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Title: An Approach to Design and Optimize an Integrated Multi Period Multi-Channel Closed Loop Supply chain Network Meeting Cost, Quantity and Environmental Requirements

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1.0 INTRODUCTION

Supply chain management has been most important field in any industry or service sector taken into consideration since it involves flow of product, process, people, information and cash and have been quite interested field of researchers. The main aim of the companies is to achieve core competencies and flexibility. In the recent years, there has been a growing awareness amongst organisations on considering reclamation of end-of-life products and reducing carbon footprints associated with the supply chain activities. Measures are being taken to consider the greenness aspect while designing the supply chain. Reclamation of used products from customers not only reduces cost to the company, but also reduces the usage of valuable resources that would be consumed if recycling wasn't done. Reclaiming products requires collection centres, willingness from customers to recycle products and a good customer-retailer relationship. Incentive based reclamation procedures are also implemented by some organisations.

Reducing the carbon footprint associated with the supply chain activities is another growing concern amongst organisations. Research is being carried out across the globe by considering carbon footprint sensitive demand i.e. an assumption that customers these days, prefer products that cause the least impact on the environment while being manufactured. The carbon tax reduction model is also preferred in supply chain design procedures these days as carbon footprint associated costs are at par with the other major costs associated with the supply chain.

1.1 SUPPLY CHAIN INTEGRATION

With the rapid development of information technology and intense global competition, many manufactures and service providers are collaborating with their primary suppliers to upgrade the traditional material management functions into part of their corporate strategy. They have adopted an integrated strategic approach to SCM. Although many efforts have failed; it still has become a significant tool for firms striving to achieve competitive advantage. Supply chain integration enables members of the supply chain to function as a unified logistics quantity wherein all the supply chain entities and operations including purchasing, manufacturing and logistics function can be more efficiently and effectively managed.

1.2 SUPPLY CHAIN MODELLING

A typical supply chain model consists of multiple stages such as suppliers, manufacturers, distribution centers, warehouses, retailers etc. It is very much needed to explore the effects of applying the mathematical models of optimization to forward/ closed loop, multi-channel, green supply chains, and the effect of their implementation on cost. The primary objective is to optimise the existing network by analysing the parameters such as warehouse/ chilling centres location etc. and the distances between the locations of the parameters. The task of knowing which distribution centre/ chilling centre to which retailer, for instance, is the main purpose of the optimisation process. This decision is arrived at, based on the transportation model which in turn, helps in coming up with a model for reducing carbon emissions. This is a direct consequence of the assumption that lesser the distance travelled by a logistics vehicle, less the carbon emission caused by it. Thus, the transportation model helps in not only reducing the transportation cost but also in keeping the emission levels within that desired.

As another part of the optimisation process, new possible changes in the organisation's supply chain are also suggested in order to make it more efficient. For instance, connecting retailers to a plant without involving a distribution center at all in some locations, might actually prove to be profitable and a practical strategy to reduce carbon foot print. Thus, stage by stage, we have explored the effects of making a supply chain closed, multi channel and green. A favourable reduction in cost is found as a result of this implementation.

In this paper, we have analysed a multi-channel multi period closed loop supply chain with reverse logistics. We have tried to compare the trade-offs between various plant locations, DC and recollection center locations. The possibilities of combining production activities and reclamation processes under one common roof at certain regions to reduce the cost and carbon foot print were also considered.

2.0 LITERATURE REVIEW

2.1 SUPPLY CHAIN NETWORK DESIGN

Benita M Beamon (1998) provided a review on present models and methods in supply chain and future research consideration to facilitate advancement in supply chain analysis and design**. Ehap H. Sabri et.al (2000)** developed a supply chain model to be used in simultaneous operations and strategic planning. The parameters considered in planning included cost, level of customer service and volume flexibility. **Hong Yan et.al (2003)** came up with logical parameters such as Bill of Materials (BOM) and the relationship aspects between suppliers, distributors and customers aspects into consideration. The MIP model developed was concerned with selecting the best supplier out of a given set of suppliers and setting up of distribution centres and specifying the plant capacities, according to the selected supplier location. **Fulya Altiparmak et.al (2006)** proposed a metaheuristic based procedure to be used in decisions involving conflicting parameters such as resource utilisation, cost, plant location etc. It relied on obtaining pareto-optimal solutions and different weight approaches**. Fulya Altiparmak et.al (2009)** proposed a procedure based on steady state genetic algorithm, to deal with the design task of choice of facilities (plant location and distribution centres) in strategic locations to fulfil the customer demands at minimum cost. The effectiveness of the procedure was compared with the solution obtained from CPLEX. **Reza Zanjirani Farahani et.al (2008)** came up with a genetic algorithm to optimise service level and cost for Just-in-time distribution in a supply chain. Delivery lead times were also considered in the process. **Sadjady et.al,(2012)** discusses a MILP model for a muti-commodity two echelon Supply chain network. The model tries to integrate both tactical and strategic decisions. The objective is to minimise the various costs that occur due to transportation, lead times, opening cost of facilities, operating cost of facilities and inventory carrying cost. They devised a legrangian based heuristic algorithm for solving a real sized problem and achieved the result in a reasonable computational time. **Shankar B. Latha, et al., (2013)** discusses the use of Swarm Intelligence to minimise the shipment and the location costs. The number and the location of the plants are the important decision variables involved in the model. The model tries to assure that maximum customer satisfaction is met. **Sadeghi et al.,(2014)** gives a vendor management problem which incorporates a redundancy allocation problem **Francesco Costantino et.al, (2014)** proposed a multi-criteria decision making methodology for selecting and evaluating the logistics distribution networks in a customized environment, basing on an analytic network process (ANP). As a first step of the design process, this method helps the decision maker in the selection of the best configuration of logistics distribution. **Linda L Zhang et al.(2016)** proposed ABC algorithm as solution approach to solve three stage supply chain problem which can solve complex problems better than LINDO and GA based approaches. The drawbacks are that the model cannot deal with the dynamics as it considers only one time horizon as it is deterministic.

2.2 CLOSED LOOP SUPPLY CHAIN NETWORK

Kannan G et.al (2009) came up with a strategy to analyse reverse logistics in a closed loop supply chain.. This paper differs from the rest in the sense that it is designed for a built-to-order supply chain environment. **Mir Saman Pishvaee et.al (2011)** proposed in their paper, a method to design a robust model in case of uncertainty in inputs. Mixed integer linear programming is implemented, whose robust counterpart is produced using developments in optimisation theory. This facilitates in supporting both recovery and disposal activities in the closed loop supply chain. The robust counterpart takes into consideration the uncertainties in returned products, demand for recovered ones and logistics costs. **Shabnam Rezapour et.al (2015)** considers a new aspect of closed loop SC where two different closed loops SCs are compared. One is an existing SC supplying new products to the market and the other SC is designed to supply both new and remanufactured products to the same market. The method involves finding an equilibrium point of flow of materials in both the supply chains. **Onur Kaya et.al (2016)** came up with a procedure to determine the most optimal facility location, new product pricings, inventory quantities and incentive values for the recovery of used products. The key objective of the procedure is to maximise the overall profit of the Supply Chain. The methodology is mixed integer nonlinear facility location-inventory-pricing model. The heuristics of the model were also developed and checked with numerical methods for effectiveness. **Pengxing Yi et.al (2016)** analysed the closed loop SC from a Retailer's perspective. The paper mainly focuses on recollecting end of life machinery. It relies on mixed integer linear model and applied an improved hybrid genetic algorithm and the solution is evaluated using LINGO optimisation software. When compared to other studies in the field, this paper considers locations of dismantling centres too.

2.3 GREEN SUPPLY CHAIN MODELLING

In the recent times, quite a bit of research has been done on reducing the greenhouse emissions associated with organisational supply chains. The following include some of the renowned works in the field.

Balan Sundarakani et.al (2010) examined the carbon footprint in the whole supply chain using long range lagrangian and Eulerian transport models. The study revealed that a slight inefficiency in the design stage of the supply chain can lead to a substantial negative impact in terms of carbon emission involved in the supply chain. Being the first of its kind, the paper also provided a means to measure the overall carbon footprint associated with the supply chain. **Fan Wang et.al (2011)** studied the supply chain network design problem and the associated environmental influence. The study analysed the trade-off between total cost and environmental influence. It is a multi-objective mixed integer formulation. A new set of decision variables called as "Environment protection levels" were introduced in this paper, thus the main objectives being minimising both cost and environmental impact. **Wei Chang Yeh et.al (2011)** extended the greenness factor in a supply chain to supplier selection for the first time. This paper developed a mathematical model for the selection of a green partner and it took cost, product quality, time and green appraisal score as parameters. Two multi-objective genetic algorithms were developed to find pareto optimal solutions, satisfying all the four above mentioned criteria at optimal levels. **Samir Elhedhli et.al (2012)** considered a supply chain network design problem where the weight of the transporting vehicle and the CO_2 emission caused by it were studied. Other parameters included emission costs, production costs, fixed and variable locations to minimise the costs. A lagrangian heuristic algorithm was used and the results showed that emission costs are also to be considered along with carbon costs while designing the supply chain. **Imen Nouira et.al (2016)** considered a scenario where the demand for the product manufactured by a company is a function of the carbon emission caused by the manufacturing process. It was assumed to be an inverse relationship i.e. lesser the carbon emission, more the demand for the product. The results suggested that such a carbon emission sensitive demand model would be profitable and thus should be taken into account while designing a Supply Chain.

2.4 CLOSED LOOP GREEN SUPPLY CHAIN NETWORK:

Reverse logistics helps in reducing waste disposal and meeting customer demands. The efficiency of the recovery process determines the profit or loss of an organization.

Kiran Garg et.al (2015) deals with a CLSC with four echelons on the forward chain and five echelons on the reverse SC. The paper considered low carbon logistics as the key and plant, reclamation centre location corresponding to the minimised optimal level of carbon emission. **Kanchan Das et.al (2015)** proposed an incentive based model where the retailers and customers could be motivated to surrender end-of-life products back to the manufacturers. Reclamation and repair of recovered goods would be carried out by trained service providers who form a part of the supply chain. **Mohammed Talaei et.al (2016)** investigated a multi-product SC consisting of manufacturing and remanufacturing units, to optimise their locations for minimum cost and minimum carbon emissions. It used mixed-integer linear programming.

2.5 MULTI CHANNEL SUPPLY CHAIN:

Yanhui Li et.al, (2013) formulated a location-inventory-routing problem model focusing on the problem in e-commerce logistics system, with no quality defects returns and developed an effective hybrid genetic simulated annealing algorithm (HGSAA) to solve this NP-hard problem. **A. Ahmadi Yazdi and M. Honarvar (2014)** proposed a new model for designing the integrated forward/reverse logistics based on pricing policy for direct and indirect sales channel. **Ahmad Yazdiet.al (2015)** proposed a model where the supply chain network is designed by comparing the pricing policy in direct and indirect sales channels. Mixed integer linear programming model is developed and the stochastic counterpart is compared to evaluate the efficiency of the procedure. **Wei Wang et.al (2016)** considered a multi-channel SC model where the manufacturer has two channels to sell his products, one of his own and one retailer channel. The cost analysis for the channels and the pricing strategies for the channels were compared using a linear demand model. The choice of the channel is also common to both retailer and the manufacturer. **Farnaz Bazinpour et.al (2016)** came up with a mathematical model which analysed the cost and carbon tax trade-offs between various possible plant and recollection centre locations. The alternatives available between various customer zones and channels had different costs associated with production and carbon footprint. The most optimal one out of the available choices was chosen, keeping cost minimisation as the objective. **Xujin Pu et.al, (2016)** studied the collection channel and the production decisions in a dual channel supply chain (CLSC) with one retailer and one dominant manufacturer from the point of view of both the firm profit and system robustness. The direct channel is more robust while facing disruptions and they generate more profits for manufacturers when there is a large positive disruption and the revenue-sharing contracts are effective in coordination.

Based on the literature review above, it is evident that there has been a lot of research done in the areas of supplier selection and supply chain modeling and a few papers combining both, using multi criteria decision making techniques. However, there is no work that integrates both the supplier selection problem along with the inventory, production and transportation problems across the various stages of the supply chain as a single mathematical model. Currently most of the literature in supply chain management either considers only a part of the supply chain or the total supply chain in some simplified manner or either the green objective, closed loop, multi period framework, multi-channel supply chain networks separately or some of them at a time, but a more sensible approach seems to be the simultaneous optimisation of all together.

This paper holistically considers the complete supply chain with all of them. Also, comparison of various cases particularly the one with the traditional supply chain. The multi channel supply chain models have not been previously considered before in depth. Moreover there is no research that has modeled supply chain models over multiple periods for a multi-channel model. This paper unlike previous research works has not assumed the customer demand but has calculated the cheaper and the better options available and then optimized the supply chain for the set of customer demand. This thesis is a first step in that direction.

3.0 METHODOLOGY

3.1 PROBLEM DESCRIPTION

A multi-channel closed loop green supply chain has been considered which includes suppliers, manufacturers, warehouse, retailers, recycling centers and three types of customer demands.

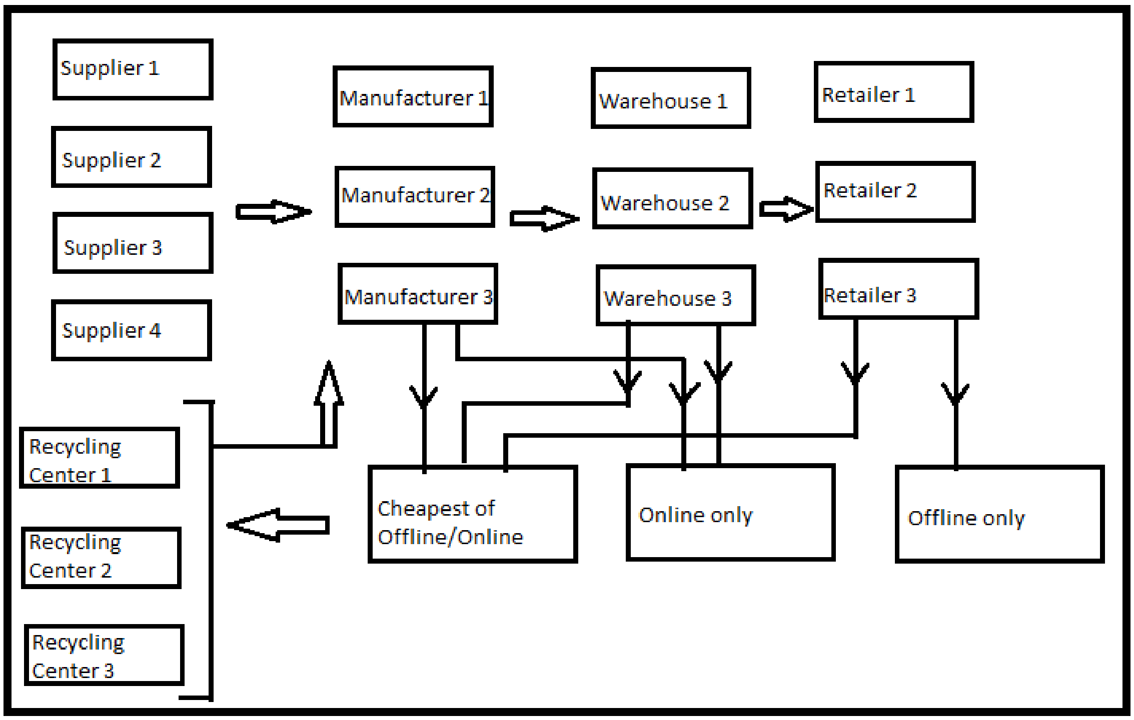

Figure.3.1 Schematic representation of the Supply Chain Problem

A leading kitchenware company in India is chosen to evaluate the benefits of multi channel closed loop Supply chain. For evaluation purpose, the network of Supply chain in Sothern part of India is selected. In order to present a detailed evaluation and realistic solution, three suppliers, three manufacturers, three warehouses, three retailers, three recycling centers and five customers each of the three demand types are considered were selected to simply the problem. It basically is a closed loop supply chain where the used products by the customer is sent to the recycling center of which 50% is sent to the manufacturer to complete the loop with a repair cost for the recycled products. To realize the multi-channel, four types of customers are being considered. By means of this, a strong link between retailers and online partner is realized. The various customer demands are:

1. Online order with direct home delivery from either warehouse or manufacturer
2. Offline customers getting products instantly from the retailer
3. Customers who choose the cheapest channel of offline/online

Green supply chain is incorporated by reducing the pollution emission. The entire supply chain is solved over multiple time periods (ten time periods). It is assumed that it takes one time period to transport the product and the raw materials between the consecutive echelons. Inventory is present at the warehouse, retailer and the recycling center. The main aim of this paper firstly is fixing the corresponding customer demand to a particular retailer or manufacturer or warehouse and secondly, the supplier selection. Two cases are considered, one where the traditional offline only supply chain is considered and the other where the multiple channels are considered. A Mixed Integer Linear Programming (MILP) model has been formulated and the optimal solution has been obtained using CPLEX. Each of the two cases is solved twice first, including the customer costs as the objective function and second, including the other objective functions related to the other parts of the supply chain. Solving it for the first time, fixes the corresponding customer demand to a particular retailer or manufacturer or warehouse. The objective functions are normalized in the second case as the objective function includes the costs and the pollution emissions which are in different units. Customer's source of purchase, supplier selection and other costs and emission outputs are discussed for three cases a) Offline only mode b) Multi-channel mode c) Multi-channel mode without green objective and two risk/ sensitivity analysis cases namely: d) Multi-channel mode with increase in the price of retailer selling price upto 5% e) Multi-channel mode with increase in customer demand upto 20%.

Product Selling Price: The selling price of the manufacturer is less than warehouse which in turn is less than the retailer as the transportation cost is avoided as the entity is far away from the customer.

Table 3.1 Selling price of Products

	1	2	3
Manufacturer	1225	1275	1250
Warehouse	1300	1350	1325
Retailer	1400	1450	1425

Customer Demand over 10 time periods: It is assumed that the customer demand is nil in the first three time periods as the time required for the retailer to receive the product is four time periods.

Table 3.2 Customer Demand over ten time periods

Type of customer	Time period									
	1	2	3	4	5	6	7	8	9	10
Customer type ‘c’ who prefer online or offline whichever is cheaper	0	0	0	0	50	0	0	0	0	0
	0	0	0	0	0	50	0	0	0	0
	0	0	0	0	0	0	75	0	0	0
	0	0	0	0	0	0	0	50	0	0
	0	0	0	0	0	50	0	0	0	0
Customer type ‘d’ who prefer online purchase	0	0	0	25	0	0	0	0	0	0
	0	0	0	0	0	50	0	0	0	0
	0	0	0	0	0	0	75	0	0	0
	0	0	0	0	0	0	0	40	0	0
	0	0	0	0	40	0	0	30	0	0
Customer type ‘e’ who prefer offline purchase	0	0	0	0	0	0	30	0	0	0
	0	0	0	0	0	40	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	75	0	0	0
	0	0	0	0	0	0	0	60	0	0

Moreover it is assumed that the customers return the product to the recycling center as average life of a product is assumed to be two time periods.

3.2 MODEL FORMULATION

Non Zero Constraints

The index set that will be used in the model formulation are defined below

h: Supplier

i: Manufacturer

j: Warehouse

k: Retailer

r: Recycling Centre

c: Cheapest of online/offline

d: Customer (prefers online)

e: Customer (prefers offline)

t: Time Period 1,2----T

3.2.1 Model Data

Supplier (h):

S_{max} – Maximum Capacity of raw material

S_{min} – Minimum Capacity of raw material

C_{pu} -Purchasing Cost per Unit of raw material

T_{sup} – Transportation cost between supplier and manufacturer

Manufacturer (i):

Manuf Max: Maximum Quantity of products manufactured

TManuf: Unit transportation cost of moving materials from manufacturer to warehouse

Manuf Cost: Cost of manufacturing per unit item

Warehouse (j):

w_{max}: Maximum capacity limit for storing items in warehouse

wInitInv: Initial inventory of finished items at warehouse wInvCost: Inventory holding cost per unit of finished product at warehouse

Wcost : Selling price of items at warehouse

wInvCost: Inventory holding cost per unit of product at warehouse

Twor: Unit transportation cost of the finished product from the warehouse to the retailer

Retailer (k):

Rmax: Maximum inventory capacity at retailer

RIntInv: Initial inventory of finished product at retailer

Rcost: Selling price of retailer

RInvCost: Holding cost of product at retailer

RBackCost: Unit backorder cost per unit time at retailer

Customer(c, d, e):

x_a: demand of customer ‘c’at time ‘t’

x_b: demand of customer ‘d’ at time ‘t’

x_c: demand of customer ‘e’ at time ‘t’

dM: distribution between customer and manufacturer

dW: distribution between customer and warehouse

MTrans: Transportation cost to customer per unit distance from manufacturer

WTrans: Transportation cost to customer per unit distance from warehouse

Recycling Centre: (r)

RecInitInv: Initial inventory at recycling center.

x_{aa}: Quantity returned back by ‘c’ customer at a later time (t+2)

x_{bb}: Quantity returned back by ‘d’ customer at a later time (t+2)

x_{cc}: Quantity returned back by ‘e’ customer at a later time (t+2)

RecMax: Maximum capacity of recycling center

Trecycle: Transportation cost from recycling center to manufacturer.

RecInvCost: Inventory holding cost at recycling center

3.2.2 Model Decision Variables

All variables are non-negative

Supplier:

W: Quantity of raw material ordered from a supplier h

S_{Bin}: Binary variable if supplier h is selected in time period t

Manufacturer:

u: Quantity of raw material transported from supplier to manufacturer.

v: Quantity of raw material reaching manufacturer

x: Quantity of items manufactured in a time period t

y: Quantity transported from manufacturer to warehouse

Warehouse:

Ø: Cumulative inventory in warehouse at end of time period t

z: Number of products transported from warehouse to retailer in time period t

Retailer:

RBO: Cumulative backorder at retailer at end of period t

RInv: Cumulative inventory at retailer at end of time period t

Customer:

CM_a: Binary if customer ‘c’ gets product from manufacturer ‘i’ online

CM_b: Binary if customer‘d’ gets product from manufacturer ‘j’ online

CWa: binary customer ‘c’ gets product from warehouse ‘j’ online

CW_b: binary customer‘d’ gets product from warehouse ‘j’ online

CR_a: binary customer ‘c’ gets product from retailer ‘k’ offline

CR_b: binary customer ‘e’ gets product from retailer ‘k’ offline

Recycling Center:

β: Inventory quantity at the recycling center at the end of time t

S: Quantity transported from recycling center to manufacturer.

Pollution (Green):

P_{oll}: Pollution per unit distance (hi, ji, jk, rj)

Dist: Distance between entities (hi, ji, jk, ri)

vehi :Vehicle capacity between (hi, ji, jk, rj)

3.2.3 Model Objective Function

Supplier (h) :

The objective function minimizes the total purchasing cost by

$$\text{Minimize } z_1 = \sum_{h}\sum_{q}\sum_{t}\left[c_{pu}(h,q) * w(h,q,t)\right]$$

Manufacturer(i):

The objective function minimizes the total transportation cost from the supplier to the manufacturer

$$\text{Minimize } z_2 = \sum_{h}\sum_{i}\sum_{t}\left[T_{sup}(h,i) * u(h,i,t)\right]$$

The objective function minimizes the total manufacturing cost involved as follows

$$\text{Minimize } z_3 = \sum_{i}\sum_{t}[\text{ManufCost}(i) * x(i,t)]$$

Warehouse (j) :

The objective function minimizes the total transportation cost and the inventory holding cost for each time period as follows

$$\text{Minimize } z_4 = \sum_{i}\sum_{j}\sum_{t} T_{manuf}(i,j) * y(i,j,t) + \sum_{j}\sum_{t} \text{WInvCost}(j) * \varphi(j,t)$$

Retailer(k):

The cost associated with products which are ordered online by the customer ‘c’ is as follows

$$\text{Minimize } z_5 = \sum_{c}\sum_{i} CM_a(i,c) * x_a(c,t) * [\text{Mcost}(i) + (\text{MTrans} * dM(c,i))]$$

$$+\sum_{c}\sum_{j} CW_a(j,c) * x_a(c,t) * [Wcost(j) + (WTrans * dW(d,j))]$$

$$+\sum_{c}\sum_{k} CR_a(k,c) * x_a(c,t) * Rcost(k)$$

The cost associated with products which are ordered online by the customer ‘d’ is as follows

$$\text{Minimize } z_6 = \sum_{d}\sum_{i} CM_b(i,d) * x_b(d,t) * [Mcost(i) + (MTrans) + dM(c,i)]$$

$$+\sum_{d}\sum_{j} CM_b(j,d) * x_b(d,t) + [Wcost(j) + (WTrans) + dW(d,j)]$$

The cost associated with products which are bought from retailer shops is as follows

$$\text{Minimize } z_7 = \sum_{c}\sum_{k} CR_a(k,c) * x_a(c,t) * Rcost(k)$$

$$+\sum_{e}\sum_{k} CR_b(k,e) * x_c(e,t) * Rcost(k)$$

$$\text{Minimize } z_8 = \sum_{j}\sum_{k}\sum_{t} Twan(j,k) * z(j,k,t) + \sum_{k}\sum_{t} RInvCost(k) * RInv(k,t)$$

$$+\sum_{k}\sum_{t} RBackCost(k) * RBO(k,t)$$

Recycling Centre (r):

Cost incurred in recycling the product and converting it into a raw material in the recycling center is as follows:

$$\text{Minimize } z_9 = \sum_{r}\sum_{i}\sum_{t} T_{recycle}(r,i) * S(r,i,t) + \sum_{r}\sum_{t} RecInvCost(r) * \beta(r,t)$$

Pollution cost:

Cost associated with pollution occurring while transporting product from one level to other using vehicles is given below

$$\text{Minimize } z_{10} = \sum_h \sum_i \sum_t \text{Poll}_{hi}\, \text{Dist}_{hi} \frac{u(h,i,t)}{vehi(h,i)} + \sum_j \sum_i \sum_t \text{Poll}_{ij}\, \text{Dist}_{ij} \frac{y(i,j,t)}{vehi(i,j)} + \sum_j \sum_k \sum_t \text{Poll}_{jk}\, \text{Dist}_{jk} \frac{z(j,k,t)}{vehi(j,k)} + \sum_r \sum_i \sum_t \text{Poll}_{ri}\, \text{Dist}_{ri} \frac{S(r,i,t)}{vehi(r,i)}$$

3.2.4 Model Constraints

Supplier: (h)

$$w(h,t) \le s_{max}(h,t) * s_{Bin}(h,t) \qquad (\forall h,t) \qquad (1)$$

$$w(h,t) \ge s_{min}(h) * s_{Bin}(h,t) \qquad (\forall h,t) \qquad (2)$$

The quantity ordered should be greater than the minimum quantity and lesser than the maximum quantity or capacity that can be handled by the supplier.

$$\sum_h s_{Bmin}(h,t) = 1 \qquad (\forall t) \qquad (3)$$

For a given time period only one supplier can be employed for supplying the raw materials.

Manufacturer: (i)

$$w(h,t) = \sum_i u(h,i,t) \qquad (\forall h,t) \qquad (4)$$

The sum of all the raw materials transported from supplier to manufacturer for a given supplier and time period is equal to the quantity ordered from the supplier.

$$\sum_r s(r,h,t_{-1}) + \sum_h u(h,i,t_{-1}) = v(i,t); \quad (t \ge 2) \qquad (\forall i,t) \qquad (5)$$

$$x(i,t) = v(i,t) \qquad (\forall i,t) \qquad (6)$$

The quantity manufactured by the manufacturer is equal to the number of used products sent by the recycling center and the transported products from supplier to manufacturer assuming one raw material is used to make one product.

$$x(i,t) \le \text{ManufMax}(i) \qquad (\forall i,t) \qquad (7)$$

The above equation is a capacity constraint constraining the quantity manufactured to be less than the maximum capacity of the manufacturer.

Warehouse: (j)

$$x(\mathrm{i,t}) = \sum_{\mathrm{j}} \mathrm{y(i,j,t)} + \sum_{\mathrm{c}} \mathrm{CM_a(i,c) * x_a(c,t)} + \sum_{\mathrm{d}} \mathrm{CM_b(i,d) * x_b(d,t)} \quad (\forall \mathrm{i,t}) \qquad (8)$$

The above constraint is a flow constraint which states that the quantity manufactured by a manufacturer is equal to the sum of all the products sent to the warehouse from manufacturer and the quantities supplied to the customers to satisfy the online demands.

$$\varphi(\mathrm{j,t}) \leq \mathrm{w_{max}(j)} \qquad (\forall \mathrm{j,t}) \qquad (9)$$

$$\varphi(\mathrm{j,t-1}) + \sum \mathrm{y(i,j,t-1)} = \varphi(\mathrm{j,t}) + \sum \mathrm{z(j,k,t)} + \sum_{\mathrm{c}} \mathrm{CW_a(j,c) * x_a(k,t)}$$
$$+ \sum_{\mathrm{d}} \mathrm{CW_b(j,d) * x_b(d,t)} \qquad (\forall \mathrm{j,t}) \ (\mathrm{t} \geq 2) \qquad (10)$$

The above constraint is a flow balance constraint of the inventory in the previous time period and the current time period at the warehouse with the quantities that are transported in and out of the warehouse inventory and the online customer demand.

$$\mathrm{WInitInv(j)} = \varphi(\mathrm{j,1}) + \sum \mathrm{z(j,k,1)} \qquad (\forall \mathrm{j,t}) \quad (\mathrm{t} = 1) \qquad (11)$$

The above is a constraint to initialize the initial inventory quantity at the warehouse

Retailer: (k)

$$\mathrm{RInv(k,t)} \leq \mathrm{R_{max}(k)} \qquad (\forall \mathrm{k,t}) \qquad (12)$$

The above is a capacity constraint constraining the maximum inventory that can be stored at the retailer inventory.

$$\mathrm{RInitInv(k) + RBO(k,1) = CR_a(k,c) * x_a(c,1) + CR_b(k,e) * x_c(e,1) + RInv(k,1)}$$
$$(\forall \mathrm{k}) \quad (\mathrm{t} = 1) \qquad (13)$$

The above constraint is a flow balance constraint of the inventory and the back order in the previous time period and the current time period at the retailer along with the offline demands of the customers.

$$\mathrm{RInv(k,t-1)} + \sum \mathrm{z(j,k,t-1) + RBO(k,t) = RInv(k,t) + RBO(k,t-1)}$$
$$\mathrm{+ CR_a(k,c) * x_a(c,t) + CR_b(k,e) * x_c(e,t)} \qquad (14)$$

The above is a constraint to initialize the initial inventory quantity at the retailer

$$\mathrm{RBO(k,t)} = 0 \qquad (15)$$

The backorder at all the time periods at the end of the time horizon should be zero or basically all the customer demands must be satisfied at the end of the time horizon.

$$\sum_{i} CM_a(i,c) + \sum_{j} CW_a(j,c) + \sum_{k} CR_a(k,c) = 1 \qquad (\forall c) \qquad (16)$$

$$\sum_{i} CM_b(i,d) + \sum_{j} CW_b(j,d) = 1 \qquad (\forall d) \qquad (17)$$

$$\sum CR_b(k,e) = 1 \qquad (\forall e) \qquad (18)$$

The above three constraints constrain that only one of the online or offline channels should satisfy the customer demands of the particular customer of a particular channel preference type.

Recycling Centre :(r)

$$\mathrm{RecInitInv}(r) = \beta(r,1) + \sum_{i} S(r,i,1) \qquad (t = 1) \quad (\forall r) \qquad (19)$$

The above is a constraint to initialize the initial inventory quantity at the recycling center.

$$\begin{aligned}\beta(r,t-1) + \sum_{c} x_{aa}(c,t-1) + \sum_{d} x_{bb}(d,t-1) + \sum_{e} x_{cc}(e,t-1) \\ = \beta(r,t) + \sum_{i} S(r,i,t) \qquad (\forall,,r,t)(t \geq 2) \quad (20)\end{aligned}$$

The above constraint is a flow balance constraint of the inventory in the previous time period and the current time period at the recycling center with the quantities that are transported in from the customer after the product is used (assuming the customers return the product after two time periods of usage) and out of the recycling center to the manufacturer for reuse.

$$\beta(r,t) = \mathrm{RecMax}(r) \qquad (\forall r,t) \qquad (21)$$

The above is a capacity constraint constraining the maximum inventory that can be stored at the recycling center.

4.0 RESULTS AND DISCUSSION

The model formulated is tested for a set of realistic data and the results are discussed. The intermediate outputs are discussed for the Multi-channel case alone. Customer's source of purchase, supplier selection and other costs and emission outputs are discussed for three cases and two risk/ sensitivity analysis cases.

For the risk/sensitivity analysis, upto 5% price increase in retailer1's selling price is considered because retailer 1 is the source of demand satisfaction for the maximum number of customers in the multi-channel only scenario.

4.1 Multi-Channel Related Intermediate Outputs:

Table 4.1 Quantity manufactured over 10 time periods

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
M1	-	-	-	-	-	100	-	90	-	-
M2	-	35	40	40	40	50	75	-	35	35
M3	-	-	-	25	115	60	75	30	-	-

The total quantity manufactured is more than that supplied because there are products coming from the recycling center to the manufacturer to be repaired and remanufactured.

Table 4.2 Quantity transported from Manufacturer to Warehouse

Manufacturer	**Warehouse**	**Time Period**	**Quantity Transported**
2	2	9	35
2	2	10	35
2	3	2	35
2	3	3	40
2	3	4	40
3	3	5	40
3	1	5	65
3	1	6	60

The above table clearly states that there is no movement of products from manufacturer 1 and the quantity ordered is more or less evenly spaced.

Table 4.3 Quantity transported from Warehouse to Retailer

Warehouse	Retailer	Time Period	Quantity Transported
1	1	6	65
1	1	7	60
3	1	5	80
3	1	6	40
3	2	3	35

The above table clearly states that there is no movement of products from warehouse 2 and 4. The difference between the total quantity transported between manufacturer to warehouse (320) and that from the warehouse to retailer(280) is the same as the total inventory stored in the warehouse which is 40 excluding the 10th time period warehouse inventory(35) as transportation cannot happen from warehouse to retailer after the time horizon has ended.

4.2 CUSTOMERS CHOICE OF BUYING

Table 4.4 Customer Source of Demand Satisfaction

Customer type 'c'		Customer type 'd'		Customer type 'e'	
Customer	Source of demand satisfaction	Customer	Source of demand satisfaction	Customer	Source of demand satisfaction
1	M3	1	M3	1	R1
2	M2	2	M1	2	R1
3	M2	3	M3	3	R1

4	M1	4	M1	4	R1
5	M1	5	M3	5	R1

Retailer price is increased for the multi channel case upto 5% and noticed that there is no change in the source of customer demand satisfaction. Customer demand is increased upto 20% for the multi channel case and observed no change in source of demand satisfaction.

4.3 AVERAGE PRODUCT COSTS

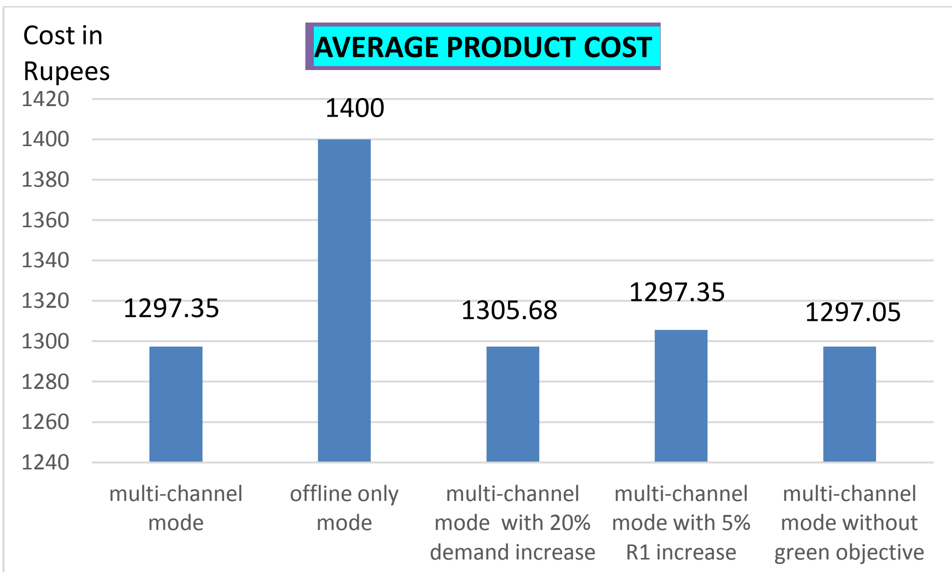

Figure.4.1 Average Production Cost

The customer decision to choose a particular channel especially for the customer types ‘c’ and ‘d’ is based on the tradeoff between the distance and the selling price of the entity selling the product .

4.4 SUPPLIER SELECTION DECISION:

4.4.1Multi channel:

Table 4.5 Selection of Supplier

Supplier	Manufacturer	Time period	Quantity ordered
2	2	1	35
2	2	8	35
2	2	9	35
3	2	2	40
3	2	3	40
3	2	4	40
3	2	5	40
3	2	6	75
3	3	6	75
4	1	7	81
4	1	10	35

4.4.2 OFFLINE:

Table 4.6 Selection of supplier in off line mode

Supplier	Manufacturer	Time period	Quantity ordered
2	2	1	35
2	2	2	35
2	2	3	35
2	2	4	35
2	2	5	35
2	2	6	35
2	2	7	35
2	2	8	35
2	2	9	35
4	1	10	35

4.4.3 Multi- Channel with 20% demand increase:

Table 4.7 Multi -Channel with 20% demand increase

Supplier	Manufacturer	Time period	Quantity ordered
2	2	1	35
2	2	8	35
2	2	9	35
3	2	2	40
3	2	3	40
3	2	4	40
3	2	5	40
3	2	6	75
3	3	6	75
4	1	7	81
4	1	10	35

4.4.4 Multi-Channel with 5% R1 Price Increase:

Table 4.8 Multi-Channel with 5% R1 Price Increase

Supplier	Manufacturer	Time period	Quantity ordered
2	2	1	35
2	2	8	35
2	2	9	35
3	2	2	40
3	2	3	40
3	2	4	40
3	2	5	40
3	2	6	90
3	3	6	90
4	1	7	105

4	1	10	35

4.4.5 Multichannel without Green Objective:

Table 4.9 Multichannel without Green Objective

Supplier	Manufacturer	Time period	Quantity ordered
4	1	1	35
4	1	2	35
4	1	3	35
4	1	4	35
4	1	5	35
4	1	7	85
4	1	8	35
4	1	9	35
4	1	10	35
4	2	6	75
4	3	6	75

The total customer demand and the number of products ordered from the supplier don’t add up as there are a lot of products being recycled and the entire supply chain is optimized for a limited number of time periods, hence there are many products at the retailer, warehouse and the manufacturer inventory at the end of the time horizon considered.

4.5 TOTAL QUANTITIES ORDERED, COSTS & EMISSIONS

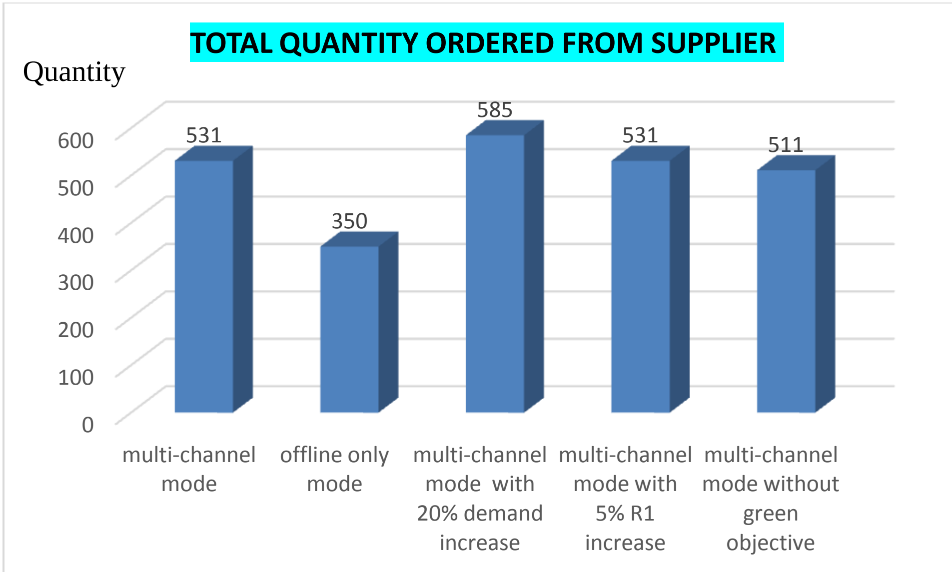

Figure 4.2 Total Quantity ordered from Supplier

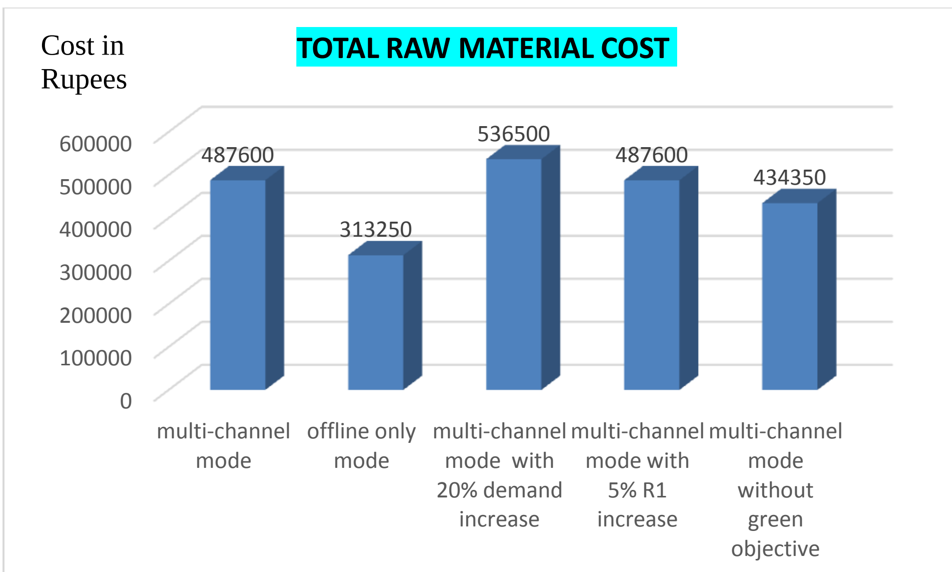

Figure 4.3 Total Raw Material Cost

The total quantity of raw materials ordered from supplier and hence the total supplier cost is comparatively lower for the offline-only mode (34.08%). Moreover, the total raw material cost and the total quantity ordered form the supplier remains a constant in spite of the increase in the retailer 1's selling price by 5%, but the total quantity ordered increases by 10.17% and the total raw material cost by 10.03% for an increase of 20% customer demand in the multi- channel scenario. When green objective is not considered in the multi- channel scenario, the total quantity ordered decreases by 3.76%.

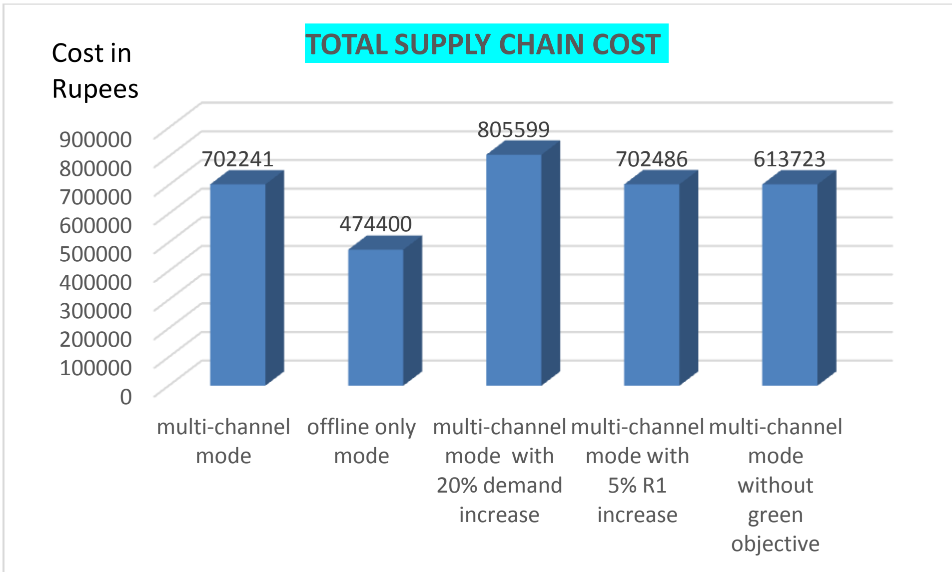

Figure 4.4 Total Supply Chain Cost

The percentage increase in total supply chain cost due to an increase of 20% customer demand is 14.72%. Similarly, the increase in the total supply chain cost due to a 5% increase in selling price of Retailer 1 is 0.35%. The total supply chain cost decreases by 32.44% for offline only scenario when compared to the multi- channel case.

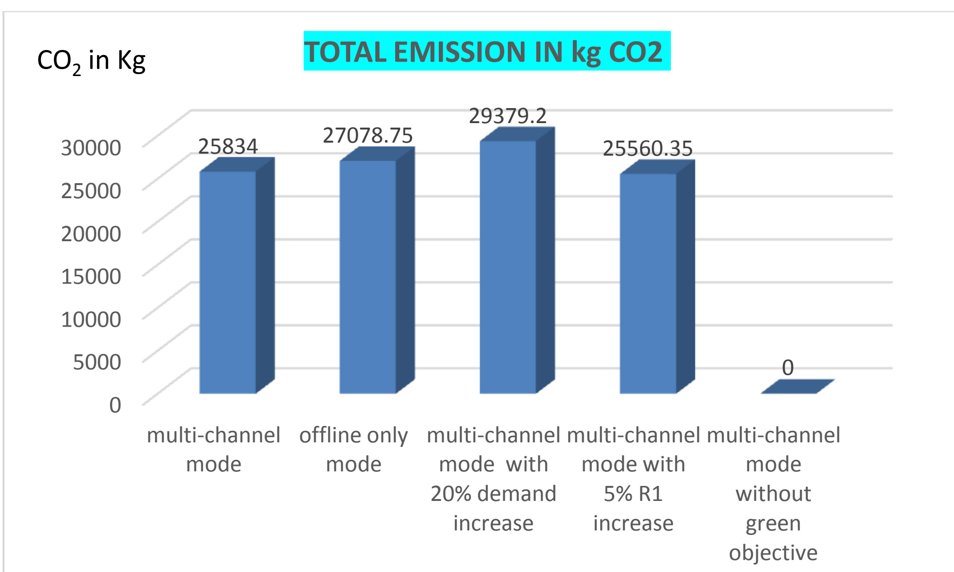

Figure 4.4 Total carbon dioxide Emission in Kg

The total emission in kg CO2 remains more or less a constant for all the cases of supply chain scenarios considered.

5.0 CONCLUSION

The primary objective of the problem was to minimize the total cost incurred across all the five stages over multiple time periods and with multiple demands satisfaction channels for the customers and to minimize the total pollution emission related to the transportation across the supply chain. The underlying assumptions, variables and constraints were defined as per the problem description. This resulted in a mixed integer linear programming problem. The problem was solved with a set of simulated data using the optimization software, CPLEX .The results obtained were tabulated and thus the model implementation was validated accordingly.

As was seen in the results, the customers sometimes prefer a particular offline or online source for buying. But this makes most of the sources obsolete as customers prefer only a select few of all the available options, like warehouses were not used at all and except for Retailer1, the other two were unused, hence reducing their product cost or shutting down of their operations if they can't make profit, reducing the prices should be undertaken for an efficient, lean and cost effective supply chain. If the customer demand increases or the demographics vary, certain other set of sources might be useful and others to be closed down. Also the average product cost is less in the multi-channel supply chain for the buyers.

The total raw materials ordered for the multi-channel case was more than the traditional retail only case. Also, in the retail only case, only one Supplier2 is selected for the major part of the four options available. This implies that the cost of raw material from other suppliers is higher and the customer demand is not that high to use all of them.

The most important significance of this work is that scenarios that can't be visualized clearly due to its practical restrictions can be analyzed by simulating it using this model over various predefined time periods considering multiple channels.

5.2.1 Future Research

More accurate representation of continuous time periods might be considered unlike the discrete time representation here. Many more objectives can be included and solved as a goal programming problem. The demand from the customers is assumed as deterministic in nature but generally even after extensive market research and forecasting, customer's demand usually ends up being stochastic in nature.

The model was validated using random data and the results were analyzed based on the same. But if available, it would be always interesting to study the effects of actual real world data on the model to help the decision makers to incorporate managerial strategies into their company's core policies.

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