Elsevier Editorial System(tm) for Expert Systems With Applications
Manuscript Draft

Manuscript Number:

Title: An Approach to Design and Optimize an Omni Channel Multi Period Closed Loop Green Supply Chain Network Meeting Customer Requirements

Article Type: Full length article

Keywords: Omni Channel; Multi period; Closed Loop; Optimization; Green; Supply chain

Corresponding Author: Dr. Parthiban Palanisamy, M.E.,Ph.D

Corresponding Author's Institution: NIT

First Author: Niranjan T, M.Tech

Order of Authors: Niranjan T, M.Tech; Parthiban Palanisamy, M.E.,Ph.D; Karthik Sundaram, B.Tech; Dhanalakshmi R, Ph.D

To
The Editor

Dear **Editor**,
Greetings and warm wishes for you
Please find enclosed of the following manuscript:

An Approach to Design and Optimize an Omni Channel Multi Period Closed Loop Green Supply Chain Network Meeting Customer Requirements

Authors: **T.Niranjan[1], P. Parthiban [2], Karthik Sundaram[3] and R.Dhanalakshmi[4]**

The manuscript is intended for consideration for possible publication in your Journal subject to your normal reviewing process.
Please acknowledge the receipt of this letter.

Yours truly,
P.Parthiban

Manuscript
Click here to download Manuscript: paper new_27122017_niranjan2_without authors and without table and figure.docx Click here to view linked References

An Approach to Design and Optimize an Omni Channel Multi Period Closed Loop Green Supply Chain Network Meeting Customer Requirements

Abstract

Omni channel Supply Chain is currently a theoretical concept and is predicted to be the future of supply chain networks. This concept can be very much useful in emerging markets where there exist opportunities for newer online firms to join hands with the local retailers. The duo achieves mutual benefits: Retailers increases its customer range and relationship through vast product variety from its partner while the online partner is able to gain customers trust and attraction through product touch and feel via the retailer stores as well as reduces distribution costs. Given the increasing focus on emissions by several countries, we also incorporate an emission or pollution factor in our objective. Going green is being used as a unique selling point in advertisements for several firms while marketing to customers. Also given the advantage of reduced material cost due to recycling of products we have considered Closed Loop Supply Chain. This work is focused on formulating a Mixed Integer Linear Programming (MILP) model for a multi period Omni Channel Closed loop Green Supply Chain, and generating an effective supply chain network for a kitchenware firm. Also, we have compared the costs for Omni channel green closed supply chain, Omni channel closed supply chain, green closed loop supply chain and closed loop supply chain and have clearly presented the results in this paper.

Key Words: Omni Channel, Multi period, Closed Loop, Optimization, Green, Supply chain

1.0 INTRODUCTION

The prime objective of a supply chain is to meet the needs of the customers with minimal resource utilization. The main concentration is usually the money spent. The design is aimed at attaining maximum productivity, customer satisfaction, flexibility etc. Supply chain network has been developed for various types of industries in the supply chain literature. In addition, several types of networks have been discussed in the literature.

A forward supply chain deals with sourcing, raw material conversion to the product etc., until the distribution of the finished item to buyers. A reverse supply chain involves the collection of the returned products and making sure that the product reaches the manufacturer for recycling and reuse. Developing a suitable model to match with the real world systems has always been a difficult task due to the uncertainty involved the factors like demand. The growth of population let to rapid exploitation of resources. Companies focused in reducing cost and did not care about the environmental impacts. Government rules and public awareness promoted the use of reverse logistics. A reverse logistic chain start from the end customer and encounter different decision points until it reaches the point of remanufacturing or repairing. Some amount of waste is involved during this process. When reverse logistics is combined with forward logistics it becomes a closed-loop supply chain. The carbon dioxide, carbon monoxide, packaging waste, toxic waste possesses a great threat to the environment. So it of great significance that some form of check is required in an industry. It can be a great marketing technique for the firm since they can advertise by giving their Carbon footprint compared to other firms. This can help them increase their customer base. The firm can also get several sops or subsidies from Government for their low emissions thereby benefitting the firm.

This study proposes a MILP model for optimising a Closed loop green Supply Chain network comprising of multiple items, manufacturing centres, customer zones and re-collection facilities. Newly manufactured items are sent to demand zones. Some items from these are sent back by the customers. The products are tested for quality and are sorted in collection centres to be recycled or to be disposed. Recyclable materials are separated and are carried to plants for remanufacturing.

1.1 Omni Channel Supply Chain

The aim of implementing a Multi-channel Supply Chain (MCSC) is to find different combinations that can be achieved by modifying the way a company procures, transports, fixes price and distributes items. Internet has revolutionized the figures one could imagine of a supply chain. This is mainly due to the fast characteristics of the Internet where information can be shared in real-time. Moreover, the use of internet has facilitated the access to different sources and clients for each of the actors of any given supply chain. One may divide this practice into two contexts of B2B and B2C where context forces different practices. In this context literature is mainly focused on the marketing aspects that each of the practices on MCSC. In another division one may look at MCSC in production and services. The inherent differences of each of these lead to different practices. By adding to the way one can bring in a customer or deliver a product it is evident to have sales increase since the product is more reachable to the customer. This increase result in cost reduction as the quantity of the production grows and it is also due to the fact that some of the practices such as internet can remove the burden of a physical store. Consequently, this practice as it involves more actors, results in a better flow of information and of course the reduction of business risks by sharing it among more actors. It is of no surprise that by involving more actors and using means to do it the cost may increase on the other hand since there will be a need to invest in the infrastructure of the current traditional means. Offering same products in different channels may cause some conflicts between the channels since each of these tries to maximize its own profit which may result in cannibalization of one channel by another one. Today customers expect to purchase material whenever and wherever possible. Therefore, a versatile SC network is very essential. Though a multi-channel supply chain can make sure the product reaches the customer, the existence of each channel as individual entities slows the process down. If there exists a good interface between various channels, it will drastically increase the customer comfort and the sales. This type of an interlinked network is called an Omni channel network .Omni channel supply chain consists of several modes for the customer to choose from, to receive their product, where each having its own carbon footprint, incurred cost and lead time.

In this work multiple channels like online direct delivery, pickup at retailer, retailer sales etc. is considered for a leading kitchenware company in southern part of India is chosen to evaluate the benefits of Omni channel closed loop green Supply chain.

2.0 LITERATURE REVIEW

2.1 Introduction

The first literature to point out major issues with conventional distribution network was by **Swaminathan and Tayur (2003)**, where they mentioned about the ways to deal with e-commerce fulfillment. They concluded that a centralized control is a very important in integrating channels which would provide better efficiency, profitability, lead to reduced inventory and provide better customer satisfaction. Another important paper on supply chain integration considering e-business was by **Agatz et al. (2008**). This paper focused on important paradigms of designing of network and inventory and managing of inventory and capacity. They categorized supply chains into integrated fulfillment which are characterized by common distribution centers for different supply channels, dedicated fulfillment characterized by separate DCs for various supply channels and store fulfillment. They also mentioned the trade-off between the pooling of inventory and the efficiency of delivery. **Lal and Sarvary (1999)**, also emphasized the requirement of net based channels and they showed that internet channels helps firms to increase their profits under certain situations by studying different distribution scenarios. **King et al. (2004)** and **Bernstein et al. (2008)** made a conclusion that cost difference for operating the second channel is not much high then operating a multi-channel supply chain would be feasible. **Farahani et al. (2008)** studied about the decision-making in a three echelon supply chain. The model involves multiple retailers, whole sale points and product varieties. It involves both direct and indirect channels in reaching the customer. **Latha et al. (2013)** aims at minimizing shipment cost while maximising fill rates of a three level supply chain problem. In order to optimize these two factors together, a four level network design is made, where the capacity, associated factors and the costs of manufacturing and transportation are considered. **Majid Eskandarpour et al. (2017)** proposed and evaluated a Large Neighborhood Search approach to select facility locations (plants and DCs), choose transportation modes between the entities of supply chain and to determine the product flows throughout the logistics network, in order to satisfy all customer demands and meet given logistics for minimizing the overall costs over one single period of planning.

2.2 Closed loop supply chain

Fleischmann et al. (2003) formulated a model out of genetic algorithm for attaining the ideal design reverse supply chain network which involved dismantling centres, reprocessing plants and distribution warehouses. They found out that, mostly, an item recovery network can use an existing forward chain network without getting deviated from the optimal solution by more than 20% using remanufacturing of copier and recycling of paper case studies. The authors conclude this to be the result of a high correlation between demands and return volumes. But, this is not the situation, when the forward network is pulled closer to the supplier or raw materials or reverse network is pulled closer to consumer due to transportation costs. **Jayaraman et al. (1999) and Jayaraman (2006)** discuss about recoverable product environment by considering recoverable manufacturing units. Products in such an environment flow to and fro between the manufacturer and the customer. The MILP problem gives the solution in the form of the number of facilities and the flow between entities. **G Kannan et al. (2010)** discussed about using Genetic Algorithm to solve a MILP Closed-Loop Multiproduct Supply Chain. The results are in the form of number of each product flowing between the entities in the supply chain. **Amin, S.H et al. (2014)** aimed to develop a MILP deterministic model for optimizing a closed-loop supply chain. The formulation is applied to copier remanufacturing. It considered three objectives. These are cost reduction, collection site operation time and defect rates. To solve the model distance and weighted sums approach are used and to analyse results value path method is used. Elements of uncertainties are not considered since a deterministic model is used. **Esmaeil Keyvanshokooh et al**. **(2016)** proposed an accelerated stochastic Benders decomposition algorithm to model qualitatively various uncertainties and solve the combinatorial problem. The model incorporates flexibility in customer service depending on the costs incurred, which is more realistic. On the downside, it considers only a single product and single objective of profit maximisation. The computational result shows that valid inequalities when combined are the most effective method to improve lower bound. **Jighyasu Gaur et al. (2017)** have however, concentrated on the tactical issue of network configuration. The integrated optimization model determined optimum sales amount, production plan and design. A case study of battery manufacturer in used to test the model. The model assumes only a single source, return of products only after a pre-specified useful life, distinct market for new and recycled products that is not true in realistic models. It also assumes that products are recycled and sold in the same period ignoring supply demand balance.

2.3 Green Supply Chain

Yeh Wei-Chang et al. (2011) used green principles for selection of suppliers. Objective of this study was introducing a planning model for partner selection in an optimum, green way. It mainly considered four factors, i.e., cost, item quality, time and the degree of green appraisal. For solving these conflicting objectives, the author fond out different sets of Pareto-optimal solutions using two multi-objective genetic algorithms, utilising weighted sum methodology, which can generate a large number of solutions. It represents a multi-commodity, two-echelon, SCND with mode selection, inventory costs and lead-time. **Samir Eldehli et al. (2012)** discussed a formulation, which deals with a green SCN considering the carbon dioxide emissions along with fixed and variable location costs. The function that relates the emission and vehicle weight is concave. Hence, a concave minimisation problem is obtained. In order to simplify the problem legrangian relaxation is applied, simplifying the problem in two easily solvable parts. This study proposed a dynamic discrete-time CLSCN model which extended the older study on static environment. **Chaabane et al. (2012)** considered carbon dioxide identical outflows and production network fetched as the natural and financial related pointers, individually. **Tao Zhang Gui et l. (2015)** analyses optimal behavior of various players on the basis of complementary theory and variational inequality where two kinds of carbon emission was included. They made use of a Modified Projection and Contraction Algorithm to obtain the model solution to establish a governing equilibrium network. It aims to balance economic benefits and environmental costs. Carbon tax is taken to be an endogenous variable. The solutions and impacts of carbon emission considerations would be more realistic considering exogenous emission values. **Kalaitzidou, Magdalini A. et al**. **(2015)** have designed a framework capable of adding flexibility to the network combining role of manufacturing, distributing, recovery and redistributing. This model is able to select suppliers as well as intra layer flow connections and is evaluated on a consumer goods chain based on Europe. Branch and bound technique is used to derive the optimal structure. Impact of Uncertainties is discounted as deterministic model is considered. **H. Ding et al. (2016)** discussed a green supply chain model and achieved it by jointly considering environmental capabilities and the carbon caps. The inference is that green model can only be achieved by cooperation between the entities in sharing the benefits of green supply chain. **Lam Jasmine Siu Lee et al. (2016)** introduced a mathematical model having two objectives for optimising port hinterland intermodal network to minimise transportation time as well as overall cost. This model provides an idea of how to plan the network in changing carbon emission restrictions. In addition, it gives an idea for the government to decide of relevant policies. **Imen Nouira et al. (2016)** showed a correlation between green performance of an item and its customer demand. It gives MILP models for both upstream and downstream supply chain. Upstream involves the product movement from suppliers to the production facilities. Downstream involves the movement from production facilities to the customers.

Claudia Colicchia et al. (2016) showed that supply chain optimisation based on cost reduction objective can lead to facilitation of green objectives. If a small increase in distribution cost can lead to a great move towards green objective, then such a change is justified. It also talks about supply chain Eco efficiency, that a supply chain model must be eco efficient. I.e., it must be able to achieve both economic as well as environmental performance.

2.4 Omni Channel Supply Chain

Shannon Cummins et al. (2016) opined Omni channel as a framework involving all buyer-seller touch points in a single interaction mechanism. The developed omni channel model considers factors such as sales, technology impact, effect on firm performance, sales processes, effect on relationships and the effect on various communication tools and platforms. **Picot-Coupey Karine et al. (2016)** provided a clear conceptual distinction between multi, cross and omni-channel strategies. It addresses five strategy related (organizational, cultural, marketing, financial and managerial) and three development related (retailing mix, IS, CRM) challenges when shifting to omni channel. It adopts a comprehensive and longitudinal approach to explore the shift from multi- to omni-channel and suggests guidelines for the process. **Hübner, Alexander et al**. **(2016**) focused on a logistic perspective for grocery SC rather than customer or service aspects alone. An integrated strategic planning network is developed to provide a structural element for planning areas and trade-offs for fulfilling. The model is also transferable to retain in industries other than grocery. **Bortolini, M., et al (2016)** proposed an amalgamated method for planning of multi modal Fresh Food Distribution Networks (FFDNs) which provides the professionals, a template on which further planning of FFDN can be done considering three objectives i.e., total cost, delivery time and carbon footprint.

From the literature, it is found that most mathematical models of supply chain not integrated the aspects such as customer requirements of multiple channels in a supply chain, multichannel inventory and transportation costs for a closed loop supply chain, supplier selection for a multi period production network and the impact of carbon emissions simultaneously. To overcome this deficiency, in this work, we consider an integrated multi-Channel (omni channel) supply chain network reflecting real life industrial scenarios. Then, we formulate the mathematical model (MILP) for the proposed multi period omni channel supply chain network. Then, we move on to solve the Mixed Integer Linear Programming (MILP) model using CPLEX optimization solver software. Then, finally after getting the results we conclude about the same. The study focuses on generating an effective omni channel supply chain network to balance economic benefits and environmental cost.

3.0 METHODOLOGY

3.1 Problem Description

A leading kitchenware company in India is chosen to evaluate the benefits of Omni Channel closed loop Supply chain. A kitchenware company has different varieties of products and has various means to reach the end customer. It also collects damaged products from customer and ships it back to the plant making it a closed loop supply chain network. The firm has 7 plants, 23 warehouses, 500 Retail Showrooms and one lakh customers spread across the country. For evaluation purpose, the network of the firm's supply chain for a small region in southern part of India is selected. Since each customer cannot be considered, the concept of customer clustering has been incorporated.

To realize the omni channel, three types of customers are being considered. By means of this, a strong link between retailers and online partner is realized. The customers are given the following options

1. Retail customers getting products instantly(designated in the problem as off line customers of 'e' type)
2. Online customers preferring Online order with direct home delivery(designated in the problem as online line customers of 'd' type)
3. Online customers preferring pickup at retail stores because of cheaper price or set of Retail customers getting direct delivery due to product unavailability which reduces their purchasing cost(designated in the problem as customers of 'c' type preferring online/offline whichever is cheaper)

The amount of products returned will be fixed based on a survey. 3 suppliers, 3 manufacturers, 3 warehouses, 3 retailers, 3 recycling centers and 5 customers each of the 3 demand types are considered. The entire supply chain is solved over multiple instances (ten instances). 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 success of this model relies on the level of co-ordination between the online partner and the retailer. Prior researches have focused on the theoretical aspects of Omni Channel Supply Chain, this is the first to attempt to mathematically model Omni Channel Green Supply Chain. Green Supply Chain is implemented by having a cost for the emissions and also a cap for the emissions for each plant. The model tries to balance economic benefits and environmental cost. Unlike prior researches considered we have considered Carbon tax to be an exogenous variable to provide a realistic solution. We have considered emissions due to production, remanufacturing and transportation. A mixed integer linear programming (MILP) model is formulated and the optimal solution has been obtained using CPLEX. Figure 3.1 depicts a schematic representation of assumed supply chain.

"Insert figure here"

Figure 3.1. Schematic Representation of Supply Chain

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 Product

“Insert table here”

Customer Demand over 10 instances:

Table 3.2 Customer Demand

“Insert Table here”

3.2 MODEL FORMULATION

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

3.2.1Sets

i	:	set of suppliers
j	:	set of plants
l	:	set of distributors
m	:	set of retailers
f	:	set of customers
q	:	set of collection points
s	:	set of Products
k	:	set of raw materials
t	:	Time Period 1,2….T

3.2.1.1 Subset of customers:

c(offline/online customers)	(cop)	:	Set of online/offline customers preferring whichever is cheaper.
d(online customers)	(co)	:	set of online customers preferring direct delivery
e(offline customers)	(cs)	:	set of Retail customers who prefer to receive from Retailers irrespective of time taken based on availability at the stores

3.2 Parameters:

$P_{i,kmax}$	:	Maximum capacity of i^{th} supplier for k^{th} raw material
$P_{i,kmin}$	:	Minimum capacity of i^{th} supplier for k^{th} raw material

C_{ik}	:	Purchasing Cost of raw material 'k' from supplier 'i' per unit
$R_{s,k}$	:	Requirement of raw material k for product s
Tijk	:	Transportation cost from supplier 'i' to plant 'j'
P_{js}	:	Capacity of plant j
PCjs	:	Production cost of product 's' per unit
D_a	:	demand of product 's' by customer 'cop'
D_b		demand of product 's' by customer 'co'
D_c		demand of product 's' by customer 'cs'
DL_s	:	Maximum capacity of inventory(Distribution center)
D_{IniInv}	:	Initial inventory (Distribution center)
T_{jls}	:	Transport cost from plant 'j' to distributor 'l' per unit
D_{InvC}	:	Holding cost of products per unit (Distribution Center)
Rt_m	:	capacity of Retailer 'm'
Rt_{IntInv}	:	Initial inventory of Retailer
P_{SP}	:	Manufacturer Selling price (at plant)
D_{SP}	:	Distributor Selling price
R_{SP}	:	Retailer Selling price
d_{jf}	:	distance between plant and customer
d_{lf}	:	distance between distributor and customer
Tjf	:	Transportation cost between plant and customer per unit distance
T_{lf}	:	Transportation cost between distributor and customer per unit distance
T_{lms}	:	Transportation cost between distributor 'l' and retailer 'm'
R_{InvC}	:	Retailer's Holding cost
REC_{IniInv}		Initial inventory at collection center
E_{cop}		Quantity returned back by customer 'cop'
E_{co}		Quantity returned by customer 'co'
E_{cs}		Quantity returned by customer 'cs'

REC_{max}	Collection center maximum capacity
TR_{qjk}	Transport cost of raw material 'k' from collection 'q' center to plant 'j'
$RECinv_C$	Collection center's holding cost
REC_c	Recycling cost per unit of raw material at collection center
EM	Emission per unit distance between p and r (p, r ∈ i,j,m,l,f,q)
Dis	Distance between p and r (p, r ∈ i,j,m,l,f,q)
Veh	vehicle capacity between p and r (p, r ∈ i,j,m,l,f,q)
EV	Emission cost per unit pollution

3.3 Decision variables :

W_{ik}	:	Quantity of raw material 'k' ordered by the manufacturer(plant) to supplier 'i'
S_{Bin}	:	Binary if supplier selected
A_{ijk}	:	Quantity of raw material k flowing from supplier i to Plant j
As	:	Quantity of raw material reaching manufacturer
Bjs	:	Quantity of product 's' produced at plant 'j'
Bjls	:	Quantity of finished products s flowing from Plant j to distributor l
CP_a		Binary if online customer 'cop' gets product from plant ' j'
CP_b		Binary if online customer 'co' gets product from plant ' j'
ID_s		Inventory quantity at Distributor
C_{lms}		Quantity of finished products s flowing from distributor l to retailer m
CD_a		binary online customer 'cop' gets product from distributor 'l'
CD_b		binary online customer 'co' gets product from distributor 'l'
CR_a		binary offline customer 'cop' gets product from retailer 'm'
CR_b		binary offline customer 'cs' gets product from retailer 'm'
IR_s		Inventory quantity at retailer
IC_k		Inventory quantity at collection center
H_{qjk}		Quantity of raw material k flowing from collection point q to

plant j

3.4 Objective function

Minimizing

Purchasing costs – The total purchasing costs of the raw material(TRPC) can be determined as follows:

$$TRPC = \sum i \sum k \sum t\,(Cik * Wikt) \quad (1)$$

Manufacturing costs – The total manufacturing costs(TMC) involved in all manufacturing of final goods can be determined as follows:

$$TMC = \sum j \sum s \sum t\,(PCjs * Bjst) \quad (2)$$

Transportation cost – The total transportation costs (TTC) in the supply chain includes the transportation cost from each supplier to manufacturers, from each manufacturer to warehouses, from each warehouse to retailers and from retailers.

$$TTC = \sum j \sum l \sum t\,(Tjl * Bjlt) + \sum i \sum j \sum t\,(Tij * Aijt) + \sum l \sum m \sum t\,(Tlm * Clmt) + \sum q \sum j \sum k\,(TRqj * Hqjt) \quad (3)$$

Inventory carrying costs – The total inventory carrying costs (TIC) in the supply chain include the inventory carrying costs of raw materials at the recycling center, inventory carrying costs at the distributor and retailer.

$$TIC = \sum l \sum t\,(DInvC[l] * IDs(l,t)) + + \sum m \sum t\,(RInvC[m] * IRs(m,t) + \sum q \sum t\,(RECinvC[q] * ICk(q,t)) \quad (4)$$

Online customer cost – The cost associated with products which are ordered online by the customer (OCC).

$$OCC = \sum cop \sum j \sum t\,\Big((CPa[j,cop] * Da[j,cop,t] * \big(Psp[j] + (Tjf[j] * djf[cop,j])\big)\Big) + \sum cop \sum l \sum t\Big((CDa[l,cop] * Da[l,cop,t] * \big(Dsp[j] + (Tlf[l] * dkf[cop,l])\big)\Big) + \sum co \sum j \sum t\,((CPb[j,co] * Db[j,co,t] * (Psp[i] + (Tjf[j] * dlf[co,j])))) + \sum co \sum l \sum t\,((CDb[l,co] * Db[l,co,t] * \quad (5)$$

$(Dsp[l] + (Tlf[l] * dkf[co, l]))))$

Retail customer cost – The cost associated with products which are bought from retailer shops (RCC).

$$RCC = \sum cop \sum m \sum t \ (CRa[m, cop] * Da[c, t] * Rsp[k]) + \sum cs \sum m \sum t \ (CRb[m, cs] * Dc[cs, t] * Rsp[k]) \quad 6$$

Recycling cost – Cost incurred in recycling the product and converting it into a raw material in the recycling center (RECC).

$$RECC = \sum q \sum j \sum t \ (Hqjt * RECc[q] \quad 7$$

Pollution cost – Cost associated with pollution occurring while transporting product from one level to other using vehicles (CPOLL).

$$CPOLL = \sum i \sum j \sum t \ (EM[i, j] * Dis[i, j] * Aijt / Veh[i, j]) + \sum j \sum l \sum t \ (EM[j, l] * Dis[j, l] * Bjlt / Veh[j, l]) + \sum l \sum m \sum t \ (EM[l, m] * Dis[l, m] * Clmt / Veh[l, m]) + \sum q \sum i \sum t \ (EM[q, j] * Dis[q, j] * Hqjt / Veh[q, j]) \quad 8$$

According to the specified costs and revenues in the supply chain, the objective function is given by the following equation:

Minimize Cost = TRPC + TMC + TRTC + TIC +OCC+RCC+RECC+CPOLL 9

3.5 Constraints: The constraints involved in the model are as follows:

Order from manufacturer should be in the limit of minimum and maximum capacity of supplier

$$w[i,k,t] <= Smax[i,k,t] * P_{Bin} [i,t] \quad \forall \quad i,k,t \quad 10$$

$$w[i,k,t] >= Smin[i,k,t] * P_{Bin} [i,t] \quad \forall \quad i,k,t \quad 11$$

Binary variable associated with the supplier

$$\sum i \ P_{Bin} [i,t] == 1 \quad \forall \ t \quad 12$$

Whatever is the quantity ordered by the manufacturers must be transported from suppliers to manufacturers so that the production can be commenced.

$$w[i,t] = \sum j \ A_{ijt} \quad \forall \quad i,t \quad 13$$

Raw material reaching plant before starting production should be equal to the sum of raw materials transported from collection centers and suppliers.

$$\sum i\ A_{i,j,t-1} + \sum q\ H_{q,j,t-1} = \sum l\ (R_{s,k} * B_{j,l,t})\ \forall j,t \qquad 14$$

Quantity of each product produced should be in limit of maximum quantity that can be produced at each plant for each product.

$$\sum s\ \ Bjs\ [j,t] \ <= \ P_{js}\ [j] \quad \forall \quad j \qquad 15$$

Quantity manufactured by each manufacturer should be enough to satisfy the demand online customers who orders directly from plant and warehouses for each product.

$$Bjs\ [j,t] == \sum l\ Bjlt + \sum cop\ (CP_a\ [j, cop] * D_a\ [cop,t]) + \sum co\ (CP_b\ [j,co] * D_b\ [co,t]\ \forall\ j,t \qquad 16$$

Final inventory at each warehouse after the demand has been satisfied should be less than the warehouse maximum capacity for each product.

$$ID\ [l,t] \ <= \ Wmax\ [l] \quad \forall \quad l,t \qquad 17$$

Initial inventory at each warehouse and the amount ordered must be enough to satisfy the retailer demand and online customer demand.

$$D_{IniInv}\ [l]=ID[l,1]+ \sum l\ C_{lm,1} \quad \forall \quad l,t\ (t=1) \qquad 18$$

$$ID[l,t-1]+ \sum j\ B_{jl,t-1} == \ ID[l,t]+ \sum m\ C_{lms} + \sum cop\ (CD_a\ [l,cop] * D_a\ [cop,t] + \sum co\ (CD_b\ [l,co] * D_b\ [co,t] \quad \forall \quad l,t \qquad 19$$

The inventory at retailer should be less than the capacity of storing at retailer

$$Rinv[m,t] <= Rmax\ [m] \quad \forall \quad m,t \qquad 20$$

Initial inventory and order at each retailer must be sufficient enough to satisfy customer demand offline.

$$RtIntInv\ [m,1] =Rinv[m,1]+\sum cop\ (CR_a[m,cop] * D_a\ [cop,1]) + \sum cs\ (CR_b[m,cs] * D_a[cs,1]) \quad \forall \quad m,t\ (t=1) \qquad 21$$

$$Rinv[m,t-1]+ \sum l\ C_{lm,t-1} == Rinv[m,t]+ \sum cop\ (CR_a[m,cop] * D_a\ [cop,t]) + \sum cs\ (CR_b[m,cs] * D_a\ [cs,t]) \quad \forall \quad m,t \qquad 22$$

Back order quantity at all time periods assumed to be zero or basically all the customer demands must be satisfied at each time period.

Binary condition for customers are constrained as follows

For the customer who prefers online or offline whichever is economical,

$$\sum j\ CP_a\ [j,cop] + \sum l\ CD_a\ [l,cop] + \sum m\ CR_a[m,cop] == 1\ \forall\ cop \qquad 23$$

For the customer who prefers online products.

$$\sum j\ CP_b\ [j,co] + \sum l\ CD_b\ [l,co] == 1\ \forall\ co \qquad 24$$

For the customer who prefers offline products.

$$\sum m\ CR_b\ [m,cs] == 1\ \forall\ cs\ (customer) \qquad 25$$

Inventory condition for every collection center

$$REC_{IniInv}\ [q] = \beta[q,1] + \sum j\ H_{qj,1} \quad \forall \quad q,t\ (t=1) \qquad 26$$

$$\beta[q,t-1] + \sum cop\ E_{cop}\ [cop,t\text{-}1] * R_{s,k} + \sum co\ E_{co}\ [co,t\text{-}1] * R_{s,k} + \sum cs\ E_{cs}\ [cs,t\text{-}1] * R_{s,k} \qquad 27$$

$$== \beta[q,t] + \sum j\ H_{qjt} \quad \forall\ q,t$$

Final inventory at recycling centre must be in the limit of maximum inventory capacity of each recycling centre.

$$\beta[q,t] <= REC_{max}\ [q] \quad \forall\ q,t \qquad 28$$

Non negative constraints

$$Aijk, Bjls, Clms \geq 0$$

4.0RESULTS AND DISCUSSION

The model formulated is tested for a set of 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. For the risk/sensitivity analysis, 5% price increase in retailer's selling price is considered

4.1 Multi Channel related Intermediate Outputs:

Table 4.1 Quantity manufactured in 10 different instances

"Insert table here"

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.

Table4.2 Quantity transported from Manufacturer to Warehouse

"Insert table here"

Above table shows that the quantity ordered is more or less evenly spaced.

Table 4.3 Quantity transported from Warehouse to Retailer

“Insert table here”

The above table clearly states that there is no movement of products from warehouse 2. The difference between the total quantity transported between manufacturer to warehouse (339) and that from the warehouse to retailer (339) is zero as no inventory is stored in the warehouse during the 10th time period.

4.2 Customer’s Source of Purchase

Table 4.4 Customer type and source of demand satisfaction

“Insert table here”

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

“Insert figure here”

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:

4.4.1 Multi Channel:

Table 4.5 Selection of Supplier for Multi channel case

“Insert table here”

4.4.2 Multi Channel With 20% Demand Increase:

Table 4.6 Multi channel with 20% demand increase

“Insert table here”

4.4.3 Multi Channel With 5% R1 Price Increase:

Table 4.7 Multi channel with 5% increase in R1 Price

“Insert table here”

4.4.4 Multi Channel without Green Objective:

Table 4.8 Multi Channel without Green Objective

“Insert table here”

4.4.5 Traditional Offline Channel:

Table 4.9 Selection of supplier in off line mode

“Insert table here”

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 and Emissions

“Insert figure here”

Figure 4.2 Total Quantity ordered from Supplier

“Insert figure here”

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. Moreover, the total raw material cost and the total quantity ordered form the supplier remains a constant despite increasing the retailer’s selling price by 5%, but the total quantity ordered increases by 10.07% and the total raw material cost by 9.96% 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 16.04%.

“Insert figure here”

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.

"Insert figure here"

Figure 4.5 Total carbon dioxide emissions in Kg

Offline only mode results in a higher CO2 emission because all the items need to travel till retailer to reach the consumer resulting in higher emission.

5.0 CONCLUSION

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 retailer 1, 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 supplier (2) 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 5% increase in the retailer 1's selling price does not seem to have a significant change in the raw material or the total supply chain cost or even the emissions whereas there is a significant difference for the 20% demand increase case as expected as the total number of products to be delivered to the customer increases which in turn increases the emissions and the costs. The traditional offline scenario though seeming to incur way lesser costs for raw materials and the total supply chain costs, cause higher amounts of pollution compared to the multi channel scenario. Also not considering the green objective does not have a significant impact on the total supply chain costs incurred, but the raw material costs seem to be on the lower side when compared to the multi channel scenario. 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.

References

1. Swaminathan, Jayashankar M., and Sridhar R. Tayur. "Models for supply chains in e-business." *Management Science* 49, no. 10 (2003): 1387-1406.
2. Agatz, Niels AH, Moritz Fleischmann, and Jo AEE Van Nunen. "E-fulfillment and multi-channel distribution–A review." *European journal of operational research* 187, no. 2 (2008): 339-356.
3. Lal, Rajiv, and Miklos Sarvary. "When and how is the Internet likely to decrease price competition?" *Marketing Science* 18, no. 4 (1999): 485-503.
4. King, Ruth C., Ravi Sen, and Mu Xia. "Impact of web-based e-commerce on channel strategy in retailing." *International Journal of Electronic Commerce* 8, no. 3 (2004): 103-130.
5. Bernstein, Fernando, Jing-Sheng Song, and Xiaona Zheng. "“Bricks-and-mortar” vs. “clicks-and-mortar”: An equilibrium analysis." *European Journal of Operational Research* 187, no. 3 (2008): 671-690.
6. Farahani, Reza Zanjirani, and Mahsa Elahipanah. "A genetic algorithm to optimize the total cost and service level for just-in-time distribution in a supply chain." *International Journal of Production Economics* 111.2 (2008): 229-243.
7. Shankar, B. Latha, et al. "Location and allocation decisions for multi-echelon supply chain network–A multi-objective evolutionary approach." *Expert Systems with Applications* 40.2 (2013): 551-562.
8. Eskandarpour, Majid, Pierre Dejax, and Olivier Péton. "A large neighborhood search heuristic for supply chain network design." *Computers & Operations Research* 80 (2017): 23-37.
9. Fleischmann, Moritz, Jo AEE Van Nunen, and Ben Gräve. "Integrating closed-loop supply chains and spare-parts management at IBM." *Interfaces* 33.6 (2003): 44-56.
10. Jayaraman, Vaidyanathan, V. D. R. Guide Jr, and Rajesh Srivastava. "A closed-loop logistics model for remanufacturing." *Journal of the operational research society* 50.5 (1999): 497-508.
11. Jayaraman, Vaidyanathan. "Production planning for closed-loop supply chains with product recovery and reuse: an analytical approach."*International Journal of Production Research* 44.5 (2006): 981-998.

12. Kannan, G., P. Sasikumar, and K. Devika. "A genetic algorithm approach for solving a closed loop supply chain model: A case of battery recycling." *Applied Mathematical Modelling* 34, no. 3 (2010): 655-670.

13. Amin, Saman Hassanzadeh, and Guoqing Zhang. "Closed-loop supply chain network configuration by a multi-objective mathematical model." *International Journal of Business Performance and Supply Chain Modelling* 6.1 (2014): 1-15.

14. Keyvanshokooh, Esmaeil, Sarah M. Ryan, and Elnaz Kabir. "Hybrid robust and stochastic optimization for closed-loop supply chain network design using accelerated Benders decomposition." *European Journal of Operational Research* 249.1 (2016): 76-92.

15. Gaur, Jighyasu, Mehdi Amini, and A. K. Rao. "Closed-loop supply chain configuration for new and reconditioned products: An integrated optimization model." *Omega* 66 (2017): 212-223.

16. Yeh, Wei-Chang, and Mei-Chi Chuang. "Using multi-objective genetic algorithm for partner selection in green supply chain problems." *Expert Systems with applications* 38.4 (2011): 4244-4253.

17. Elhedhli, Samir, and Ryan Merrick. "Green supply chain network design to reduce carbon emissions." *Transportation Research Part D: Transport and Environment* 17.5 (2012): 370-379.

18. Chaabane, Amin, Amar Ramudhin, and Marc Paquet. "Design of sustainable supply chains under the emission trading scheme." *International Journal of Production Economics* 135, no. 1 (2012): 37-49.

19. Tao, Zhang Gui, Zhong Yong Guang, Sun Hao, and Hu Jin Song. "Multi-period closed-loop supply chain network equilibrium with carbon emission constraints." *Resources, Conservation and Recycling* 104 (2015): 354-365.

20. Kalaitzidou, Magdalini A., Pantelis Longinidis, and Michael C. Georgiadis. "Optimal design of closed-loop supply chain networks with multifunctional nodes." *Computers & Chemical Engineering* 80 (2015): 73-91.

21. Ding, Huiping, Qilan Zhao, Zhirong An, and Ou Tang. "Collaborative mechanism of a sustainable supply chain with environmental constraints and carbon caps." *International Journal of Production Economics* 181 (2016): 191-207.

22. Lam, Jasmine Siu Lee, and Yimiao Gu. "A market-oriented approach for intermodal network optimisation meeting cost, time and environmental requirements." *International Journal of Production Economics* 171 (2016): 266-274.

23. Nouira, Imen, Ramzi Hammami, Yannick Frein, and Cecilia Temponi. "Design of forward supply chains: Impact of a carbon emissions-sensitive demand." *International Journal of Production Economics* 173 (2016): 80-98.

24. Colicchia, Claudia, Alessandro Creazza, Fabrizio Dallari, and Marco Melacini. "Eco-efficient supply chain networks: development of a design framework and application to a real case study." *Production Planning & Control* 27, no. 3 (2016): 157-168.

25. Cummins, Shannon, James W. Peltier, and Andrea Dixon. "Omni-channel research framework in the context of personal selling and sales management: a review and research extensions." *Journal of Research in Interactive Marketing* 10.1 (2016): 2-16.

26. Picot-Coupey, Karine, Elodie Huré, and Lauren Piveteau. "Channel design to enrich customers' shopping experiences: Synchronizing clicks with bricks in an omni-channel perspective–the Direct Optic case." *International Journal of Retail & Distribution Management* 44.3 (2016): 336-368.

27. Hübner, Alexander, Heinrich Kuhn, and Johannes Wollenburg. "Last mile fulfillment and distribution in omni-channel grocery retailing: A strategic planning framework." *International Journal of Retail & Distribution Management* 44.3 (2016): 228-247.

28. Bortolini, Marco, Maurizio Faccio, Emilio Ferrari, Mauro Gamberi, and Francesco Pilati. "Fresh food sustainable distribution: cost, delivery time and carbon footprint three-objective optimization." *Journal of Food Engineering*174 (2016): 56-67.

***Highlights (for review)**

Highlights of the paper

- Present work was done in the areas of supplier selection and supply chain modelling
- An integrated multi period omni channel closed loop green supply chain network
- It is a single integrated collaborative model for a five stage supply chain
- Considered most of the strategic and tactical decisions faced by a real world

Table(s)

Table 3.1 Selling price of Product

No of Entities	1	2	3
Manufacturer	1225	1275	1250
Warehouse	1300	1350	1325
Retailer	1400	1450	1425

Table 3.2 Customer Demand

Customer type	Customer	1	2	3	4	5	6	7	8	9	10
Offline/online Customer('c' type)	1	10	0	0	0	50	0	0	0	75	0
	2	0	0	30	0	0	50	0	0	0	0
	3	0	0	0	10	0	0	75	0	0	0
	4	0	40	0	0	0	0	0	50	0	0
	5	10	0	0	0	0	50	0	0	0	75
Online customer('d' type)	1	0	0	200	25	0	0	0	0	0	0
	2	0	0	0	0	0	50	0	0	0	0
	3	50	20	0	0	50	0	75	0	60	0
	4	0	0	30	0	0	0	0	40	0	0
	5	0	10	0	100	0	0	0	30	0	0
Retail customer(off line customer of 'e'type)	1	0	0	0	0	0	0	30	0	0	14
	2	0	35	0	0	0	40	0	0	0	0
	3	30	0	0	0	40	0	0	0	0	0
	4	0	0	0	30	0	0	75	0	0	0
	5	0	0	35	0	0	0	0	60	50	0

Table 4.1 Quantity manufactured in 10 different instances

	1	2	3	4	5	6	7	8	9	10
M1	-	40	30	-	-	100	-	90	-	75
M2	-	-	40	40	40	50	75	-	35	35
M3	-	30	200	195	165	124	75	30	135	-

Table4.2 Quantity transported from Manufacturer to Warehouse

Manufacturer	Warehouse	Time Period	Quantity Transported
2	3	3	10

2	3	4	30
2	3	5	40
3	1	4	70
3	1	5	65
3	1	6	124

Table 4.3 Quantity transported from Warehouse to Retailer

Warehouse	Retailer	Time Period	Quantity Transported
1	1	5	70
1	1	6	65
1	1	7	124
3	1	5	40
3	1	6	40

Table 4.4 Customer type and 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

Table 4.5 Selection of Supplier for Multi channel case

Supplier	Manufacturer	Time period	Quantity ordered
3	2	2	40
3	2	3	40
3	2	4	40

3	2	5	40
3	2	6	75
3	3	6	75
3	3	8	40
4	1	1	35
4	1	7	81
4	1	9	35
4	1	10	35

Table 4.6 Multi channel with 20% demand increase

Supplier	Manufacturer	Time period	Quantity ordered
3	2	2	40
3	2	3	40
3	2	4	40
3	2	5	40
3	2	6	90
3	3	6	90
3	3	8	40
4	1	1	35
4	1	7	105
4	1	9	35
4	1	10	35

Table 4.7 Multi channel with 5% increase in R1 Price

Supplier	Manufacturer	Time period	Quantity ordered
3	2	2	40
3	2	3	40
3	2	4	40
3	2	5	40
3	2	6	75
3	3	6	75
3	3	8	40

4	1	1	35
4	1	7	81
4	1	9	35
4	1	10	35

Table 4.8 Multi Channel without Green Objective

Supplier	Manufacturer	Time period	Quantity ordered
4	1	1	40
4	1	3	10
4	1	5	50
4	1	6	35
4	1	7	35
4	1	9	35
4	1	10	35
4	3	2	100
4	3	3	25
4	3	4	50
4	3	8	35

Table 4.9 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

Figure(s)

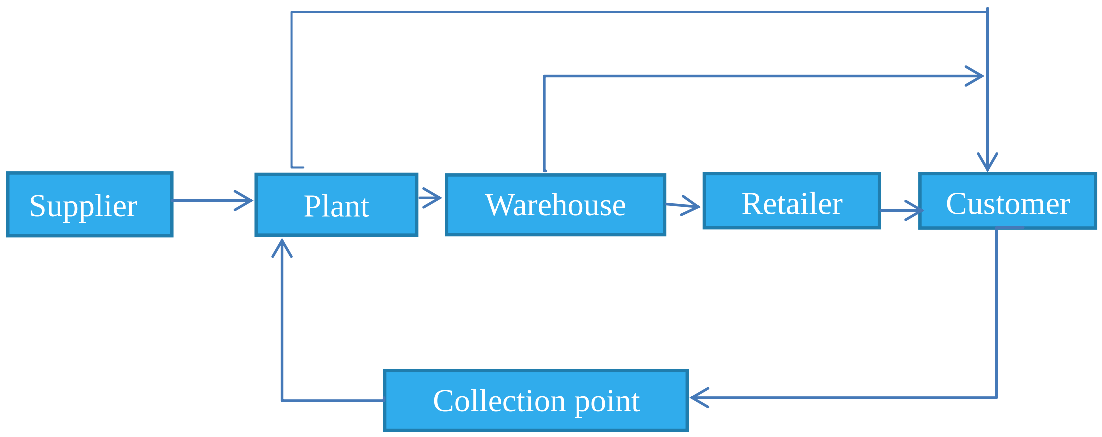

Figure 3.1. Schematic Representation of Supply Chain

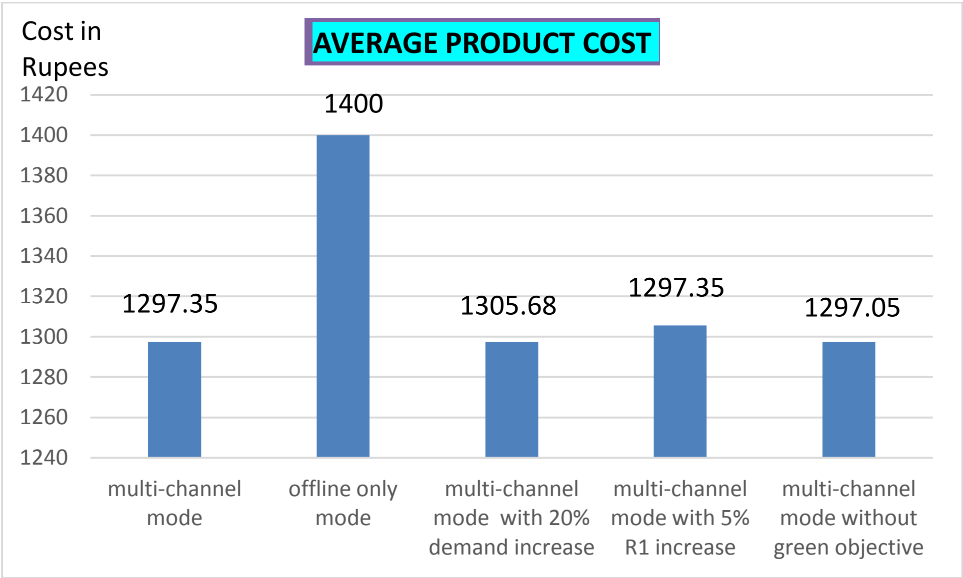

Figure.4.1 Average Production Cost

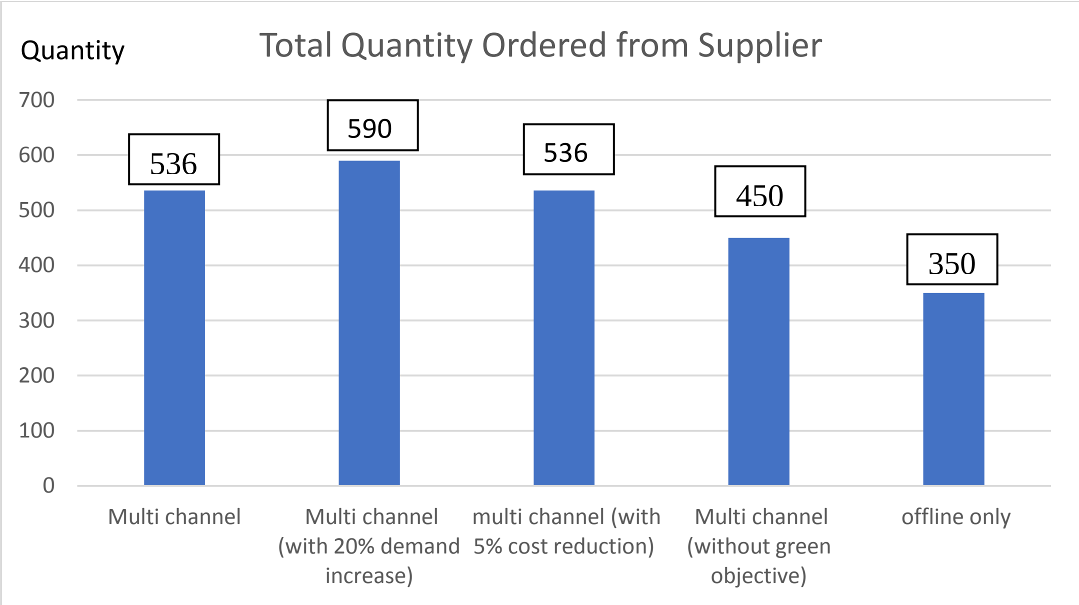

Figure 4.2 Total Quantity ordered from Supplier

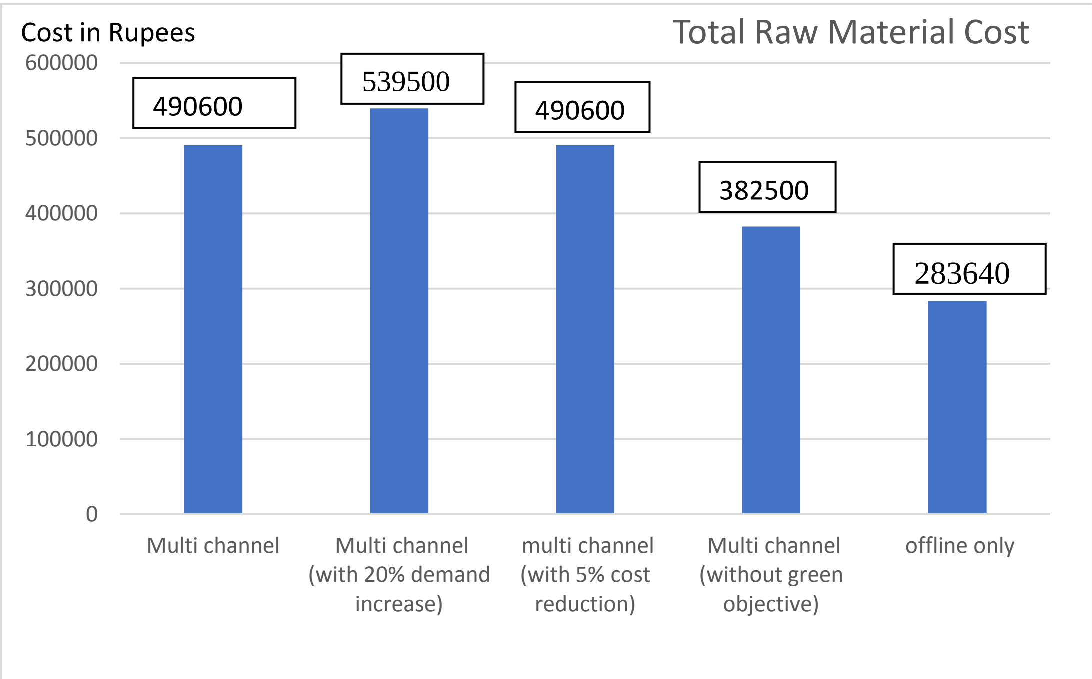

Figure 4.3 Total Raw Material Cost

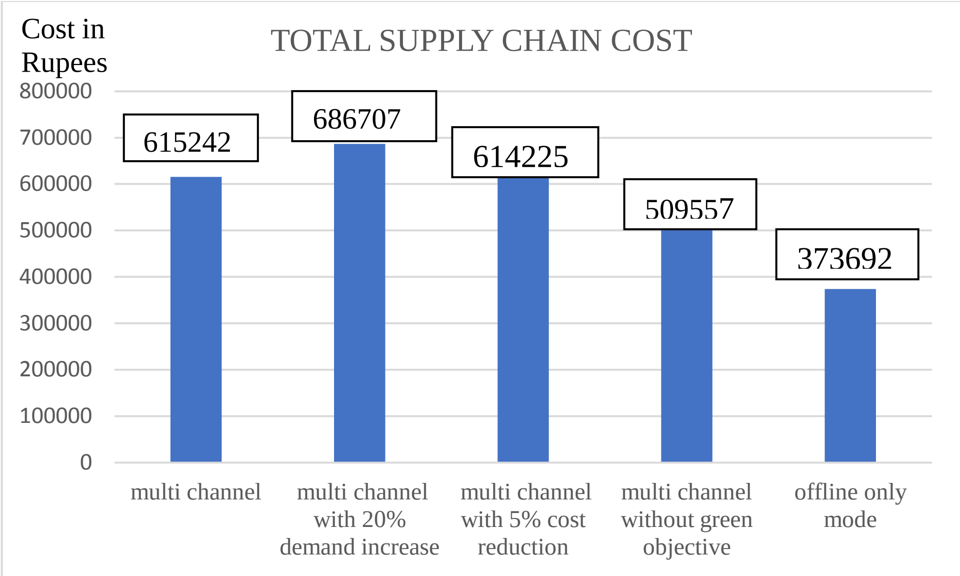

Figure 4.4 Total Supply Chain Cost

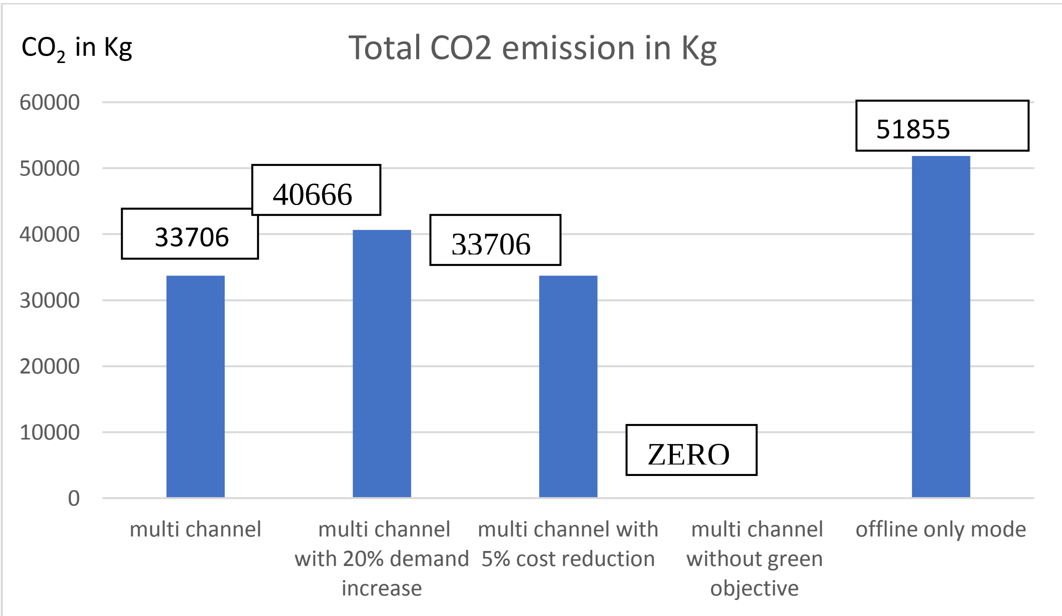

Figure 4.5 Total carbon dioxide emissions in Kg