International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-4, November 2019

Eco Friendly Closed Loop Supply Chain Model Under Fuzzy Conditions

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Abstract: ***Profits of a business organization can be sustained in the long term when the organization focus on environmental benefits and customer satisfaction along with company's financial benefit. Customer satisfaction index (CSI) can be increased with minimization of the product delivery time and maximization of the quality. Reduction of carbon emission during product manufacture/remanufacture process contributes to the environmental benefit of the organization. The proposed model is a multi-objective, multi-stage, multi-product eco-friendly closed loop supply chain linear programming problem with four objective functions and various constraints under fuzzy environment. A sub model is formulated as an application to an automobile dealership company in Visakhapatnam, India and an experimental study is done using actual data from the company. Profit margin on sale and service of three types (Type P_1, $P_2$and P_3) of new cars and sale of two types (Type A and B) of old cars are calculated. From the result analysis we can conclude that increase in the sale of new cars of type P_1 and old cars of type A increases the profit margin of the company.***

Keywords: Closed loop supply chain network; Linear programming; Fuzzy sets, Linear fractional programming.

I. INTRODUCTION

Supply Chain Management (SCM) plays an important role in a business organization. It integrates various activities and stages starting with acquisition of raw material from the supplier, manufacture of product at the manufacturing unit and finally sale to the customer through retail units. Any business organization's aim is to balance both customer satisfaction and quality of the service or product delivery whilst making profits.Study on Supply Chain Management (SCM) helps to meet the customer expectations and handle the business efficiently. Research on SCM started in early 1980's. The term SCM was introduced in 1982 and various definitions were given by different scholars [1]-[3]. Later studies on supply chain theory gave rise to different methods of optimizing the cost of production under various parameters of customer's uncertain demands that includes discount from supplier, fixed, operational and transportation costs. Fuzzy capacities of the plants and distribution centers are determined considering opportunity cost in the total cost minimization [4]. Ref [5] developed a tactical SCM as an application to automobile industry to minimize total cost in fuzzy environment. A survey on the recent developments in integrated supply chain design, gives a generic model for facility location decisions. Increased demand for new or upgraded products tends the customer to exchange used products [6]. The network of different stages that involves various activities related to the returned products starting with collection of products from customer back to the producer is called reverse logistic network. Many models were developed on reverse logistics under different perspectives. Ref [7]-[11] give a review of reverse logical network that discuss the implication of emerging reuse efforts in the areas of inventory control, distribution and production planning. In a Closed loop supply chain network (CLSCN) [21] the products that are returned by customer at collection centers are tested to check the level of damage. The reusable products are sent to remanufacture/repair centers and thereafter sent back to retailer for resale with reduced/discounted price. The products which are beyond repair are dismantled and sold to material customers. Ref [12] reviewed reverse logistics and CLSCN to fill the gaps in the literature, [13] refers the formulation of multi objective CLSCN plan based on the network flow model measuring time value to recover maximum assets lost due to delay at different stages. The application of fuzzy linear programming approach is discussed to give optimal solution for different objective functions [14]. Ref [15] gives fuzzy multi objective linear programming problem which minimizes total cost and delivery time with respect to inventory level, available machine capacity and labor levels. Performance of CLSCN system was measured using a case study from automobile industry [16]. Ref [17] designed dynamic location and allocation model and proposed sampling method in heuristic algorithm with numerical experiment in stochastic model. Ref [18] evaluated the chain performance in terms of customer responsiveness, supplier quality and profit, while another model [19] maximized delivery tardiness along with minimizing total cost of CLSCN through possibilistic programming. Scenario relaxation algorithm was used under robust approach to cope with uncertainty in return rate and demand [20], while fuzzy optimization approach was used and the model tried to concentrate on maximizing net profit value along with quality while minimizing time [21]. A comparative study of various distribution network was also undertaken [22]. It is observed that while in all the above cases only transportation time is considered, the proposed model in this paper considers both manufacturing and remanufacturing times along with transportation time.

Manuscript published on November 30, 2019.
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Reduction of carbon emission during product manufacture is essential to reduce the environmental pollution and comply with the Kyoto protocol. Following Kyoto protocol is necessary for global emission reduction regime that stabilizes GHG emissions and can provide the architecture for future international agreement on climate change [23],[24]. Literature on green supply chain management which integrated green purchasing of raw material from the suppliers to manufacturer and finally to the customer is given in [25]. Later survey of papers came up with environmental conscious product design closed loop supply chain and summarized the evolution of Environmentally conscious manufacturing and product recovery (ECMPRO) [26]. Ref [27] designed supply chain network by considering environmental effects under uncertainty and gave a balance between two objective functions of minimizing both cost and environmental impact, while [28] gave an insight of green supply chain design by studying the example of sustainability of companies that follow supply chain in North Arctic region.Present model aims to increase overall customer satisfaction considering four objective functions that minimizes two parameters-(a) product delivery time, (b) total carbon emission from supplier to the customer while maximize the other two parameters (i) product/service quality and (ii)organization's profit. Cost and time parameters are considered in fuzzy environment. The rest of paper organization is as follows: - Section II gives the preliminaries of some basic definitions, section III deals with the problem description of eco- friendly closed loop supply chain design, section IV defines various notations used in the problem, section V explains the mathematical model of multi-objective linear programming problem with various constraints in fuzzy environment and its equivalent crisp model. An application of the model for an automobile dealership company is discussed in section VI while section VII gives the analysis and conclusion.

II. PRELIMENARIES

Fuzzy set theory was first introduced by Loti A. Zadeh in 1965 [29] and fundamentals of fuzzy set theory can be obtained from [30]. In real world situations we deal with many uncertainties like demand for a product, time of manufacture or product delivery time. Cost of the product also depends on various parameters that can be defined in fuzzy logic. Following definitions are from Rommelfanger's work on Fuzzy linear programming and applications [31].

A. Fuzzy set:

Let X be a universal set. Any subset A of X is said to be fuzzy set whose elements are ordered pairs in which 1st element belongs to the set while the other is its membership degree given by $\mathrm{A} = \{(x, \mu_{\mathrm{A}}(x))/x \in X\}$ where $\mu_{\mathrm{A}}(x) \in [0,1]$ is the membership grade.

B. Normal Fuzzy set:

A fuzzy set with maximum membership grade 1 is said to be Normal fuzzy set.

C. α-cut:

The α-cut of a fuzzy set A is a crisp set containing all the elements of the universal set X whose membership grades are greater than or equal to the value α. It is denoted by

${}^{\alpha}\mathrm{A} = \{x \in \mathrm{A} / \mathrm{A}(x) \geq \alpha\}$ and it is said to be strong α-cut when it is strictly greater than α value. Given by ${}^{\alpha+}\mathrm{A} = \{x \in \mathrm{A}/ \mathrm{A}(x) > \alpha\}$

D. Fuzzy Number:

A fuzzy set A is said to be a fuzzy number when it satisfies the following properties.

(i) A must be normal fuzzy set

(ii) ${}^{\alpha}\mathrm{A}$ must be a closed interval for every $\alpha \in (0,1]$

(iii) ${}^{0+}\mathrm{A}$ must be bounded.

E. Triangular Fuzzy Number:

A fuzzy number is said to be triangular fuzzy number denoted by *(a, b, c)* whose membership function is given by

$$\mu_{\mathrm{A}}(x) = \begin{cases} 0, x \in (-\infty, a) \\ \frac{x-a}{b-a}, x \in [a,b] \\ \frac{c-x}{c-b}, x \in [b,c] \\ 0, x \in (c, \infty) \end{cases}$$

F. Trapezoidal Fuzzy Number:

A fuzzy number is said to be trapezoidal fuzzy number denoted by *(a, b, c, d)* with membership function

$$\mu_{\mathrm{A}}(x) = \begin{cases} 0, x \in (-\infty, 0) \\ \frac{x-a}{b-a,} x \in [a,b] \\ 1, x \in [b,c] \\ \frac{d-x}{d-c}, x \in [c,d] \\ 0, x \in (d, \infty) \end{cases}$$

G. Supply Chain Network (SCN) [2]:

A multistage network that integrates various activities of a business organization beginning with collection of raw material from supplier, manufacture of product at manufacturing unit and sale of the finished product to the customers through distributors. Fig.1 shows different stages of SCN.

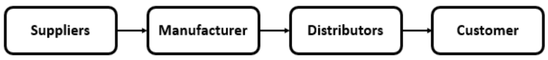


Figure 1 Supply chain network

H. Closed Loop Supply Chain Network (CLSCN) [21]:

It is a combination of both forward and reverse supply chain network that reduces the waste through repair and resale of the returned products from the customer. Fig.2 illustrates a CLSCN design.

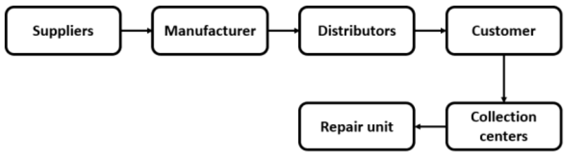


Figure 2 Closed loop supply chain network

I. Eco-friendly closed loop supply chain network (EFCLSCN) [26]:

A closed loop supply chain network with reduced carbon emission techniques is called eco-friendly closed loop supply chain network.

J. Kyoto Protocol:

The Kyoto protocol [32]-[34] is an international treaty which extends 1992 United Nations Framework Convention on Climate change (UNFCC) that commits the parties to reduce greenhouse gas (GHG) emission. It was adopted in Kyoto, Japan on 11th december1997 and came into force from 16th February 2005. At present there are 192 countries in the group. The main objective of UNFCC is to fight global warming by reducing GHG concentration in the atmosphere to a level that would prevent dangerous anthropogenic inferences due to climate change. It puts obligations on developing countries to reduce carbon emission. In recent years, many manufacturing companies understood the importance of this and trying to comply with UNFCC and Kyoto protocol.

III. PROBLEM DESCRIPTION (EFCLSCN)

The proposed model is a multi-stage, multi-product and closed loop supply chain network model designed to decrease delivery time of the manufactured product and achieve double bottom line for the company by providing both financial and environmental benefits.Profit margin, expressed in percentage, is the profitability ratio of a company that measures and reflects how well a company controls its costs in relation to their revenue. The higher the number the more profitable is the business. The model comprises of four stages in the forward network that includes suppliers, manufacturing units, retailers and customers. In the reverse network, the returned products from the customer are collected at the collection centers and sent to re-manufacturing/repair units for re-manufacture of the products and then to the retailers which are sold to customers at a lesser price. The products which are beyond repair are dismantled at dismantling units and sent to the material customers to manage the waste. We assume the product cost, transportation cost, demand of the customer and time in proposed model are fuzzy numbers. The model is called Eco -friendly closed loop model as it minimizes carbon emission during both manufacturing and remanufacturing process. Fig.3 gives the various stages of the network design.

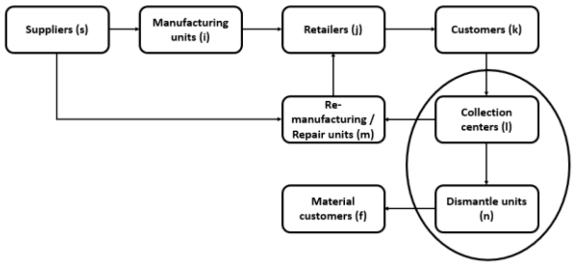


Figure 3 Eco- friendly closed loop supply chain model with material customer

IV. NOTATIONS

Following notations, parameters and variables are used for the formation of mathematical model of the above design.

s- suppliers

i -manufacturing units

a-machines at manufacturing unit

j- retailers

k- customers

l-collection centers

m- re-manufacturing/repair units

b-machines at re-manufacturing/repair units

n-dismantling units

f-material customers

p-type of product

r-raw material

q-mode of transport

σ -dismantled product/scrap

A. Parameters

Time and Eco parameters

$\tilde{TM}_{pai}$ - Time of manufacturing product *p* using machine *a* in manufacturing unit *i*.

$\tilde{TM}_{pbm}$ -Time of remanufacturing/ repairing product *p* with machine *b* at remanufacturing unit *m*.

$\tilde{TH}_{pjk}$ - Waiting time of the manufactured product *p* at retailer *j* before it reaches the customer *k*.

$\tilde{TW}_{pjk}$ - Waiting time of the remanufactured/repaired product *p* at retailer *j* before it reaches customer *k*.

$\tilde{T}_{pl}$ - Testing time of the returned product *p* at collection center *l*.

$\tilde{T}^{q}_{rsi}$ - Transport time of raw material *r* from supplier *s* to manufacturing unit *i* using *q* transport mode.

$\tilde{T}^{q}_{pij}$ - Transport time of the product *p* from manufacturing unit *i* to retailer *j* using *q* transport mode.

$\tilde{T}^{q}_{pmj}$ - Transport time of the product *p* from remanufacturing/repair unit *m* to retailer *j* using *q* transport mode.

$\tilde{T}^{q}_{pjk}$ - Transport time of the product *p* from retailer *j* to customer *k* using *q* transport mode.

$\tilde{T}^{q}_{plm}$ - Transport time of the product *p* from collection center *l* to remanufacturing/repair unit *m*, using *q* transport mode.

$\tilde{T}_{q}$ - Time delay due to traffic congestion with *q* transport mode.

$\widetilde{TE}_{pk}$- Expected delivery time of the product *p* to reach the customer *k*.

$\widetilde{TD}_{pk}$- Expected repair/re-manufacturing time of the product *p* to reach the customer *k*.

$\tilde{T}_{ai}$ - Available time of the machine *a* at manufacturing unit *i*.

$\tilde{T}_{bm}$ - Available time of the machine *b* at remanufacturing/repair unit *m*.

$\tilde{L}_{pai}$ - Carbon emission per unit of product *p* produced by machine *a* at manufacturing unit *i*.

$\tilde{\psi}_{pbm}$ -Carbon emission per unit of product *p* produced by machine *b* at remanufacturing unit *m*.

Cost parameters

$\tilde{PS}_{pjk}$ - Selling price of each manufactured product *p* from retailer *j* to customer *k*.

$\tilde{RS}_{pjk}$ - Selling price of each remanufactured/repaired product *p* from retailer *j* to customer k.

$\tilde{SP}_{\sigma nf}$ - Selling price of each dismantled product *σ* from dismantling unit *n* to material customer *f*.

$\tilde{PC}_{rsi}$ - Unit cost of raw material *r* from supplier *s* to manufacturing unit *i*.

$\tilde{PC}_{rsm}$ - Unit cost of raw material *r* from supplier *s* to remanufacturing unit *m*.

$\tilde{C}_{pai}$ - Manufacturing cost of unit product *p* with machine *a* at manufacturing unit *i*.

$\tilde{C}_{pbm}$ - Remanufacturing/repair cost of unit product *p* with machine *b* at remanufacturing unit *m*

$\tilde{C}_{pkl}$ - Cost of testing unit product *p* returned from customer *k* in collection center *l*.

$\tilde{C}_{pln}$ - Cost of dismantling unit product *p* at the dismantling unit *n*.

$\tilde{CT}^{q}_{rsi}$ - Unit transport cost to transfer raw material *r* from supplier *s* to manufacturing unit i using *q* transport mode.

$\tilde{CT}^{q}_{pij}$ - Unit transport cost of product *p* from manufacturing unit *i* to retailer *j* using *q* transport mode.

$\tilde{CT}^{q}_{pjk}$ - Unit transport cost of product *p* from retailer *j* to customer *k* using *q* transport mode.

$\tilde{CT}^{q}_{pmj}$ - Unit transport cost of product *p* from collection center *l* to remanufacturing unit *m* using *q* transport mode.

$\tilde{CT}^{q}_{rsm}$ - Unit transport cost to transfer raw material *r* from supplier *s* to remanufacturing unit *m* using *q* transport mode.

$\tilde{DR}_{pk}$ - Return rate of product *p* by customer *k*.

$\tilde{\mu}_p$ - Pollution penalty of unit product *p*.

$\tilde{VO}_p$ - volume of product *p*.

$\tilde{VOR}_j^z$ - Available volume of product *p* at retailer *j* with capacity *z*.

$\tilde{B}_{pij}^q$ - Equivalent carbon emission by transport mode *q* while transporting product *p* from manufacturing unit *i* to retailer *j*.

$\tilde{E}_{pmj}^q$ - Equivalent carbon emission by transport mode *q* while transporting product *p* from remanufacturing unit *m* to retailer *j*.

$\tilde{RD}_{rsi}$ - Defect rate of the raw material *r* from supplier *s* to the manufacturing unit *i*.

W_r - Weight factor of importance of raw material *r* from supplier *s*.

α_p - Recovery ratio of the returned product *p*.

$(1-\alpha_p)$ - Disposal ratio of the returned product *p*.

M - Permissible emission rate.

NM_{ai} - Number of machines of type *a* at manufacturing unit *i*.

NM_{bm} - Number of machines of type *b* at remanufacturing unit *m*.

$\tilde{d}_{pk}$ - Demand for the product *p* at the customer zone *k*.

$\tilde{MC}_q$ - Maximum capacity of the transport mode *q*.

$\tilde{\kappa}_{sr}$ - Capacity of each supplier *s* of raw material *r*.

B. Decision variables

X_{rsi} - Quantity of raw material *r* from supplier *s* to the manufacturing unit *i* .

H_{rsm} - Quantity of raw material *r* from supplier *s* to the remanufacturing unit *m*.

x_{rsi}^q - Quantity of raw material *r* transferred from supplier *s* to manufacturing unit *i* using *q* transport mode.

h_{rsm}^q - Quantity of raw material *r* transferred from supplier *s* to remanufacturing unit *m* using *q* transport mode.

Y_{pai} - Quantity of product *p* manufactured at manufacturing unit *i* using machine *a*.

y_{pij}^q - Quantity of manufactured product *p* transferred from manufacturing unit *i* to retailer *j* using *q* transport mode.

Z_{pjk} - Quantity of product *p* from retailer *j* to customer *k*.

z_{pjk}^q - Quantity of product *p* from retailer *j* to customer *k* using *q* transport mode.

ZR_{pjk} - Quantity of remanufactured/repaired product *p* from retailer *j* to customer *k*.

u_{pkl} - Quantity of returned product *p* from customer *k* to collection center *l*.

A_{plm} - Quantity of returned product *p* from collection center *l* to remanufacturing/repair unit *m*.

V_{pbm} - Quantity of product *p* remanufactured/repaired at remanufacturing unit *m* using machine b.

v_{pmj}^q - Quantity of remanufactured/repaired product *p* transferred from remanufacturing unit *m* to retailer *j* using *q* transport mode.

B_{pln} - Quantity of returned product *p* from collection center *l* to dismantling unit *n*.

$W_{\sigma nf}$ - Quantity of dismantled product σ from dismantling unit *n* to material customer *f*.

$\lambda_j^z = 1$ when retailer *j* of capacity *z* is open.

$\theta_{sr} = 1$ when supplier *s* is selected.

V. MULTI OBJECTIVE LINEAR PROGRAMMING MODEL

The model comprises of four objective functions. The first function aims to increase customer satisfaction by minimizing total delivery time of the product that includes time taken to manufacture, repair time, testing time of returned products, waiting time at distribution centers before reaching the customer and transport time between two stages(i.e., from plant to the distribution center; and distribution center to the retail outlet)including time taken due to traffic congestion with each mode of transport. The second objective function tries to comply with Kyoto protocol and seeks to minimize total carbon emission during manufacturing and remanufacturing process and helps to choose transport mode which emits less carbon. The third objective function maximizes the quality by choosing the raw material with low defective rate and minimizing the sale of defective products at the retailer units. The fourth objective function aims at financial benefit and tries to maximize the profit margin of the company.

A. Objective functions

1. Minimization of time of manufacture/Re-manufacture and transport time

Min z_1

$$:\left[\sum_p\sum_a\sum_i \tilde{TM}_{pai}Y_{pai}+\sum_p\sum_b\sum_m \tilde{TM}_{pbm}V_{pbm}\right]+$$
$$\left[\sum_p\sum_j\sum_k (\tilde{TH}_{pjk}Z_{pjk}+\tilde{TW}_{pjk}ZR_{pjk})\right]+$$
$$\left[\begin{array}{l}\sum_r\sum_s\sum_i \tilde{T}^q_{rsi}x^q_{rsi}+\sum_p\sum_i\sum_j \tilde{T}^q_{pij}y^q_{pij}+\\ \sum_p\sum_j\sum_k \tilde{T}^q_{pjk}z^q_{pjk}+\sum_p\sum_m\sum_j \tilde{T}^q_{pmj}v^q_{pmj}\\ +\sum_p\sum_l\sum_m \tilde{T}^q_{plm}A_{plm}\end{array}\right]+$$
$$\left[\sum_p\sum_k\sum_i \tilde{T}_{pl}u_{pkl}\right]+\tilde{T}_q$$

2. Minimization of carbon emission during Transport, manufacturing and remanufacturing/repair process.

Min z_2 :

$$\left[\sum_p\sum_a\sum_i \tilde{L}_{pai}Y_{pai}+\sum_p\sum_b\sum_m \Psi_{pbm}V_{pbm}\right]+$$
$$\sum_p\sum_i\sum_j \tilde{B}^q_{pij}y^q_{pij}+\sum_p\sum_m\sum_j \tilde{E}^q_{pmj}v^q_{pmj}$$

3. Maximization of quality

Min z_3 =

$$\sum_r\sum_s\sum_i X_{rsi}\tilde{RD}_{rsi}w_r+\sum_p\sum_l\sum_n(1-\alpha_p)B_{pln}$$

4. Maximizing Profit Margin of the company

(PM) Profit Margin = $\frac{\text{Net income}}{\text{Net sales}}$, Net income= Net Sales-Cost of Goods.

$$\text{Max } z_4 : PM=\frac{[\text{Net sales-Cost of Goods}]}{\text{Net Sales}}$$

Net Sales =

$$\left[\begin{array}{l}\sum_p\sum_j\sum_k \tilde{PS}_{pjk}Z_{pjk}+\sum_p\sum_j\sum_k \tilde{RS}_{pjk}ZR_{pjk}+\\ \sum_\sigma\sum_n\sum_f \tilde{SP}_{\sigma nf}W_{\sigma nf}\end{array}\right]$$

Cost of Goods

$$\left[\sum_r\sum_s\sum_i \tilde{PC}_{rsi}X_{rsi}+\sum_r\sum_s\sum_m \tilde{PC}_{rsm}H_{rsm}\right]+$$
$$\left[\sum_p\sum_a\sum_i \tilde{C}_{pai}Y_{pai}+\sum_p\sum_b\sum_m \tilde{C}_{pbm}V_{pbm}\right]+$$
$$\left[\sum_p\sum_k\sum_l \tilde{C}_{pkl}u_{pkl}+\sum_p\sum_l\sum_n \tilde{C}_{pln}B_{pln}\right]+$$
$$=\left[\begin{array}{l}\sum_r\sum_s\sum_i \tilde{CT}^q_{rsi}x^q_{rsi}+\sum_p\sum_i\sum_j \tilde{CT}^q_{pij}y^q_{pij}+\\ \sum_p\sum_j\sum_k \tilde{CT}^q_{pjk}z^q_{pjk}+\\ \sum_p\sum_l\sum_m \tilde{CT}^q_{plm}A_{plm}+\sum_r\sum_s\sum_m \tilde{CT}^q_{rsm}h^q_{rsm}\end{array}\right]+$$
$$\sum_p\sum_a\sum_b\sum_i\sum_m \tilde{\mu}_p(Y_{pai}+V_{pbm})$$

B. Constraints:

Constraints of the proposed model are categorized as Time, carbon emission, demand and capacity constraints.

Time constraints ((1) to (5)):

Constraint (1) ensures that total time taken to manufacture and transfer the product to the customer through retailer do not exceed the expected delivery time of the product by the customer. Constraint (2) guarantees that each returned product is repaired and delivered in minimum time. Constraint (3) ensures that spare parts and required raw material for remanufacture/repair reaches the remanufacturing/repair unit before the defective product returned by the customer arrives from collection center. Constraints (4) and (5) shows that the time taken to manufacture or remanufacture/repair any product do not exceed maximum availability time of each machine at respective units.

$$\sum_p\sum_a\sum_i \tilde{TM}_{pai} Y_{pai} + \sum_p\sum_i\sum_j \tilde{T}^q_{pij} y^q_{pij} + \sum_p\sum_j\sum_k \left(\tilde{TH}_{pjk} Z_{pjk} + \tilde{T}^q_{pjk} z^q_{pjk}\right) \le \tilde{TE}_{pk} \tag{1}$$

$$\sum_p\sum_k\sum_l \tilde{T}_{pl} u_{pkl} + \sum_p\sum_l\sum_m \tilde{T}^q_{plm} A_{plm} + \sum_p\sum_b\sum_m \tilde{TM}_{pbm} V_{pbm} + \sum_p\sum_j\sum_k \tilde{TW}_{pjk} ZR_{pjk} \le \tilde{TD}_{pk} \tag{2}$$

$$\sum_r\sum_s\sum_m \tilde{T}^q_{rsm} h^q_{rsm} \le \sum_p\sum_l\sum_m \tilde{T}^q_{plm} A_{plm} \tag{3}$$

$$\sum_p\sum_a\sum_i \tilde{TM}_{pai} Y_{pai} \le \sum_a\sum_i \tilde{T}_{ai} NM_{ai} \tag{4}$$

$$\sum_p\sum_b\sum_m \tilde{TM}_{pbm} V_{pbm} \le \sum_b\sum_m \tilde{T}_{bm} NM_{bm} \tag{5}$$

CO_2 Constraint

Constraint (6) ensures that total carbon emission during manufacturing and remanufacturing/repairing a product do not exceed maximum permissible emission rate.

$$\sum_p\sum_a\sum_i \tilde{L}_{pai} NM_{ai} + \sum_p\sum_b\sum_m \tilde{\psi}_{pbm} NM_{bm} \le M \tag{6}$$

Demand, Cost, Capacity and balance Constraint

Constraint (7) is the demand constraint which makes sure that total quantity of product *p* sold to the customer *k* from the retailer *j* meets the demand of the product *p*. Constraint (8) is the cost constraint which shows that total cost of manufacturing or remanufacturing a product is less than the selling price of the product. Constraint (9) is quality constraint which ensures that the number of products of type *p* returned by the customer do not exceed the minimum defective rate of the products sold. Constraint (10) shows that total amount of raw material supplied to manufacturing and remanufacturing/repair units by each supplier do not exceed the maximum capacity. Constraint (11) refers to the storage capacity of the product at each retailer unit. While constraints (12) to (14) ensure that amount of raw material or products transported from one stage to other do not exceed the capacity of the transport mode used. (15) and (16) are the balance constraints which shows that the quantity of products that reaches the remanufacture unit and dismantle unit are equal to the product of defect ratio of the returned product.

$$\sum_p\sum_j\sum_k Z_{pjk} \ge \sum_p\sum_k \tilde{d}_{pk} \tag{7}$$

$$\sum_p\sum_a\sum_i \tilde{C}_{pai} Y_{pai} + \sum_p\sum_b\sum_m \tilde{C}_{pbm} V_{pbm} \le \sum_p\sum_j\sum_k \tilde{PS}_{pjk} Z_{pjk} + \sum_p\sum_j\sum_k \tilde{RS}_{pjk} ZR_{pjk} \tag{8}$$

$$\sum_p\sum_k\sum_l u_{pkl} < \sum_p\sum_j\sum_k \tilde{DR}_{pk} Z_{pjk} \tag{9}$$

$$\sum_r\sum_s\sum_i X_{rsi} + \sum_r\sum_s\sum_m H_{rsm} \le \sum_s\sum_r \tilde{\kappa}_{sr} \theta_{sr} \tag{10}$$

$$\sum_p\sum_j\sum_k Z_{pjk} VO_p \le \sum_j\sum_z VOR^z_j \lambda^z_j \forall z \tag{11}$$

$$\sum_r\sum_s\sum_i x^q_{rsi} \le \tilde{MC}_q \ \forall q \tag{12}$$

$$\sum_p\sum_i\sum_j y^q_{pij} \le \tilde{MC}_q \ \forall q \tag{13}$$

$$\sum_p\sum_j\sum_k z^q_{pjk} \le \tilde{MC}_q \ \forall q \tag{14}$$

$$\sum_l\sum_m A_{plm} = \sum_k\sum_l \alpha_p u_{pkl} \forall p \tag{15}$$

$$\sum_l\sum_n B_{pln} = \sum_k\sum_l (1-\alpha_p) u_{pkl} \forall p \tag{16}$$

From the above equations it is noted that the objective functions for Minimization of time and carbon emission and quality maximization are expressed in Linear programming problem (LPP) while Profit maximization is in Linear fraction programming (LFP) problem. Profit maximization can be obtained by converting LFP to LPP using the method given in [35].

C. Method to convert LFP into LPP

Consider a LFP Max: $Q(x) = \dfrac{P(x)}{D(x)}$ where

$$P(x)=\sum_{j=1}^{n} p_i x_i + p_0\,,\ D(x)=\sum_{i=1}^{n} d_i x_i + d_0\,.$$

With constraints

$$\sum_{j=1}^{n} a_{ij}x_j \le 0, i=1,2....m_1$$

$$\sum_{j=1}^{n} a_{ij}x_j \ge 0, i=m_1+1, m_1+2....m_2$$

$$\sum_{j=1}^{n} a_{ij}x_j = 0, i=m_2+1, m_2+2....m$$

Equivalent LPP

To convert the given LFP into a LPP new variables t_j 's are introduced as in Cranes &Cooper transformation. Since $D(x)>0$,multiply all constants with $\dfrac{1}{D(x)}$ and then append new constraint $\sum_{j=0}^{n} d_j t_j = 1$.

Equivalent Linear programming problem will be as follows:

Max $L(t)=\sum_{j=0}^{n} p_j t_j$

Subject to the constraints

$$\sum_{j=0}^{n} d_j t_j = 1$$

$$-b_i t_0 + \sum_{j=1}^{n} a_{ij}x_j \le 0, i=1,2....m_1$$

$$-b_i t_0 + \sum_{j=1}^{n} a_{ij}x_j \ge 0, i=m_1+1, m_1+2....m_2$$

$$-b_i t_0 + \sum_{j=1}^{n} a_{ij}x_j = 0, i=m_2+1, m_2+2....m$$

$$t_j \ge 0,\ j=1,2,...n$$

Above converted LPP is solved using TORA software to get t_j for j=1, 2,…n. Then x_j is obtained by $x_j = \dfrac{t_j}{t_0}$.

D. Auxiliary crisp model to convert triangular fuzzy parameters

Time, cost and capacity parameters considered in the model are assumed to follow triangular fuzzy number and are converted to crisp values as follows.

Objective functions

1. Min

$$z_1 = \left[\begin{array}{l} \sum_p\sum_a\sum_i \left[\left(\dfrac{(TM_{pai}^{pes} + 2TM_{pai}^{mos} + TM_{pai}^{opt})}{4} \right) Y_{pai} \right] + \\ \sum_p\sum_b\sum_m \left(\dfrac{(TM_{pbm}^{pes} + 2TM_{pbm}^{mos} + TM_{pbm}^{opt})}{4} \right) V_{pbm} \end{array} \right]$$

$$+$$

$$\sum_p\sum_j\sum_k \left[\begin{array}{l} \left(\dfrac{\left(TH_{pjk}^{pes} + 2TH_{pjk}^{mos} + TH_{pjk}^{opt}\right)}{4} \right) Z_{pjk} + \\ \left(\dfrac{\left(TW_{pjk}^{pes} + 2TW_{pjk}^{mos} + TW_{pjk}^{opt}\right)}{4} \right) ZR_{pjk} \end{array} \right] +$$

$$\sum_r\sum_s\sum_i \left[\dfrac{\left(T_{rsi}^{qpes} + 2T_{rsi}^{qmos} + T_{rsi}^{qopt}\right)}{4} x_{rsi}^{q} \right] +$$

$$\sum_p\sum_i\sum_j \left[\dfrac{\left(T_{pij}^{qpes} + 2T_{pij}^{qmos} + T_{pij}^{qopt}\right)}{4} y_{pij}^{q} \right] +$$

$$\sum_p\sum_j\sum_k \left[\dfrac{\left(T_{pjk}^{qpes} + 2T_{pjk}^{qmos} + T_{pjk}^{qopt}\right)}{4} z_{pjk}^{q} \right] +$$

$$\sum_p\sum_m\sum_j \left[\dfrac{\left(T_{pmj}^{qpes} + 2T_{pmj}^{qmos} + T_{pmj}^{qopt}\right)}{4} v_{pmj}^{q} \right] +$$

$$\sum_p\sum_m\sum_l \left[\dfrac{\left(T_{pml}^{qpes} + 2T_{pml}^{qmos} + T_{pml}^{qopt}\right)}{4} A_{pml} \right] +$$

$$\left[\sum_p\sum_k\sum_l \left(\dfrac{(T_{pl}^{pes} + 2T_{pl}^{mos} + T_{pl}^{opt})}{4} \right) u_{pkl} \right] +$$

$$\left[\dfrac{\left(T_q^{pes} + 2T_q^{mos} + T_q^{opt}\right)}{4} \right]$$

2. Min

$$z_2 = \left[\begin{array}{l} \sum_p\sum_a\sum_i \left(\dfrac{\left(L_{pai}^{pes} + 2L_{pai}^{mos} + L_{pai}^{opt}\right)}{4} \right) Y_{pai} + \\ \sum_p\sum_b\sum_m \left(\dfrac{\left(\psi_{pbm}^{pes} + 2\psi_{pbm}^{mos} + \psi_{pbm}^{opt}\right)}{4} \right) V_{pbm} \end{array} \right] +$$

$$\sum_p\sum_i\sum_j\left[\frac{\left(B_{pij}^{qpes}+2B_{pij}^{qmos}+B_{pij}^{qopt}\right)}{4}\right]y_{pij}^{q}+$$

$$\sum_p\sum_m\sum_j\left(\frac{\left(E_{pmj}^{qpes}+2E_{pmj}^{qmos}+E_{pmj}^{qopt}\right)}{4}\right)v_{pmj}^{q}$$

3.Min

$$z_3=\sum_r\sum_s\sum_i X_{rsi}\left(\frac{\left(\tilde{RD}_{si}^{pes}+2\tilde{RD}_{si}^{mos}+\tilde{RD}_{si}^{opt}\right)}{4}\right)w_r+$$

$$\sum_p\sum_l\sum_n(1-\alpha_p)B_{pl\ln}$$

$$\sum_p\sum_k\sum_l\left(\frac{\left(C_{pkl}^{pes}+2C_{pkl}^{mos}+C_{pkl}^{opt}\right)}{4}\right)u_{pkl}+$$

$$\sum_p\sum_l\sum_n\left(\frac{\left(C_{pl\,n}^{pes}+2C_{pl\,n}^{mos}+C_{pln}^{opt}\right)}{4}\right)B_{pl\,n}+$$

$$\sum_r\sum_s\sum_i\left(\frac{\left(CT_{rsi}^{qpes}+2CT_{rsi}^{qmos}+CT_{rsi}^{qopt}\right)}{4}\right)x_{rsi}^{q}+$$

$$\sum_p\sum_i\sum_j\left(\frac{\left(CT_{pij}^{qpes}+2CT_{pij}^{qmos}+CT_{pij}^{qopt}\right)}{4}\right)y_{pij}^{q}+$$

$$\sum_p\sum_j\sum_k\left(\frac{\left(CT_{pjk}^{qpes}+2CT_{pjk}^{qmos}+CT_{pjk}^{qopt}\right)}{4}\right)z_{pjk}^{q}+$$

$$\sum_p\sum_l\sum_m\left(\frac{\left(CT_{plm}^{qpes}+2CT_{plm}^{qmos}+CT_{plm}^{qopt}\right)}{4}\right)A_{plm}+$$

$$\sum_r\sum_s\sum_m\left(\frac{\left(CT_{rsm}^{qpes}+2CT_{rsm}^{qmos}+CT_{rsm}^{qopt}\right)}{4}\right)h_{rsm}^{q}+$$

$$\sum_p\sum_a\sum_b\sum_i\sum_m\left(\frac{\left(\mu_p^{pes}+2\mu_p^{mos}+\mu_p^{opt}\right)}{4}\right)\left(Y_{pai}+V_{pbm}\right)$$

4. Max z_4: $\text{PM}=\dfrac{(\text{Net sales-Cost of Goods})}{\text{Net Sales}}$

Net Sales:

$$\sum_p\sum_j\sum_k\left(\frac{\left(PS_{pjk}^{pes}+2PS_{pjk}^{mos}+PS_{pjk}^{opt}\right)}{4}\right)Z_{pjk}+$$

$$\sum_p\sum_j\sum_k\left(\frac{\left(RS_{pjk}^{pes}+2RS_{pjk}^{mos}+RS_{pjk}^{opt}\right)}{4}\right)ZR_{pjk}$$

+

$$\sum_p\sum_n\sum_f\left(\frac{\left(SP_{\sigma nf}^{pes}+2SP_{\sigma nf}^{mos}+SP_{\sigma pnf}^{opt}\right)}{4}\right)W_{\sigma nf}$$

Cost of Goods:

$$\sum_r\sum_s\sum_i\left(\frac{\left(PC_{rsi}^{pes}+2PC_{rsi}^{mos}+PC_{rsi}^{opt}\right)}{4}\right)X_{rsi}+$$

$$\sum_r\sum_s\sum_m\left(\frac{\left(PC_{rsm}^{pes}+2PC_{rsm}^{mos}+PC_{rsm}^{opt}\right)}{4}\right)H_{rsm}+$$

$$\sum_p\sum_a\sum_i\left(\frac{\left(C_{pai}^{pes}+2C_{pai}^{mos}+C_{pai}^{opt}\right)}{4}\right)Y_{pai}+$$

$$\sum_p\sum_b\sum_m\left(\frac{\left(C_{pbm}^{pes}+2C_{pbm}^{mos}+C_{pbm}^{opt}\right)}{4}\right)V_{pbm}+$$

Time Constraints:

$$\sum_p\sum_a\sum_i\left(\frac{\left(TM_{pai}^{pes}+2TM_{pai}^{mos}+TM_{pai}^{opt}\right)}{4}\right)Y_{pai}+$$

$$\sum_p\sum_i\sum_j\left(\frac{\left(T_{pij}^{qpes}+2T_{pij}^{qmos}+T_{pij}^{qopt}\right)}{4}\right)y_{pij}^{q}+$$

$$\sum_p\sum_j\sum_k\left[\left(\frac{\left(TH_{pjk}^{pes}+2TH_{pjk}^{mos}+TH_{pjk}^{opt}\right)}{4}\right)Z_{pjk}+\left(\frac{\left(T_{pjk}^{qpes}+2T_{pjk}^{qmos}+T_{pjk}^{qopt}\right)}{4}\right)z_{pjk}^{q}\right]\le$$

$$\sum_p\sum_k\left(\frac{\left(TE_{pk}^{pes}+2TE_{pk}^{mos}+TE_{pk}^{opt}\right)}{4}\right)$$

(17)

$$\sum_{p}\sum_{k}\sum_{l}\left(\frac{\left(T_{pl}^{pes}+2T_{pl}^{mos}+T_{pl}^{opt}\right)}{4}\right)u_{pkl}+\sum_{p}\sum_{l}\sum_{m}\left(\frac{\left(T_{plm}^{qpes}+2T_{plm}^{qmos}+T_{plm}^{qopt}\right)}{4}\right)A_{plm}+\sum_{p}\sum_{b}\sum_{m}\left(\frac{\left(TM_{pbm}^{pes}+2TM_{pbm}^{mos}+TM_{pbm}^{opt}\right)}{4}\right)V_{pbm}+\sum_{p}\sum_{j}\sum_{k}\left(\frac{\left(TW_{pjk}^{pes}+2TW_{pjk}^{mos}+TW_{pjk}^{opt}\right)}{4}\right)ZR_{pjk}\le\sum_{p}\sum_{k}\left(\frac{\left(TD_{pk}^{pes}+2TD_{pk}^{mos}+TD_{pk}^{opt}\right)}{4}\right)\quad(18)$$

$$\sum_{r}\sum_{s}\sum_{m}\left(\frac{\left(T_{rsm}^{qpes}+2T_{rsm}^{qmos}+T_{rsm}^{qopt}\right)}{4}\right)h_{rsm}^{q}\le\sum_{p}\sum_{l}\sum_{m}\left(\frac{\left(T_{plm}^{qpes}+2T_{plm}^{qmos}+T_{plm}^{qopt}\right)}{4}\right)A_{plm}\quad(19)$$

$$\sum_{p}\sum_{a}\sum_{i}\left(\frac{\left(TM_{pai}^{pes}+2TM_{pai}^{mos}+TM_{pai}^{opt}\right)}{4}\right)Y_{pai}\le\sum_{a}\sum_{i}\left(\frac{\left(T_{ai}^{pes}+2T_{ai}^{mos}+T_{ai}^{opt}\right)}{4}\right)NM_{ai}\quad(20)$$

$$\sum_{p}\sum_{b}\sum_{m}\left(\frac{\left(TM_{pbm}^{pes}+2TM_{pbm}^{mos}+TM_{pbm}^{opt}\right)}{4}\right)V_{pbm}\le\sum_{b}\sum_{m}\left(\frac{\left(T_{bm}^{pes}+2T_{bm}^{mos}+T_{bm}^{opt}\right)}{4}\right)NM_{bm}\quad(21)$$

***CO_2** Constraint:*

$$\sum_{p}\sum_{a}\sum_{i}\left(\frac{\left(L_{pai}^{pes}+2L_{pai}^{mos}+L_{pai}^{opt}\right)}{4}\right)NM_{ai}+\sum_{p}\sum_{b}\sum_{m}\left(\frac{\left(\psi_{pbm}^{pes}+2\psi_{pbm}^{mos}+\psi_{pbm}^{opt}\right)}{4}\right)NM_{bm}\le M\quad(22)$$

Demand, cost and capacity constraints:

$$\sum_{p}\sum_{j}\sum_{k}Z_{pjk}\ge\sum_{p}\sum_{k}\left(\frac{\left(d_{pk}^{pes}+d_{pk}^{mos}+d_{pk}^{opt}\right)}{4}\right)\quad(23)$$

$$\sum_{p}\sum_{a}\sum_{i}\left(\frac{\left(C_{pai}^{pes}+2C_{pai}^{mos}+C_{pai}^{opt}\right)}{4}\right)Y_{pai}+\sum_{p}\sum_{b}\sum_{m}\left(\frac{\left(C_{pbm}^{pes}+2C_{pbm}^{mos}+C_{pbm}^{opt}\right)}{4}\right)V_{pbm}\le\sum_{p}\sum_{j}\sum_{k}\left[\left(\frac{\left(PS_{pjk}^{pes}+2PS_{pjk}^{mos}+PS_{pjk}^{opt}\right)}{4}\right)Z_{pjk}+\left(\frac{\left(RS_{pjk}^{pes}+2RS_{pjk}^{mos}+RS_{pjk}^{opt}\right)}{4}\right)ZR_{pjk}\right]\quad(24)$$

$$\sum_{p}\sum_{k}\sum_{l}u_{pkl}<\sum_{p}\sum_{j}\sum_{k}\left(\frac{\left(DR_{pjk}^{pes}+2DR_{pjk}^{mos}+DR_{pjk}^{opt}\right)}{4}\right)Z_{pjk}\quad(25)$$

$$\sum_{r}\sum_{s}\sum_{i}X_{rsi}+\sum_{r}\sum_{s}\sum_{m}H_{rsm}\le\sum_{s}\sum_{r}\left(\frac{\left(\kappa_{sr}^{pes}+2\kappa_{sr}^{mos}+\kappa_{sr}^{opt}\right)}{4}\right)\theta_{sr}\quad(26)$$

$$\sum_{p}\sum_{j}\sum_{k}Z_{pjk}VO_{p}\le\sum_{j}VOR_{j}^{z}\lambda_{j}^{z}\forall z\quad(27)$$

$$\sum_{r}\sum_{s}\sum_{i}x_{rsi}^{q}\le\left(\frac{\left(MC_{q}^{pes}+2MC_{q}^{mos}+MC_{q}^{opt}\right)}{4}\right)\forall q\quad(28)$$

$$\sum_{p}\sum_{i}\sum_{j}y_{pij}^{q}\le\left(\frac{\left(MC_{q}^{pes}+2MC_{q}^{mos}+MC_{q}^{opt}\right)}{4}\right)\forall q\quad(29)$$

$$\sum_{p}\sum_{j}\sum_{k}z_{pjk}^{q}\le\left(\frac{\left(MC_{q}^{pes}+2MC_{q}^{mos}+MC_{q}^{opt}\right)}{4}\right)\forall q\quad(30)$$

$$\sum_{l}\sum_{m}A_{plm}=\sum_{k}\sum_{l}\alpha_{p}u_{pkl}\forall p\quad(31)$$

$$\sum_{l}\sum_{n} B_{p\ln} = \sum_{k}\sum_{l}\left(1-\alpha_p\right)u_{pkl} \forall p \quad (32)$$

VI. MODEL FOR THE APPLICATION IN AUTOMOBILE DEALERSHIP COMPANY

A sub model is designed as an application to study the data from an automobile dealership company in Visakhapatnam, India. The dealer company considered has a car sale business that purchases cars from the manufacturer and sell to the customers through their distribution centers at various places. Apart from sale of new cars, the company also provides service/repairs and resale of the old cars.

The sub model designed comprises of 4 stages in the forward direction. Manufacturer that produces different types of cars, the stock yards at which dealer company stores the purchased cars, primary retailer units and customers. While the reverse network comprises of service centers where the new cars sold to the primary customers will be serviced. Apart from the cars that are sold from the company other cars are also serviced at the service centers to generate income. As a part of reverse network, the company also has secondary retailer unit where the dealer company buys the old cars, repairs them at service centers and sell back to the secondary customers. Those vehicles which are beyond repair are dismantled and sold to material customers who purchases the dismantled scrap.

The Sub model in the example concentrates on 3 Objective functions.

1)Minimization of total time delay both in forward and reverse wings.

2)Maximization of quality service.

3) Maximization of profit margin of the company.

Fig.4 below gives the design of the sub model of the example considered

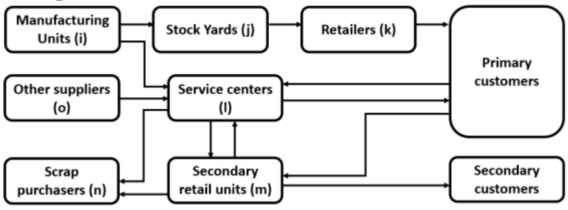


Figure 4 Eco- friendly closed loop supply chain model with material customer

A. Index sets

i- Manufacturing units

j- Stock yards

k- Primary retailer units

l- Service centers

m-Secondary retailer units

o-Other suppliers

n- Scrap purchasers

p-Type of vehicle

q- Mode of transport

v - quantity of scrap sold to material customer

Only one mode of transport is considered in the example hence q is constant.

B. Parameters:

Time parameters:

$\tilde{T}^{q}_{pij}$ - Time taken to transport vehicle of type p from manufacturing unit i to stock yard j using q transport mode.

$\tilde{T}^{q}_{pjk}$ - Time taken to transport vehicle of type p from stock yard j to the primary retailer unit k using q transport mode.

$\tilde{TH}_{pjk}$ - Holding time of the vehicle p at the stock yard j before transferring to the primary retailer unit k.

$\tilde{PT}_{pk}$ - Process time of the vehicle p at the primary retailer unit k.

$\tilde{ST}_{pl}$ - Service time of the new vehicle p at the service center l.

$\tilde{TS}_{al}$ - Service time of the other vehicle of type a at the service center l.

$\tilde{TR}_{bml}$ - Service time of the secondary vehicle of type b from secondary retailer m at the service center l.

$\tilde{TE}_{pk}$ - Expected delivery time of the vehicle p at the primary retailer unit k.

$\tilde{TCT}_{q}$ - Time delay due to traffic congestion in the q transport mode.

$\tilde{MST}_{p}$ - Expected service time of the primary vehicle p.

$\tilde{MTS}_{a}$ - Maximum expected time to repair the vehicle of type a.

$\tilde{MHT}_{pjk}$ - Maximum holding time of the vehicle of type p at the stock yard j.

$\tilde{RT}_{pl}$ - Complaint resolution time of vehicle *p* at the service center *l*.

Cost Parameters:

$\tilde{PS}_{pk}$ - selling price of the new vehicle of type *p* to primary customers at primary retailer unit *k*.

$\tilde{PS}_{bm}$ - selling price of the repaired vehicle of type *b* to the secondary customers at secondary retailer unit *m*.

$\tilde{SC}_{al}$ - service /repair charge of vehicle of type *a* at the service center *l*.

$\tilde{CPS}_{vn}$ - selling price of the scrap *v* at material customer *n*.

$\tilde{PC}_{pij}$ - purchase cost of vehicle *p* from manufacturer *i* that goes to stockyard *j*.

$\tilde{PC}_{bm}$ - purchase cost of old vehicle *b* at the secondary retailer *m*.

$\tilde{CT}^{q}_{pij}$ - cost of transporting vehicle *p* from manufacturing unit *i* to the stock yard *j* using *q* transport mode.

$\tilde{CT}^{q}_{pjk}$ - cost of transporting vehicle *p* from stock yard *j* to the retailer unit *k* using *q* transport mode.

$\tilde{RC}_{bml}$ - cost of repair of vehicle *b* at the service center *l* that comes from secondary retailer *m*.

S_{sol} - Total revenue on selling of spare parts.

C. Decision Variables:

X_{pij} - number of cars of type *p* purchased from manufacturing unit *i* that goes to stock yard *j*.

Y_{pjk} - number of cars of type *p* moved from stock yard *j* to the primary retailer unit *k*.

Z_{pk} - number of cars of type *p* sold to customers at retailer unit *k*.

u_{pl} - number of cars of type *p* that come for servicing to the service center *l*.

V_{al} - number of other cars of type *a* that are serviced at the service center *l*.

A_{bm} - number of old cars of type *b* that are purchased from the customers at the secondary retailer unit *m*.

W_{bml} - number of old cars of type *p* that goes for servicing/ repairing from secondary retailer unit *m* to the service center *l*.

G_{bm} - number of repaired cars of type *b* that are sold to secondary customers at secondary retailer unit *m*.

f_{vn} - amount of dismantled scrap *v* that is sold to material customer *n*.

C_{sol} - total cost of spare parts

D. Objective functions:

(1) Minimization of time (Minimizing Transport time of vehicles from manufacturing unit to the retailer unit, waiting time of the vehicle at the stock yard, processing time at the retailer and time of servicing)

Min

$$z_1 = \sum_p \sum_i \sum_j \tilde{T}^{q}_{pij} X_{pij} + \sum_p \sum_j \sum_k \tilde{T}^{q}_{pjk} Y_{pjk} + \sum_p \sum_j \sum_k \tilde{TH}_{pjk} Y_{pjk} + \sum_p \sum_k \tilde{PT}_{pk} Z_{pk} + \sum_p \sum_l \tilde{ST}_{pl} u_{pl} + \sum_a \sum_l \tilde{TS}_{al} V_{al} + \sum_b \sum_m \sum_l \tilde{TR}_{bml} W_{bml} + \tilde{TCT}_q$$

(2) Maximization of Quality: (Service quality can be increased by reducing resolution time, number of complaints)

$$\text{Min } z_2 = \sum_p \sum_l \tilde{RT}_{pl} u_{pl}$$

(3) Maximization of profit margin of the company

(PM) Profit Margin = $\frac{\text{Net income}}{\text{Net sales}}$, Net income= Net Sales-Cost of Goods.

(4) $$\text{Max } z_3 : PM = \frac{(\text{Net sales-Cost of Goods})}{\text{Net sales}}$$

Net sales=

$$\sum_p \sum_k \tilde{PS}_{pk} Z_{pk} + \sum_p \sum_m \tilde{PS}_{bm} G_{bm} +$$

$$\sum_v \sum_m \sum_n \tilde{CPS}_{vn} f_{vn} + \sum_a \sum_l \tilde{SC}_{al} V_{al}$$

$$+S_{sol}$$

Cost of Goods=

$$\sum_p \sum_i \sum_j \tilde{PC}_{pij} X_{pij} + \sum_b \sum_m \tilde{PC}_{bm} A_{bm} +$$

$$+$$

$$\sum_p \sum_i \sum_j \tilde{CT}^q_{pij} X_{pij} + \sum_p \sum_j \sum_k \tilde{CT}^q_{pjk} Y_{pjk}$$

$$\sum_b \sum_m \sum_l \tilde{RC}_{bml} W_{bml} + C_{sol}$$

E. Constraints:

$$\sum_p \sum_k \tilde{PT}_{pk} Z_{pk} \le \sum_p \sum_k \tilde{TE}_{pk} \qquad (33)$$

$$\sum_p \sum_l \tilde{ST}_{pl} u_{pl} \le \sum_p \tilde{MST}_p \qquad (34)$$

$$\sum_a \sum_l \tilde{TS}_{al} V_{al} \le \sum_p \tilde{MTS}_a \qquad (35)$$

$$\sum_p \sum_j \sum_k \tilde{TH}_{pjk} Y_{pjk} \le \tilde{MTH}_{pjk} \qquad (36)$$

$$\sum_p \sum_l u_{pl} \le \sum_a \sum_l V_{al} \qquad (37)$$

$$\sum_b \sum_m G_{bm} = \alpha \sum_b \sum_m A_{bm} \qquad (38)$$

$$\sum_p \sum_i \sum_j X_{pij} = \sum_p \sum_k Z_{pk} \qquad (39)$$

$$\sum_v \sum_n f_{vn} < \sum_b \sum_m \sum_l W_{bml} \qquad (40)$$

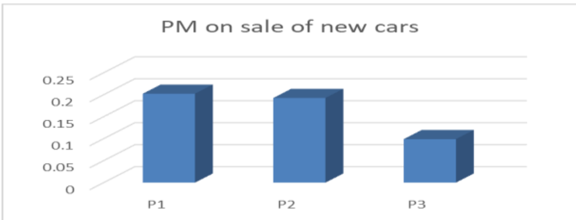
$$\sum_b \sum_m \tilde{PC}_{bm} A_{bm} + \sum_b \sum_m \sum_l \tilde{RC}_{bml} W_{bml} <$$

$$\sum_p \sum_m \tilde{PS}_{bm} G_{bm}$$

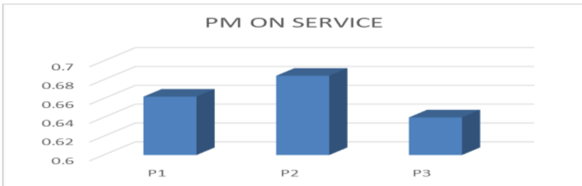
$$(41)$$

VII. CONCLUSION

A multistage, multi objective multi product closed loop supply chain design is formulated that optimizes time, quality, carbon emission and profit margin. Depending on the requirement the stages of the model can be restructured. Given illustration of the sub model is a Manufacturer - Distributor network that considers the stages from manufacture to customer but excludes the supplier. Profit margin on sale of three types of new cars (P1, P2, P3), service of the cars (P1, P2, P3) and sale of two types of secondhand cars (A, B) are calculated and result is analyzed with the graphs shown below. Graph 1 represents the profit margin on the sale of each of three types of new cars P1, P2, P3 .It can be seen that margin on the sale of car of type P_1 is the highest among the three cars. Graph 2 shows profit obtained on the service of each car of types P1, P2, P3 and it is observed that service of P2 type of car yields more profit. While Graph 3 compares profit obtained on both sale and service of new cars. It also shows that overall profit margin in the forward direction is obtained on car of type P1. Graph 4 shows the profit margin on the sale of type A car is greater than that on type B car. Hence from graphs shown below we can conclude that increase in the sale of number of cars of type P1 of new cars and type A of old cars increases overall profit margin of the company.

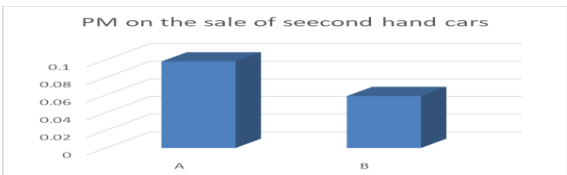


Graph 1



Graph 2

Graph 3



Graph 4

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