carbon emission.

$$WQ_{mst} \geq B_{fumst} Z_{fumst} \quad \forall f, \text{u}, \text{m}, \text{s}, \text{t} \tag{20}$$

$$\sum_{f=1}^{F} Z_{fumst} = 1 \quad \forall u, m, s, t \tag{21}$$

$$\sum_{u=1}^{U} \sum_{f=1}^{F} Z_{fumst} K_{fumst} = 1 \quad \forall m, s, t \tag{22}$$

Next two equations show inventory balancing at the warehouse, keeping zero inventory in first period.

$$IS_{ciyt} = IS_{ciy(\text{t}-1)} + \sum_{\substack{m=1 \\ y \in s}}^{M} Q_{cimyt} \alpha_m - \sum_{r=1}^{R} D_{ciyrt} \quad \forall t > 1, c \neq 2, i, y \tag{23}$$

$$\sum_{t=1}^{T} IS_{ciyt} + \sum_{\substack{m=1 \\ y \in s}}^{M} \sum_{t=1}^{T} Q_{cimyt} \alpha_m \geq \sum_{r=1}^{R} \sum_{t=1}^{T} D_{ciyrt} \quad \forall c \neq 2, i, y \tag{24}$$

Equation (25) calculates safety stock at warehouse.

$$SY_{ciyt} = \sqrt{\sum_{r=1}^{R} \left(LT_{ciyrt} \sigma^2_{Dciyrt} + D^2_{ciyrt} \sigma^2_{LT\,ciyrt} \right)} \quad \forall c \neq 2, i, y, t \tag{25}$$

Equation (26) ensures that quantity received from warehouse and supplier will be within capacity limits.

$$\sum_{y=1}^{Y} D_{ciyrt} + \sum_{j=1}^{J} D_{cijrt} V_{cijrt} \leq Cap_{cirt} \quad \forall c, i, r, t \tag{26}$$

$X_{cijt}, \text{I}_{\text{cimt}}, SS_{cimt}, \phi_{jmt}, IS_{ciyt}, SY_{ciyt} \geq 0;$

$V_{cijt}, R_{cijt}, \alpha_m, G_{abms}, G_{ms}, Z_{fumst}, K_{fumst}$ are binary

4. Solution Algorithm

4.1 Fuzzy ANP – Define the Criteria for Supplier Selection

For the evaluation process of the suppliers, we have their credibility data that include past delivery time data (DT), the quality they have offered (Q), capacity (Cap), consistency (Con) and competency (Com). Here, product category 1 is supplied by first four suppliers (S1, S2, S3 and S4), product category 2 is supplied by supplier no. 6, 7 and 8 and product category 3 is supplied by supplier no. 9, 10 and 11. In the second stage, goal programming approach is discussed.

4.2 Fuzzy ANP – Calculate the Priorities of the Criteria

After the first step, paired comparison for the priorities of the convenience store is performed and the comparison results are combined by geometric mean. As priorities for each attribute may differ, therefore fuzzy values for the priorities helped in reaching at a crisp priority value. In the process, three decision makers have participated and triangular fuzzy number is used to obtain one value. In the same way, paired comparisons for the priorities of the suppliers are performed. The elements in a cluster are compared by applying Saaty's 1–9 scales according to their influence on an element in another cluster which they are connected to or on elements in their own cluster. The inconsistency ratio for each comparison matrix is to be obtained so the most consistent value for the entries can be determined. The inconsistency measure is useful for identifying possible errors in judgements as well as actual inconsistencies in the judgements themselves. In general, the consistency ratio should be less than 0.1. The inconsistency value is considered in all stages whilst doing the pairwise comparison. For tangible criteria, real quantitative data are used in ANP to improve the system's consistency. After all the cluster and node comparisons, the weights of the clusters and nodes (cluster matrix and weighted super matrix) are calculated. The weighted supermatrix is obtained by multiplying the elements of the unweighted supermatrix by the appropriate cluster weight. The unweighted supermatix, weighted supermatrix and limit supermatrix for both the products were calculated. Following table shows normalized values for the product category 1.

Table 1. Normalized Values of Supplier for Product Category I

Supplier 1	Supplier 2	Supplier 3	Supplier 4
0.21	0.13	0.48	0.17

4.3 Goal Programming Approah (Charnes and Cooper 1997)

Step 1: Solve the mathematical model keeping one objective at a point and the values of Z_1* and Z_2*.

Step 2: Min Z_1 and Min Z_2 s.t. $Z_1 \geq Z_1^*$; $Z_2 \geq Z_2^*$; and all the constraints. This problem provides infeasible solution.

Step 3: Min η-ρ s.t. constraints' LHS+η-ρ=RHS.

Step 4: Min η-ρ s.t. constraints' LHS+η-ρ=RHS; $Z_1+\eta_1-\rho_1=Z_1^*$ and $Z_2+\eta_2-\rho_2=Z_2^*$. The above process helps in reaching at a compromized solution, which creates a trade-off between objectives also.

5. Case Study

The model discussed in the paper is validated on the case problem of a convenience store company that operates like a retail store for perishable consumable, non-perishable consumable and usable goods. As per the available information, for each product category, some old suppliers are associated with the company. The company also has some options to open new distribution centers. Further, a number of warehouses already exist near the retail stores. The scenario discusses the movement of goods from supplier to each activated DC, further the company already has warehouses and retail stores data region wise, which helped a lot whilst discussing the case and mathematical model. The main aim in the case is to develop a pathway for the company to procure optimal quantity minimizing inventory, maintaining safety stock at 98% service level, keeping transportation cost and emission of carbon to minimum such that constraints like capacity, vehicle type, shelf life, deviations in demand and lead time etc. are satisfied. In the full process, the cost should be optimal and the process should be able to accept the demand and its deviations' data from the retail stores.

Table 2. Demand in Period 1

	Product		
Retail Store	**PC1**	**PC2**	**PC3**
R1	52	24	29
R2	32	41	67
R3	43	21	52
R4	32	42	36
R5	53	32	63
R6	27	54	43
R7	25	67	42
R8	46	24	54
R9	45	59	46

Weight of the products vary from 250 g to 1.5 kg. Lead time for delivery varies from 1 day to 2 days with the standard deviation of approx 10%. On the other side demand deviation is also approxmimately 10%. Holding cost at DC and warehouses varies from ₹7 to ₹10 per item. Procurement cost and transportation cost contribute major portion of the total cost. Procurement cost varies from ₹35 to ₹245, which is also dependent on the product category. Transportation is to take place from selected supplier to DC, DC to group warehouses and further to retail stores, which is considered as per the DC distant from the connected warehouses, weight load from supplier to DC and warehouse to retail store. The cost per kilometer from first DC is Rs12; from second DC is Rs12.5 and from third and fourth DC is Rs13. Variation in cost takes place as per the distances among all the nodes in each cluster. Third supplier for first product category, second supplier for the second product category and third supplier for the third product cateogy is chosen, it helps in keeping the procurement and transportation cost minimum with least possible carbon emission.

Minimizing carbon emission is the second important objective for the company, for which carbon emission varies as per vehicle type. Company employs heterogeneous vehicle type in terms of load as well level of carbon emission. The model checks both the levels, i.e. firstly, a truck type is chosen as per the load to be transported from the warehouse to a particular cluster, and in the next level, a truck with a specific carbon emission is selected from the multiple carbon emission level for each truck type.

5.1 Results and analysis

High product cost is leading high procurement cost in the total cost. Resulting cost aspiration level as ₹31,816,141 and carbon emission aspiration level as 12,523 from step 1 of goal programming approach that helps in creating a trade off between the two objectives. In the final solution, the cost and carbon emission values are a bit higher than the aspired values. The total cost is ₹32,966,424 and carbon emission value is 13,594. In the proposed green supply chain network, reducing carbon emission with some target value becomes really essential. Initially, we understood the transportation framework of the company, which provided us the idea of carbon emission values. The repeat movement at the same location for different warehouses is creating environmental issues. The carbon emission value provided by the company on the basis of their older transportation framework is approximately. 14,910. The proposed model gives the trade-off between the two objectives, i.e. minimize cost as well carbon emission values. It is observed from the results that the trade-off carbon emission value is 13,594, which is approximately 10% lower than the company's exiting value. From the model results, it is observed that the company shall be able to fulfil the demand and a very small quantity of safety Stock shall be required at retail stores keeping 98% service level. The safety stock level is obtained to be 2 units to 5 units per article. DC2 is activated for the warehouses of first region and DC3 is selected for the second region. The route within each region connecting warehouses to be covered in route using TSP model are also obtained. The route between *DC2* and *first region* is: start from *DC2* then moves to Y_4 further in a sequence Y_2, Y_1, Y_3 and returns to DC. Route of *D*C3 is: start from *DC3* then in a sequence connected like Y_7, Y_5, Y_6, Y_8.

6. Conclusion

This study analyses an integrated procurement and transportation planning problem with carbon emissions calculations. The model minimizes the combined expense associated with the cost of procurement, holding and safety stock. Another important aspect is transportation from supplier to DC and further to warehouses. Travelling salesman problem helped in creating shortest route among connected warehouses and DC. In the case of multi-warehouses which have been spread region wise, transporting goods to each warehouse individually becomes expensive, hence transportation has been done region wise. The information sharing between the supply chain and the retailers helps them in receiving the demanded quantity in time that further creates a positive environment at retail stores kepping zero shortages. The retailer prespecifies the quality requirements that helps the model in specifying its own quality specifications and selects best performing suppliers. Heterogeneity in vehicle type is also an important aspect and opens many options to transport weighted quantity. In the study, carbon emission is an important aspect considered for reducing it from the current level by choosing appropriate vehicle type. Therefore, heterogeneity in vehicle does not take place only for load but also for carbon emission. Each vehicle type is considered to have distinct per vehicle capacities as well as emissions generations. In particular, each vehicle type is assumed to generate a specific amount of emissions because of its empty vehicle weight. The rates of emissions generated because of the loads of the vehicles depend on the vehicle type.

The proposed work is dealing with many product categories like perishable, non-perishable and usable and for each category, one supplier is chosen from many on the basis of their credibility. Many credibility attributes were selected from literature and weight of each supplier is obtained using FANP. The proposed model is bi-objective in nature with constraints like inventory balancing, warehouse capacity, travelling salesman and load transportation thresholds for choosing vehicle. Creating coordination among many entities of supply chain is a complex problem. Solving it with a mathematical model is very difficult and leads to infeasibility due to contradicting objectives. Thus, goal programming approach is used to generate a trade-off between the objectives with respect to the constraints.

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