Low Carbon Textile Supply Chain: Modelling Using Goal Programming

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Abstract

The purpose of this paper is to optimise the total cost and carbon footprint of a supply chain network. This paper proposes a network model where the carbon footprint of the raw material, carbon emissions of the logistics, carbon emission of manufacturing, logistics costs, manufacturing cost, handling cost, over emission penalty cost and the choice of transportation trucks are considered in the design phase of the supply chain. The model is developed using multi-objective nonlinear goal programming. B2B emission boundary is used for optimising the carbon footprint. A tradeoff between cost and carbon emission is incorporated in this model. The proposed model is validated by an insightful case of a textile supply chain. This proposed model provides the information to the decision maker, how much to order, where to produce the material and which truck is to be used for transporting the material. This model plays a vital role in minimizing carbon emission of the supply chain.

Keywords: Low carbon supply chain, carbon emission, mixed integer non linear goal programming, network design

1. Introduction

Carbon emission in the environment is a leading cause of global warming. To tackle this problem, Kyoto Protocol was ratified by the industrialized nations in the year 1997. The protocol suggested some solutions of global warming. The protocol suggested that the ratified parties have to reduce their green house gas emissions during their first commitment period year 2008 to year 2012, as compared to year 1990 base level. In order to prompt abatement efforts, the protocol adopted three market mechanisms, which are Clean Development Mechanism, Joint

Implementation and Emission Trading. Clean development mechanism (CDM) helps developed countries to get emission credits for financing environmental projects in developing countries (Ramudhin *et al.* 2008; Diabat and Levi, 2009). Developed countries can earn emission credits through Joint Implementation (JI), which is a market-based instrument helps countries to obtain credit from projects undertaken in another ratified country (Ramudhin *et al.* 2008; Diabat and Levi, 2009). Emission trading serves as an economic incentive for companies to reduce pollution and emissions (Diabat and Levi, 2009). Government imposes limits, or caps, on the amount of certain pollutants allowed to be emitted. Each company will have an allocated amount of carbon emission allowance. If a company wishes to exceed that allocated quota, it would have to buy emission credits from that companies which produce less GHGs, or from the carbon trading market (Diabat and Levi, 2009).

Nowadays, supply chain members are responding on this matter very seriously. They are taking initiatives to measure the carbon footprint of their processes for mitigating the risk against these legislations. The main aim of these initiatives is to minimise the direct emissions which generate from business operations (Benjafar, 2010). Supply chain members are adopting energy efficient technologies and investing on alternative energies for reducing their emission. Technology adoption is a popular way to minimise the emissions in the supply chain. Technology adoption for minimising carbon emission in the supply chain requires huge amount investment. As a result, companies generally hesitate to adopt technology in spite of the possibility of emission reduction in the supply chain. It can be argued that by changing the supply chain design, it is possible to minimise carbon emission in a supply chain. The advantage of this approach over the previous one is that a huge capital investment is not required although simultaneously, emission reduction is possible. Carbon emission in a supply chain can be minimised by changing the transportation mode. It is observed that carbon intensity varies widely between different transportation modes (McKinnon, 2008). Shifting from a mode having higher carbon intensities (such as air and road) to much lower carbon intensity mode, (such as rail and water), can help to de-carbonize freight transport operations (McKinnon, 2008). Carbon emission in the supply chain depends on the procurement frequency of the raw material from the supplier. Carbon emission in a supply chain depends on how frequently an order is being placed to the suppliers' or how frequently the delivery of a raw material is made (Benjafar, 2010). Popular business process such as, the just-in-time (JIT) and lean manufacturing principle follow these types of the frequent delivery system with less than truck load. From this scenario, one can argue that what is the tradeoff between the carbon emissions generates from frequent delivery of the material and the saving of emission in manufacturing process by adopting new technology (Benjafar, 2010).

Supply chain can be defined as, a network of facilities and distribution options that performs the function of procurement materials, transformation of these materials into intermediate and finished products, and distribution of this finished product to customer (Lee and Billington, 1993; Ding and Chen, 2008). Good supply chain design is a prime requirement for managing any supply chain efficiently. It is well known that strategically designed supply chain can generate profit in a long term (Paksoy, 2010). Long term survival of a firm not only depends on profit but also depends on environmental sustainability. Companies cannot survive in a long term ignoring the issue of environmental sustainability. Therefore, companies have to handle the climate risk properly for gaining competitive advantage (Lash and Wellington, 2007). It has been seen that manufacturing and transportation are the major contributor of green house gas emission in the environment. Therefore, optimizations of these operations would help to minimize the emission in the supply chains (Paksoy, 2010; Benjafar, 2010). To minimise carbon emission, carbon foot print of the process is to be included in the design phase of the supply chain. Integration of the carbon footprints into the supply chain creates extra complexity for designing the system. Due to governmental pressures on companies to reduce their emissions and protect the environment, supply chain managers will have to find an optimal strategy for greening their supply chain, and this is now an area of intense ongoing research (Diabat and Levi, 2009).

2. Literature review

There are a large number of literatures available on the green supply chain (Wang *et al.* 2011). Srivastava (2007) has done a comprehensive literature review on the green supply chain. There are plenty of literatures available on supply chain network design. But, very few works have been done on supply chain network design considering the carbon emission issue. Therefore, this area needs careful attention of the researchers. In this paper, it is tried to develop a supply chain model considering the carbon emission issue. The review of the earlier research is given below. Pishvaee and Torabi (2010) developed a closed-loop supply chain network using fuzzy multi-objective mixed integer probabilistic optimisation technique. Uncertainty in terms of demands, transportation cost, manufacturing cost, processing cost, remanufacturing cost, recycling cost, delivery time, capacity, etc. have been incorporated in the model. Pati *et al.* (2008) proposed a mixed-integer goal programming (MIGP) model for paper recycling logistics network design. Three goals have been considered in their model. The goals are minimizing the positive deviation from the planned budget allocated for reverse logistics activities, minimising the positive deviation from the maximum limit of non-relevant wastepaper and minimising the negative deviation from the minimum desired waste collection. Sim *et al.* (2004) formulated a closed loop supply chain design using LP based genetic algorithm for global companies. The model covers the following factors which are potential facilities, multi-commodity aspects, planning period, and reverse flow of the return products while minimising the overall cost, which includes transportation cost, operating cost and production/storing cost. Kannan *et al.* (2010) developed a multi echelon, multi period, and multi-product closed loop supply chain network model using the genetic algorithm. Paksoy *et al.* (2011) formulated a multiproduct closed loop supply chain model. Linear programming has been used in the model. The model optimises four objective functions, which are cost of transportation and emission for forward logistics, cost of transportation and emission for reverse logistics, cost of purchasing, profits obtained by introducing recycled materials back into the (forward) supply chain.

Carbontrust (2006) developed a methodology for determining the carbon footprints of different products and process by analysing the carbon emissions generated from the energy used across the supply chain. Publicly Available Specification (PAS) 2050 suggested a methodology for calculating the carbon footprint of the product. PAS (2050) considers two types of boundaries such as business-to-consumer (B2C) and business-to-business (B2B) for calculating the carbon footprint of products. B2C measures the carbon footprint from raw material through manufacture, distribution and retail, to consumer use and finally disposal and recycling of the products. B2B footprint measurement stops at the point at which the product is delivered to another supply chain member. B2B, therefore, captures raw materials through production up to the point where the product arrives in a new organization, including distribution and transport to the customers' site. It excludes additional manufacturing steps, final product distribution, retail, consumer use and disposal/recycling.

Sheu *et al.* (2005) proposed an optimisation based model to deal with integrated logistics operational problems of green-supply chain management. They have optimised forward logistics and corresponding used-product reverse logistics in a given green supply chain using linear programming. Hugo and Pistikopoulos (2005) developed a mathematical programming-based methodology with explicit inclusion of life cycle assessment (LCA) criteria as part of the strategic investment decisions related to the design and planning of supply chain networks.

Rosic *et al.* (2009) examined a single-period dual sourcing model, which incorporates the effects of emission costs on the offshore, onshore and total order quantity in a supply chain. Kim *et al.* (2009) developed the relationship between the freight transport costs and CO_2 emissions in given inter modal and truck-only freight networks using multi-objective optimisation. Different freight combinations (i.e., a truck only system, a rail-based inter modal system, and a short sea-based inter modal system) have been incorporated in the model. The study shows six tradeoff curves between cost and carbon emission. Hoen *et al.* (2010) examined the effects of two regulation mechanisms (emission cost vs. emission constraint) on the transport mode selection decision and suggested that policy-makers should impose a constraint on freight transportation emissions. Sundarkani *et al.* (2010) presented an analytical model which measures the carbon emissions from both stationary and non-stationary supply chain processes. The model proposed complex heat flux methodology for calculating carbon emission in the supply chain. Frota Neto *et al.* (2008) formulated a model for the design and evaluation of sustainable logistic networks considering the profitability and environmental impacts in a supply chain. Ramudhin *et al.* (2008) presented a mixed integer programming model for designing a sustainable supply chain network. The model minimises the logistics cost in the supply chain which includes the fixed cost and variable cost. It also minimises green house gas emission in the supply chain. Carbon emission cap and carbon price per ton have been incorporated in the model. Three transportation modes (such as: road, rail, air) have been used in the model. The model only considers the single period system. As a result, it is very difficult to get an idea about multi period problem. Diabat and Levi (2009) designed a carbon capped supply chain network model using mixed integer programming. The model specially talks about where to open a plant and distribution centre (DC) and how the DC satisfies the retailers' demands, in such a way that the facility opening and products distribution costs are minimised, and carbon emission is not more than a predetermined emission cap. Cholette and Venkat (2009) calculated the energy and carbon emissions associated with each transportation link and storage echelon in a wine supply chain. They have found that variation in supply chain configurations can result in different energy consumption and carbon emissions.

Paksoy (2010) developed a supply chain network using mixed integer programming. The model considers the logistics cost, logistics and manufacturing emissions, penalty cost for exceeding the carbon emission quota, and incentives for lower emissions. The drawback of the model is that incentive for lowering the carbon emission in the supply chain is also minimised in objective function. Three alternatives truck having the different emission level have been used in this model. The model did not consider the purchasing cost of the raw material. Wang *et al.* (2010) proposed a multi-objective model for green supply chain network design. The model has two objectives to minimise. The first objective is cost, and the second is carbon emission. The cost objective consists of a fixed setup cost, environmental protection investment, transportation cost, and handling cost. The model is solved by using normalized normal constraint method. It is reported that at the same CO_2 emission level, a larger capacity ratio leads to less total cost while at the same total cost, CO_2 emission monotonically decreases with the capacity ratio. Benjafar (2010) presented some insightful simple models regarding the carbon emission issue in the supply chain. They have incorporated several regulatory policies for model development, which are firm is subject to mandatory caps on the amount of carbon they emit, firms are taxed on the amount of emissions they emit, firms can participate in a cap-and-trade system, and firms can invest in carbon offsets to mitigate carbon caps. The model shows that there is a possibility to cut emission without much increasing the cost. It is suggested that emission caps can be met more cost-effectively by adjusting operational decisions rather than by investing in costly more energy-efficient technology. It is suggested that imposing supply chain-wide emission caps leads to lower emissions at lower cost. Chabbane *et al.* (2010) developed another sustainable supply chain model considering the emission of green house gas. Goal programming has been used to obtain the compromise solution. Chabbane *et al.* (2011) developed a mixed-integer linear programming based framework for sustainable supply chain. The framework considers life cycle assessment (LCA) principles in addition to the traditional material balance constraints at each node in the supply chain.

3. Textile Supply chain

The Textile Supply Chain consist of varied raw material sectors, ginning sectors, spinning and extrusion processes, dyeing sector, weaving and knitting factories and garment manufacturing. This supply chain is possibly one of the most diverse in terms of the raw materials used, technologies deployed and products produced (Chandra, 2006). Indian textile industry is now trying to ally more closely with the goals of reducing its carbon foot print, because of a growing consciousness that, a smaller carbon foot print is not only environmentally friendly, but it also creates good business sense on a number of counts. The Indian textile industry will need to cover a lot of ground on critical environmental issues that will impact both competitiveness and bottom line in a regime driven by environmental and sustainability concerns. A world-wide paradigm shift toward cleaner and greener processes has been already initiated therefore Indian textile supply chain can no longer afford to remain a mute spectator if they would like to come out as a significant player in the globalised market.

In India, Industrial sector is a major consumer of energy. Environmental impact of the industrial sector can be minimised by improvements of their operations. In India, the industrial sector consumes about 36% of total energy and contributes about 30% of GDP. Major energy-intensive industries in India are iron and steel, chemicals, textiles, aluminum, fertilizers, cement, paper and non-ferrous metals. It is assumed that companies which consume more energy are emitting more carbon in the environment. Energy consumption is responsible for roughly 90% of CO_2 emissions in India (Reddy and Roy, 2010). According to Reddy and Roy (2010), carbon emissions from both steel and cement industries have grown nearly 1.4 and 1.8 times, respectively, during their study period, while emissions from copper, chemical and textile industries have more than doubled in that study period. The textile industry has emerged as the leader in terms of carbon dioxide emissions (Reddy and Roy, 2010). Therefore, the purpose of the present paper is to design and optimise a textile supply chain network considering the issue of carbon emission. The model is dealing with the multiple conflicting goals which can be solved using goal programming.

4. Goal programming model formulation

4.1 Goal programming

Goal programming (GP) is a powerful methodology in the field of multi-criteria decision making. Goal programming is generally used for dealing multi-objective optimization problem. In this paper we are dealing with different conflicting objective therefore, goal programming is the suitable methodology for obtaining compromise solution (Romero 2004; Chang 2007). For example, carbon emission in supply chain and the cost are the two conflicting objectives and by using goal programming we can handle these two objectives efficiently. Goal programming is developed and modified by Chranes et al. (1977). GP is an efficient method for multi-objective decision making problems where the decision maker tries to minimise the deviation between the achievement of the goals and their aspiration levels (Azmi and Tamiz, 2010). It is said that GP is the most widely used multi-objective optimization technique in management science (Romero 2004; Chang 2007). Caballero *et al.* (2009) has done an extensive literature review on goal programming from year 2000 – 2009. They have classified the published paper according to the application areas. The normal goal programming model can be represented in the following manner (Chang, 2007)

Min $\sum_{i=1}^{n} \{ f_i(X) - g_i \}$

Subjected to,

$X \in F$ (F is a feasible set)

Where $f_i(x)$ is the linear function of the i th goal and g_i is the aspiration level of the i th goal. There are different types of goal programming available in the literature such as Lexicographic GP (LGP), Weighted GP (WGP), and MINMAX (Chebyshev) GP, fuzzy goal programming, mixed binary goal programming (Chang, 2007). In this paper we have used weighted goal programming for optimizing our model. A weighted goal programming can be written as:

Min $\sum_{i=1}^{n} (\alpha_i d_i^+ + \beta_i d_i^-)$

Subjected to,

$f_i(X) - d_i^+ + d_i^- = g_i, \quad i = 1,2,3,\dots,n$

$d_i^+, d_i^- \geq 0 \quad i = 1,2,3,\dots,n$

$X \in F$ (F is a feasible set)

α_i and β_i are the respective positive weights attached to these deviations in the achievement function; $d_i^+ = \max(0, f_i(X) - g_i)$ and $d_i^- = \max(0, g_i - f_i(X))$ are, respectively, over- and under-achievements of the i th goal.

4.2 Model development

The model is developed considering a set of supplier, manufacturer, and customer. The most critical issue to design a low carbon supply chain is the proper boundary definition. Without proper boundary definition, it is impossible to apply the carbon cap concept in the modeling because supply chain members are not liable to pay other chain members' carbon emission penalty cost. Most of the earlier works ignored this issue while modeling the system. This model integrates carbon foot print of the raw material during the material procurement from the supplier. Earlier model did not consider this issue while modeling the green supply chain network. This paper integrates the cost versus carbon emission concept proposed by Paksoy (2010). Three different trucks having different rental fees are considered to develop the model. It is assumed that the truck which has lower rental fees emits more carbon dioxide than the higher rental fee truck. It is assumed that if the supply chain member exceeds its allocated carbon emission quota then it has to buy the extra carbon credit from the outside the carbon market. To develop the model, we have considered the following assumptions:

(a) Single product supply chain is considered.
(b) Facilities and truck capacities are known with certainty.
(c) Customer demands are deterministic in nature.

4.2.1. Sets

I = Set of suppliers, indexed by i

J = Set of manufacturer, indexed by j

T = Sets of different types of trucks, indexed by t

P = Set of time periods, indexed by p

4.2.2. Parameters

PUC_{ijp} Unit purchasing cost of the material purchase from supplier i by manufacturer j at a time period p

TC_{ijtp} Unit cost of transportation from supplier i to manufacturer j using truck t at a period p

TC_{jktp} Unit cost of transportation from each manufacturer j to each customer k with transportation mode t at period p

UHC_{ijtp} Unit handling cost of the material from supplier i to manufacturer j using truck t at period p

UHC_{jktp} Unit handling cost of the material from manufacturer j to each customer k using truck t at period p

MC_{jp} Unit manufacturing cost at manufacturer j at period p

D_{ij} Distance between supplier i and manufacturer j

D_{jk} Distance between manufacturer j and customer k

CE_t Carbon emission from the transportation mode t

CE_j Carbon emission for manufacturing one unit of product at manufacture j

C_p^{cap} Allocated carbon cap to the company at any time period p

UPC_p Penalty cost for one unit extra carbon emission at time period p

SC_{ip} Capacity of the supplier i at time period p

MC_{jp} Capacity of the manufacturer at time period p

TC_{tp} Transport capacity of truck t at time period p

CD_{kp} Demand of customer k at a time period p

UPC_p Unit penalty cost at time period p for exceeding the carbon cap allocated to company.

UIC_p Unit incentive cost at time period p for emitting lower than the allocated carbon cap.

ξ_{ijp} The fixed number of order during procurement from supplier i to manufacturer j at time period p

ψ_{jp} Minimum number supplier from which manufacturer j will procure the material at time period p

4.2.3. Decision variables

QP_{ijp} Quantity of material purchased from supplier i by manufacturer j at a time period of p

$QTSM_{ijtp}$ Quantity transferred from supplier i to manufacturer j using truck t at time period p

$QTMC_{jktp}$ Quantity transferred from manufacturer j to customer k using truck t at time period p

MQ_{jp} Manufacturing quantity in manufacturer j at a time period p

$\gamma_{ijtp}, \delta_{jktp}, \beta_{ijp}$ Binary variables

$\beta_{ijp} = 1$ if the material is purchased from supplier i by manufacturer j at time period p ; otherwise $\beta_{ijp} = 0$

$\gamma_{ijtp} = 1$ if transportation occurs from supplier i to manufacturer j using truck t at time period p ; otherwise $\gamma_{ijtp} = 0$

$\delta_{jktp} = 1$ if transportation occurs from manufacturer j to customer k using truck t at time period; otherwise $\delta_{jktp} = 0$

4.2.4. Deviational variables

d_a^-, d_a^+ Under achievement and overachievement from fixed purchasing cost goal

d_{cf}^-, d_{cf}^+ Under achievement and overachievement from purchasing carbon footprint of product

d_b^-, d_b^+ Under achievement and overachievement goal regarding transportation cost from supplier to manufacturer

d_c^-, d_c^+ Under achievement and overachievement goal regarding transportation cost from manufacturer to customer

d_d^-, d_d^+ Under achievement and over achievement goal regarding handling cost from customer to manufacturer

d_e^-, d_e^+ Under achievement and over achievement goal regarding handling cost from manufacturer to customer

d_f^-, d_f^+ Under achievement and over achievement goal regarding total manufacturing cost

de_p^-, de_p^+ Under achievement and over achievement from carbon emission goal at period p

d_g^-, d_g^+ Under achievement and over achievement from carbon emission penalty cost goal

d_h^-, d_h^+ Under achievement and over achievement from carbon emission incentive

4.2.5. Model

$$Min = d_a^+ + d_b^+ + d_c^+ + d_d^+ + d_e^+ + d_f^+ \quad (1)$$

Total ordering cost and purchasing cost

$$\sum_{i\in I}\sum_{j\in J}\sum_{p\in P}\beta_{ijp} \times OC_{ijp} + \sum_{i\in I}\sum_{j\in J}\sum_{p\in P} QP_{ijp} \times UPC_{ijp} + d_a^- - d_a^+ = A \quad (2)$$

Total product carbon footprint of purchasing material

$$\sum_{i\in I}\sum_{j\in J}\sum_{p\in P} QP_{ijp} \times UPE_{ijp} + d_b^- - d_b^+ = B \quad (3)$$

Total transportation cost

$$\sum_{i\in I}\sum_{j\in J}\sum_{t\in T}\sum_{p\in P} QTSM_{ijtp} \times UTC_{ijtp} + \sum_{j\in J}\sum_{k\in K}\sum_{t\in T}\sum_{p\in P} QTMC_{jktp} \times UTC_{jktp} + d_c^- - d_c^+ = C \quad (4)$$

Total handling cost

$$\sum_{i\in I}\sum_{j\in J}\sum_{t\in T}\sum_{p\in P} QTSM_{ijtp} \times UHC_{ijtp} + \sum_{j\in J}\sum_{k\in K}\sum_{t\in T}\sum_{p\in P} QTMC_{jktp} \times UHC_{jktp} + d_d^- - d_d^+ = D \quad (5)$$

Total production cost

$$\sum_{j\in J}\sum_{p\in P} MQ_{jp} \times MC_{jp} + d_e^- - d_e^+ = E \quad (6)$$

Carbon emission penalty cost

$$\sum_{p\in P} de_p^+ \times UPC_p + d_f^- - d_f^+ = F \quad (7)$$

Constraints

$$\sum_{t\in T} QTSM_{ijtp} \times \gamma_{ijtp} = QP_{ijp} \times \beta_{ijp} \quad \forall\, i \in I, j \in J, p \in P \quad (8)$$

$$\sum_{j\in J}\sum_{t\in T} QTSM_{ijtp} \times \gamma_{ijtp} \times \beta_{ijp} \le SC_{ip} \quad \forall\, i \in I, p \in P \quad (9)$$

$$\sum_{k\in K}\sum_{t\in T} QTMC_{jktp} \times \delta_{jktp} \le MC_{jp} \quad \forall\, j \in J, p \in P \quad (10)$$

$$\sum_{i\in I}\sum_{j\in J} QTSM_{ijtp} \times \gamma_{ijtp} \times \beta_{ijp} \le TC_{tp} \quad \forall\, t \in T, p \in P \quad (11)$$

$$\sum_{j\in J}\sum_{k\in K} QTMC_{jktp} \times \delta_{jktp} \le TC_{tp} \quad \forall\, t \in T, p \in P \quad (12)$$

$$\sum_{i\in I}\sum_{t\in T} QTSM_{ijtp} \times \gamma_{ijtp} \times \beta_{ijp} - \sum_{k\in K}\sum_{t\in T} QTMC_{jktp} \times \delta_{jktp} = 0 \quad \forall\, j \in J, p \in P \quad (13)$$

$$\sum_{i\in I}\sum_{t\in T} QTSM_{ijtp} \times \gamma_{ijtp} \times \beta_{ijp} - MQ_{jp} = 0 \quad \forall\, j \in J, p \in P \quad (14)$$

$$\sum_{j\in J}\sum_{t\in T} QTMC_{jktp} \times \delta_{jktp} \ge CD_{kp} \quad \forall\, k \in K, p \in P \quad (15)$$

$$\sum_{i\in I}\sum_{j\in J}\sum_{t\in T} \gamma_{ijtp} \times D_{ij} \times CE_t + \sum_{j\in J}\sum_{k\in K}\sum_{t\in T} \delta_{jktp} \times D_{jk} \times CE_t + \sum_{j\in J} MQ_{jp} \times CE_j +$$
$$de_p^- - de_p^+ = C_p^{cap} \quad \forall\, p = 1 \quad (16)$$

$$\sum_{i\in I}\sum_{j\in J}\sum_{t\in T} \gamma_{ijtp} \times D_{ij} \times CE_t + \sum_{j\in J}\sum_{k\in K}\sum_{t\in T} \delta_{jktp} \times D_{jk} \times CE_t + \sum_{j\in J} MQ_{jp} \times CE_j +$$
$$de_p^- - de_p^+ = C_p^{cap} + de_{p-1}^- - de_{p-1}^+ \quad \forall\, p \in P \quad (17)$$

$$QTSM_{ijtp} > \xi_{ijp} \times \beta_{ijp} \quad \forall\, i \in I, j \in J, t \in T, p \in P \quad (18)$$

$$\sum_{i\in I} \beta_{ijp} \ge \psi_{jp} \quad \forall\, j \in J, p \in P \quad (19)$$

$$QP_{ijp}, QTSM_{ijtp}, QTMC_{jktp}, MQ_{jp}, \xi_{ijp}, \psi_{jp} \ge 0 \text{ and integer} \quad \forall\, i \in I, j \in J, k \in K, t \in$$
$$T, p \in P \quad (20)$$

$$d_1^+, d_2^+, d_3^+, d_4^+, d_5^+, d_6^+, d_7^+, d_8^+, d_9^-, de_p^-, de_p^+, de_{p-1}^-, de_{p-1}^+ \ge 0 \quad (21)$$

$$\gamma_{ijtp}, \delta_{jktp}, \beta_{ijp} \in \{0,1\} \quad \forall\, i \in I, j \in J, k \in K, t \in T, p \in P \quad (22)$$

The objective function of this model is to minimize the deviation of the goals. Equation (1) minimises the deviations of the goals. Equation (2) shows the total purchasing cost and purchasing order cost goal of the manufacturer. In this equation, the manufacturer can fix their purchasing cost amount. d_a^- and d_a^+ are the deviations from the purchasing cost goal. The over achievement of the purchasing goal (d_a^+) is to be minimised. Equation (3) calculates the total carbon footprint of the purchased item. Carbon footprint consideration during purchasing of the raw material is a positive step towards minimising the carbon emission in the supply chain.

d_b^- and d_b^+ are the deviations from the carbon footprint goal of the purchased item. Overachievement of carbon footprint goal (d_b^+) is to be minimised. Equation (4) computes the total transportation cost of the products in supply chain. Transportation cost between supplier to manufacturer and manufacturer to customer are shown in the equation. d_c^- *and* d_c^+ are the deviations of the transportation cost goal. The overachievement of the transportation cost (d_c^+) is to be minimised in the objective function. Equation (5) measures the total handling cost of the products in the supply chain. The handling cost from supplier to manufacturer and manufacturer to customer are considered in this equation. The overachievement of the handling cost (d_d^+) is minimised in this equation. Equation (6) calculates the total production cost of the products. Overachievement of production cost (d_f^+) is minimised in this equation. Equation (7) measure the total penalty cost due to over carbon emission in supply chain. The overachievement of the penalty cost (d_f^+) is minimised in this equation. In ideal case, the penalty cost should be zero. Equations (8) – (22) show the various constraints of the model. Equation (8) ensures that amount of purchased material is transported by using any one of the three available truck at any point of time. Equation (9) specifies that the transportation amount, from suppliers to manufacturers, should not exceed the capacity of the supplier at any given period. Equation (10) guarantees that the transportation amount, from manufacturers to customer zones should not exceed the capacity of the manufacturer at any given period. Equation (11) is the constraint, ensuring that the quantities transported from suppliers to manufacturer should not exceed the capacity of trucks at any given time period. Equation (12) is the constraint, certifying that the quantities transported from manufacturers to customer should not exceed the capacity of trucks at any given time period. Equation (13) ensures that there should be a balance between the input and output of the products in manufacturing unit. We are not considering the inventory and backorder issue in this model. The amount of incoming material from supplier to manufacturer is equal to the amount of outgoing material from manufacturer to customer for any given period. Equation (14) certifies that the total amount, which is transported from suppliers to manufacturers, is equal to all products that are manufactured by these manufacturers. Equation (15) is the constraints for fulfillment of customer demand. The transport amount from manufacturer to customer should not less than the customer demand. Equations (16) and (17) ensures that all CO_2 emissions caused by transportation and manufacturing must be balanced with the given emission quota at any given period of time. Equation (16) deals with first period carbon emission. The underachievement and overachievement is further adjusted in equation (17). Equation (18) ensures that the raw material procurement quantity from supplier to manufacturer should be more than a certain fixed amount. If the quantity of the purchased item is below the specified number then no transportation would carry out from the supplier to the manufacturer. Equation (19) confirms that the number of suppliers from which material is procured should be more or equal to a specified number. Equation (20), (21) and (22) ensures that all variable must be greater than or equal to zero. Equation (21) also ensures that the decision variables must be integer. Equation (22) represents all the binary variables in the model.

5 A case study of Textile supply chain

We have taken a case of a textile supply chain for illustrating our proposed model. ABC is a garment manufacturing company has its three production plant across the India. ABC company fulfills the customer demand from its three manufacturing plant. The company sources fabric from three reliable suppliers. After manufacturing the T-shirts, company sells the garments to its buyers. These buyers are the big retailer like Benetton, GAP etc. We have taken the realistic value for optimizing the supply chain. Table (1 – 18) shows the data set for solving the model. The experiment was carried out on Pentium dual core (2 GHz) desktop computer. We have taken, I = 3, J = 3, K= 3, T = 3 and P = 3 for illustrating the case. We have considered the following constraints goal which are total ordering and purchasing cost goal (A) = \$ 451516, total transportation cost goal (C) = \$ 66167, total product handling cost goal (D) = \$ 1634, total production cost goal (E) = \$ 227400, carbon footprint goal of purchased raw material = 149970 Kg, and the extra carbon emission penalty cost goal (F) = \$ 0. Unit penalty cost for exceeding the quota of carbon dioxide (UPC_p) = 0.03 \$/Kg is considered in this model. This model has six objective functions. The goal value of individual objective function is decided by minimising the objective function separately using the same set of constraints. The first five objective (2-6) functions have been minimized for getting the goal value.

Table 1: Ordering cost (\$)

		Supplier								
		1			2			3		
		Period								
		1	2	3	1	2	3	1	2	3
Manufacturer	1	25	35	22	32	27	25	28	36	37
	2	20	30	26	35	38	24	33	28	28
	3	27	25	32	28	20	26	30	28	20

Table 2: Product purchasing cost ($)

		Supplier 1			Supplier 2			Supplier 3		
		Period 1	2	3	1	2	3	1	2	3
Manufacturer	1	4	5	5	6	7	5	4	6	7
	2	5	7	6	5	8	7	5	8	8
	3	7	9	8	8	9	9	7	8	9

Table 3: Purchased product carbon footprint (Kg)

		Supplier 1			Supplier 2			Supplier 3		
		Period 1	2	3	1	2	3	1	2	3
Manufacturer	1	2.4	2.7	2.8	1.9	2	2.2	1.5	1.8	2.1
	2	2.4	2.7	2.8	1.9	2	2.2	1.5	1.8	2.1
	3	2.4	2.7	2.8	1.9	2	2.2	1.5	1.8	2.1

Table 4: Product handling cost ($) from supplier to manufacturer

				Supplier 1			Supplier 2			Supplier 3		
				Period 1	2	3	1	2	3	1	2	3
Manufacturer	1	Trucks	1	0.01	0.01	0.02	0.015	0.02	0.01	0.015	0.013	0.011
			2	0.01	0.01	0.02	0.015	0.02	0.01	0.015	0.013	0.011
			3	0.01	0.01	0.02	0.015	0.02	0.01	0.015	0.013	0.011
	2	Trucks	1	0.02	0.011	0.014	0.01	0.012	0.014	0.011	0.013	0.012
			2	0.02	0.011	0.014	0.01	0.012	0.014	0.011	0.013	0.012
			3	0.02	0.011	0.014	0.01	0.012	0.014	0.011	0.013	0.012
	3	Trucks	1	0.009	0.008	0.01	0.008	0.009	0.02	0.011	0.012	0.013
			2	0.009	0.008	0.01	0.008	0.009	0.02	0.011	0.012	0.013
			3	0.009	0.008	0.01	0.008	0.009	0.02	0.011	0.012	0.013

Table 5: Product handling cost from manufacturer to customer ($)

				Manufacturer							
				1			2			3	
				Periods							
				1	2	3	1	2	3	1	2	3
Customer	1	Trucks	1	0.009	0.01	0.013	0.015	0.02	0.011	0.014	0.013	0.011
			2	0.009	0.01	0.013	0.015	0.02	0.011	0.014	0.013	0.011
			3	0.009	0.01	0.013	0.015	0.02	0.011	0.014	0.013	0.011
	2	Trucks	1	0.015	0.011	0.014	0.02	0.012	0.013	0.012	0.02	0.012
			2	0.015	0.011	0.014	0.02	0.012	0.013	0.012	0.02	0.012
			3	0.015	0.011	0.014	0.02	0.012	0.013	0.012	0.02	0.012
	3	Trucks	1	0.01	0.015	0.02	0.008	0.011	0.02	0.011	0.012	0.013
			2	0.01	0.015	0.02	0.008	0.011	0.02	0.011	0.012	0.013
			3	0.01	0.015	0.02	0.008	0.011	0.02	0.011	0.012	0.013

Table 6: Transportation cost ($) from supplier to manufacturer

				Supplier								
				1			2			3		
				Periods								
				1	2	3	1	2	3	1	2	3
Manufacturer	1	Trucks	1	0.4	0.4	0.4	0.3	0.4	0.4	0.5	0.4	0.4
			2	0.5	0.5	0.5	0.4	0.5	0.5	0.6	0.5	0.5
			3	0.6	0.6	0.6	0.5	0.6	0.6	0.7	0.6	0.6
	2	Trucks	1	0.5	0.5	0.4	0.5	0.5	0.4	0.5	0.5	0.4
			2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
			3	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	3	Trucks	1	0.3	0.3	0.5	0.3	0.3	0.5	0.3	0.3	0.5
			2	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4	0.6
			3	0.6	0.6	0.7	0.6	0.6	0.7	0.6	0.6	0.7

Table 7: Transportation cost ($) from manufacturer to customer

				Manufacturer								
				1			2			3		
				Periods								
				1	2	3	1	2	3	1	2	3
Customer	1	Trucks	1	0.3	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.5
			2	0.4	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6
			3	0.5	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.7
	2	Trucks	1	0.5	0.5	0.4	0.5	0.5	0.4	0.4	0.5	0.4
			2	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6
			3	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.7	0.7
	3	Trucks	1	0.3	0.3	0.5	0.3	0.3	0.4	0.3	0.3	0.5
			2	0.4	0.4	0.6	0.4	0.4	0.5	0.4	0.4	0.6
			3	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.7

Table 8: The carbon footprint of the product during manufacturing process

	Manufacturers		
Carbon emission per product (Kg)	1	2	3
	1.5	1.2	1.4

Table 9: The carbon emission from truck per kilometer (Kg)

	Trucks		
Carbon emission per truck per kilometer	1	2	3
	0.4	0.21	0.15

Table 10: The carbon emission quota (Kg) during any period

	Periods		
Carbon emission quota	1	2	3
	30000	25000	30000

Table 11: Production cost of unit material ($)

		Manufactures		
		1	2	3
Periods	1	2.5	4	2
	2	3	3.5	4
	3	4	2.5	5

Table 12: Distances between supplier and manufacturer (Km)

		Manufactures		
		1	2	3
Suppliers	1	850	950	1000
	2	1200	1000	950
	3	1100	980	1200

Table 13: Distances between manufacture to customer (Km)

		Customer		
		1	2	3
Manufacturer	1	900	1100	1200
	2	1000	850	980
	3	1100	950	1200

Table 14: Capacities of the suppliers

		Suppliers		
		1	2	3
Periods	1	12500	12000	11000
	2	10000	13000	12000
	3	12000	12000	12500

Table 15: Storage capacities of the manufacturers

		Manufacturers		
		1	2	3
Periods	1	13200	12500	11500
	2	10500	13500	12000
	3	12000	12500	12500

Table 16: Production capacity of the manufacturer

		Manufacturers		
		1	2	3
Periods	1	13200	12500	11500
	2	10500	13500	12000
	3	12000	12500	12500

Table 17: Demand of the customers

		Customers		
		1	2	3
Periods	1	8500	8700	8600
	2	9000	8000	8500
	3	7500	8500	9000

Table 18: Truck capacities of each echelon

		Periods		
		1	2	3
Trucks	1	35000	35000	35000
	2	36000	36000	36000
	3	37000	37000	37000

Table 19: Solution of the case study

Variables	Values	Variables	Values	Variables	Values
d_a^+	5725	$QTSM_{2311}$	500	$QTMC_{1122}$	9000
d_b^+	18600	$QTSM_{3221}$	500	$QTMC_{2222}$	6500
d_c^+	14573	$QTSM_{3321}$	10500	$QTMC_{3322}$	2500
d_d^-	142	$QTSM_{1131}$	12500	$QTMC_{1232}$	1500
d_e^+	2250	$QTSM_{2131}$	700	$QTMC_{2332}$	6000
d_f^+	2084	$QTSM_{2231}$	1100	$QTMC_{2213}$	8500
QP_{111}	12500	$QTSM_{3112}$	10000	$QTMC_{3323}$	1000
QP_{211}	700	$QTSM_{1212}$	9500	$QTMC_{1133}$	7500
QP_{221}	1100	$QTSM_{3312}$	2000	$QTMC_{1333}$	4500
QP_{321}	500	$QTSM_{2132}$	500	$QTMC_{2333}$	3500
QP_{231}	500	$QTSM_{2232}$	3000	MQ_{11}	13200
QP_{331}	10500	$QTSM_{1332}$	500	MQ_{21}	1600
QP_{212}	500	$QTSM_{1313}$	500	MQ_{31}	11000
QP_{312}	10000	$QTSM_{2133}$	11500	MQ_{12}	10500
QP_{122}	9500	$QTSM_{3133}$	500	MQ_{22}	12500
QP_{222}	3000	$QTSM_{1233}$	11500	MQ_{32}	2500
QP_{132}	500	$QTSM_{3233}$	500	MQ_{13}	12000
QP_{332}	2000	$QTSM_{2333}$	500	MQ_{23}	12000
QP_{213}	11000	$QTMC_{2111}$	1600	MQ_{33}	1000
QP_{313}	500	$QTMC_{1211}$	7500	de_1^+	11327
QP_{123}	11500	$QTMC_{3311}$	8600	de_2^+	25236
QP_{323}	500	$QTMC_{1131}$	5700	de_3^+	32919
QP_{133}	500	$QTMC_{3131}$	1200		
QP_{233}	500	$QTMC_{3231}$	1200		

To solve this problem, programming code was written in Lingo 8.0 software. In this model, total number of variables is 405. Among the variables, 378 variables are non-linear and 377 variables are integer. There are 199 variables in the constraints. Among the constraint variables, 177 variables are nonlinear. After running the code, we obtained the optimized solution, which is shown in Table (19). The total ordering and purchasing cost goal was considered \$ 451516 before computation of the model. After solving the model, it is observed that there is a deviation of \$ 5725 from total ordering and the purchasing cost goal. The deviation is 1.26 percent from the goal of ordering and purchasing cost. The total purchasing cost of the raw material is \$ 139883 for the first period, \$171157 for the second period and \$142674 for the third period. Figure (1) shows the purchasing cost at different periods. At all periods, a total of 76300 product units are transported from suppliers to manufacturers.

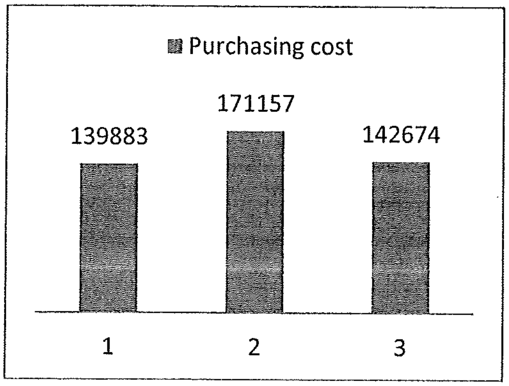


Figure 1. Purchasing cost at different time periods ($)

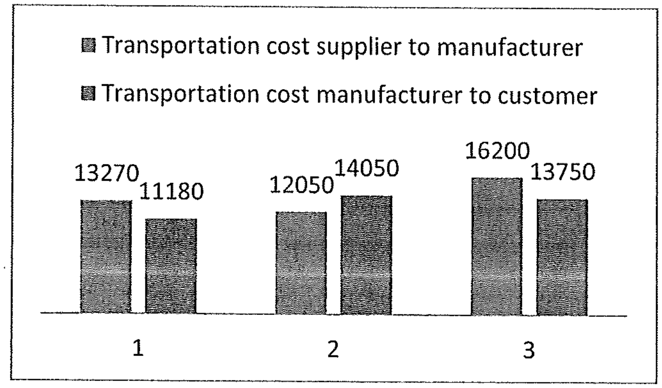


Figure 2. Transportation cost at different time periods ($)

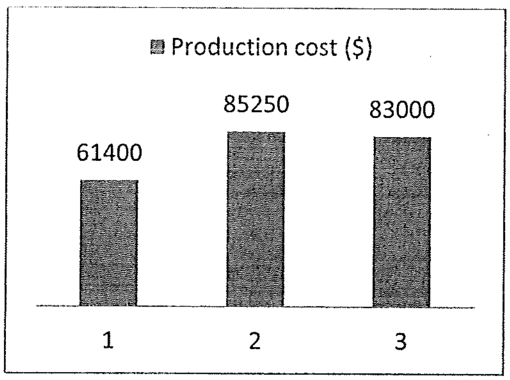


Figure 3. Production cost at different time periods ($)

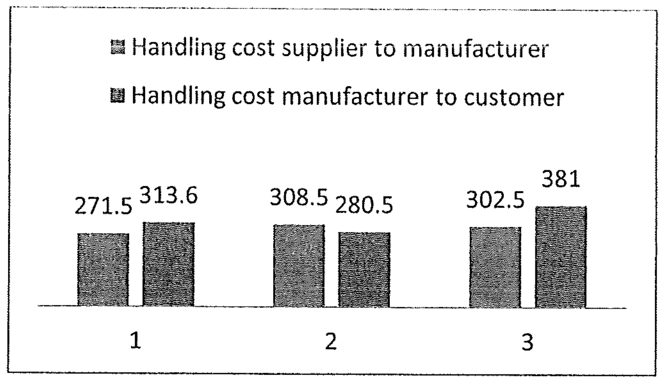


Figure 4. Handling cost at different time periods ($)

The total transportation cost from the supplier to the manufacturer in the first period is $ 13270 in second period is $ 12050 and in the third period is $ 16200. Figure (2) shows the transportation cost from supplier to manufacturer at different periods. In the first period, a total of 25800 product units are transported from the supplier to the manufacturer. According to Table (19), 55.42 percent of the total material is transported from the supplier to the manufacturer at time period 1 using truck 3, 42.63 percent of the material is transported by truck 2, and 1.93 percent of the material is transported using truck 1. In second period, a total of 25500 product units are transported from the supplier to the manufacturer. Among these products, 84.31 percent of the products are transported using truck 1 and 15.69 percent of the products are transported using truck 3. In second period no transportation is carried out by truck 2. In third period 25000 products are transported from the supplier to the manufacturer. In this period, 2 percent of the total product is transported using truck 1 and the remaining 98 percent is transported by truck 3. Truck 2 has not been used for transporting the material for this period. Figure (5) shows the transport amount by different trucks at different time periods from supplier to manufacturer.

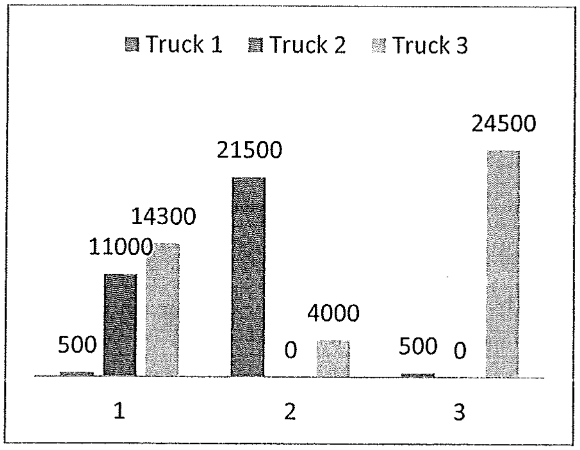


Figure 5. Amount transported by different trucks at different time periods from supplier to manufacturer

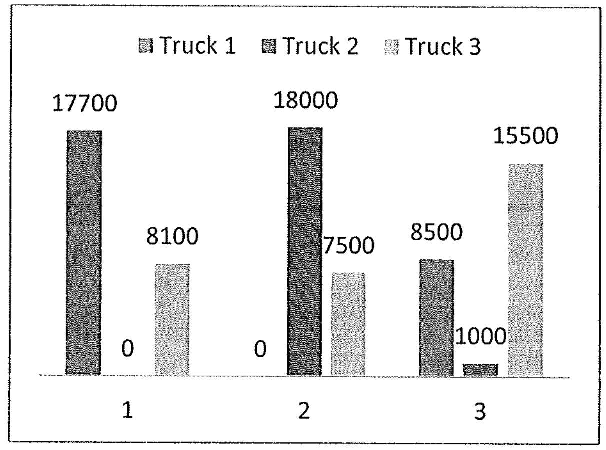


Figure 6. Amount transported by different trucks at different time periods from manufacturer to customer

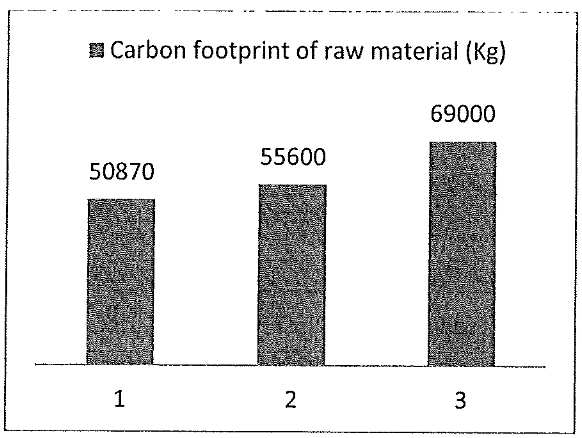


Figure 7. Carbon footprint of raw material purchased at different periods (Kg)

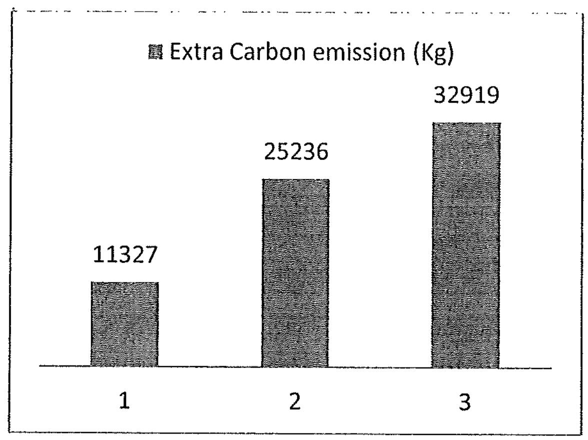


Figure 8. Extra carbon emission at different periods (Kg)

The total transportation cost from manufacturer to customer in the first period is \$ 11180 in second period is \$ 14050 and in the third period is \$ 13750. Figure (2) shows the transportation cost from manufacturer to customer. In the first period, a total of 25800 product units are transported from manufacturer to customer.

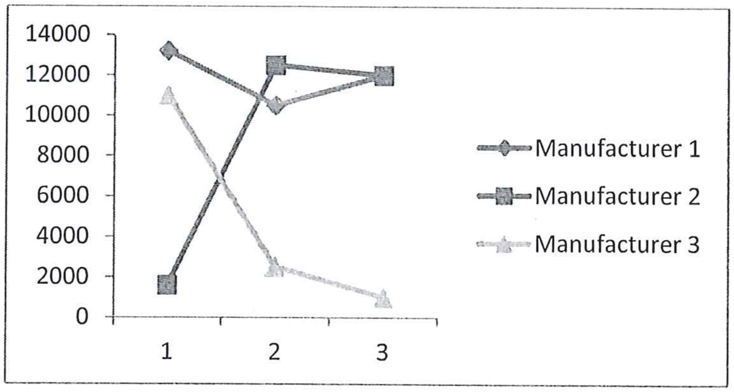
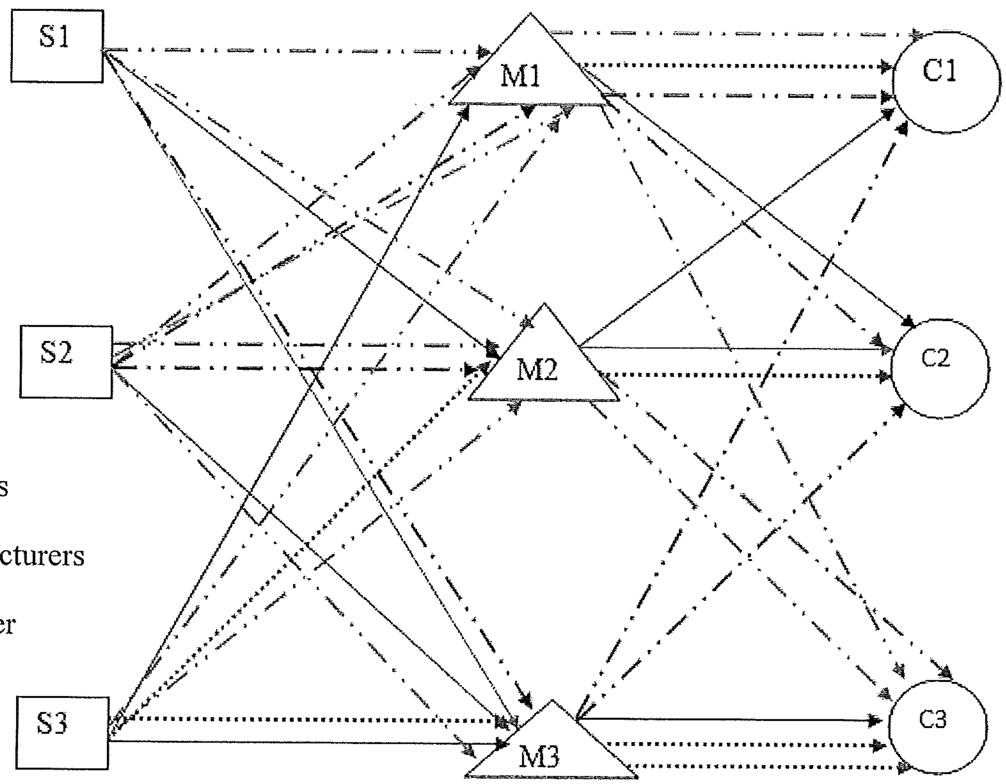


Figure 9. Amount of products manufactured at different periods to the different manufacturer

In first period 68.6 percent material is transferred from the manufacturer to customer using truck 1 and rest 31.4 percent material is transferred by truck 3. In second period, 70.58 percent of the total material is transferred from the manufacturer to customer using truck 2 and rest 29.42 percent of the material is transferred by using truck 3. In the third period, 34 percent material of the total amount is transported from the manufacturer to customer using truck 1, 4 percent is transferred by truck 2 and rest 62 percent is transported by truck 3. Figure (6) shows the transport amount by different trucks from supplier to manufacturer. It is observed from Table (19) is that the deviation of transportation cost goal is 22.02 percent from the earlier allocated goal value. Total carbon footprint of the raw material procured from the suppliers is 50870 Kg for the first period, 55600 Kg for second period and 69000 Kg for the third period. Figure (7) shows the carbon footprint of the raw material purchased from different suppliers at different periods. Product handling cost is optimized in this model during transportation of the material from the supplier to the manufacturer and manufacturer to customer. We obtained the optimised handling cost \$ 271.5, \$ 308.5 and \$ 302.5 for first, second and third periods for transportation of the material from the supplier to the manufacturer. The handling costs are \$ 313.6, \$ 280.5 and \$ 381 for transportation of material from the manufacturer to customer at first, second and third periods. Figure (4) shows the handling cost of the products at different periods. A deviation of 8.69 percent of product handling cost goal is observed in this model. The handling cost is lower than the allocated cost goal. The demand of the customers for the first period is satisfied by three manufacturers. The amount produces by the manufacturer is different. Table (19) shows the amount of production quantity to the different manufacturer during three periods. Figure (3) shows the production cost of the material in different manufactures at different periods. Figure (9) shows the manufacturing amount at different time periods. The optimized production cost of the material is \$ 61400 for the first period, \$ 85250 for second period and \$83000 for the third period. The deviation of the goal is 0.98 percent. The total carbon emission in the supply chain is optimised in this model.



S – Suppliers

M – Manufacturers

C – Customer

Truck 1 at period 1, Truck 1 at period 2, Truck 1 at period 3

Truck 2 at period 1, Truck 2 at period 2, Truck 2 at period 3

Truck 3 at period 1, Truck 3 at period 2, Truck 3 at period 3

Figure 10. Supply chain network model

From Table (19) it is observed that the total carbon emission produced due to logistics and manufacturing operations in the supply chain exceeds the total carbon cap at different periods.

For the first period, the extra carbon emission is 11327 Kg, for the second period it is 25236 Kg, and in the third period it is 32919 Kg. Figure (8) shows the extra carbon emission at different time periods. Therefore, the total extra carbon emission is 69482 Kg. Due to exceeding the carbon emission limit; company has to buy carbon credit from different sources for avoiding legal problems. The optimised cost for buying carbon credit is $ 2084 for three periods. Figure (10) shows the optimised network model. The figure shows the transportation link between supplier to manufacturer and manufacturer to customer. Three different lines have been used to represent this complex model. The transportation amount from one node to another node can be obtained from Table (19).

6 Conclusions

Carbon emission modeling of a supply chain is a complicated task. There is always a tradeoff between cost and carbon emission in the supply chain. Therefore, it is always advisable to maintain cost versus carbon emission tradeoff efficiently for long term survival of the firm. In this model, various conflicting goals such as: purchasing cost goal, handling cost goal, manufacturing cost goal, transportation cost goal, and carbon emission penalty cost goal, carbon footprint goal of the raw material have been considered efficiently. A compromise solution is obtained from the model. Carbon emission modeling is done considering B2B emission boundary. Carbon emission optimisation considering B2B boundary appears to be essential because without the proper boundary definition it is very difficult to map individual supply chain members' emission for which supply chain members are liable to pay if they exceed their emission quota. Incorporation of emission versus cost tradeoff concept makes this model more usable. The model considered the high penalty cost for exceeding the quota of carbon emission. High penalty cost implementation is very important for minimising the carbon emission of the supply chain. High penalty cost would compel to think the manager to develop an alternative strategy for reducing carbon emission of the supply chain. Sustainable supply chain network design incorporating the carbon footprint of the raw material has not been earlier studied. This model illustrates how to use the raw material carbon footprint issue in the modeling of the green supply chain. This is a mixed integer programming model, dealing with multiple time periods. A set of real life data is used to illustrate the case. This model would help the managers to take a decision regarding the business operations such as how much to order, how much to produce, and which truck is to be used. This model would help the decision maker to estimate the carbon footprint of their supply chain. Our proposed model is very useful to the practitioners for minimizing carbon emission in the supply chain. Implementation of our proposed model would help the company to survive in carbon constrained world. The complexity of the model can be increased by increasing the time periods, increasing the number of suppliers, incorporating the inventory issue, increasing the number of product. Incorporation of fuzziness in the model such as price variability of raw materials, demand variability of the product may show a more realistic scenario.

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