DESIGNINIG FORWARD AND REVERSE SUPPLY CHAIN NETWORK FOR REFURBISHED PRODUCTS

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ABSTRACT

In this paper, we have addressed a problem related to forward and reverse logistics design for refurbished products. Nowadays, E-commerce firms have started recycling used products and selling them in the market as refurbished products. To address this, a mixed integer nonlinear programming (MINLP) model is proposed to minimize the total expected costs, which involves material costs, production costs, shortage costs, purchasing costs, recycling costs, inventory holding costs, repairing costs, disposal costs, and transportation costs associated with the entire forward and reverse supply chain network. The proposed model considers all pickup and delivery points of retailers/customers within the promised time window. The proposed model is solved using IBM CPLEX. Computational experiments are presented to generate comparative data for analyzing and deriving managerial insights using practical cases.

Keywords: forward logistics, reverse logistics, refurbished products, multimodal transportation, CPLEX.

1. INTRODUCTION

From the last few decades, the research domain of Sustainable logistics and supply chain network design has influenced manufacturing companies a lot. Reverse logistics is one of the crucial areas of supply chain, in which defective parts are moved from customers to the manufacturing plants. The defective parts are first repaired and recycled, and then are sold as refurbished products. The retailers sell refurbished products as discounted items. Logistics service providers fulfil the refurbished product and new product demand to the retailers. In the Global competitive world, the transportation network needs more attention to increase the profit revenue of E-commerce companies. The manufacturing firms produce the finished goods/orders and supply the products to the supplier warehouses through various modes of transportation. The E-commerce company has information related to suppliers (i.e. availability of products, Cost, distance from warehouse etc.) and customers (i.e. location of the customers). The customers indent the orders through E-commerce platform and suppliers deliver those products to the customer within the promising time horizon, but sometimes, customers received damaged/defective, unsatisfied products. In companies' policy, the customer can return the orders within the some certain time. Due to lack of information synchronization of system, the E-commerce company assigns the service provider to collect the return product from the customers and it causes a loss in transportation cost and increase in carbon emission.

In general, the phenomenon, the suppliers and customer's information are independent to each service system, so the suppliers supply the products through E-commerce company warehouse. The large numbers of truck capacity used for transportation service due to lack of information sharing. The transportation cost increases and the product cost also increased, customer have to pay more charge as the delivery cost. The researchers focus to allocate the trucks based on order capacities and develop the shortest route network to minimize the travel distance.

2. LITERATURE REVIEW

Some of researchers focused on the logistic network design and minimize the transportation time and cost. (Cattaruzza et al., 2017) surveyed the vehicle routing problem for the urban cities. They have classified the product movement based on statistical analysis on urban goods movement. A hybrid priority-based genetic algorithms is proposed by (Gen et al., 2018) for the logistics and supply chain management network design. (Zhang et al., 2017) developed a mixed integer non-linear model to capture all the practical constraints associated with truck allocation, route selection, supplier selection problem. They have maximized the total profit, revenue with price sharing among the logistics service providers.

The firms are focused toward the sustainable supplier selection (Mokhtar et al., 2019)**.** The supplier's performance measures based on reverse product supply chain. Due to environment prevention, the companies are emphasized on recycled manufacturing (Özceylan & Paksoy, 2013). Reverse supply chain is one of the major transportation activities, which helps to achieve the recycle goal. They have formulated a model to minimize the total transportation cost while taking the account disassembly balancing. (Ramezani et al., 2013) introduced a stochastic multi-objective model for forward and reverse logistics network and tried to capture the three-echelon supply chain (suppliers, plants, and distribution centres: forward, two echelons in backward direction, collection centres and disposal centres).

The parameters of carbon emission are incorporated by Choudhary et al. (2015) with several decision variables, and for minimizing the carbon footprint and the transportation cost they modified the traditional integrated model of forward and reverse logistics into the quantitative operational decision making model. (Gao & Ryan, 2014) developed a model related to closed loop supply chain and captured the uncertainties associated with demands.

3. PROBLEM STATEMENT

3.1 Problem description

In this problem, we have considered a practical scenario of E-commerce, logistics, which captures the forward and reverse logistics operations of transportation service providers. The figure 1 represents a framework of forward and reverse network in E-commerce platform. Let, there are n ($n=1, 2, 3....N$) numbers of manufacturing firms, which transport the products to the m ($m=1, 2, 3$……...) Suppliers. The finished products flow from Suppliers' warehouse to retailer distribution centers i ($i=1, 2,.....I$). The unsatisfied products/ refurbished products, which are not satisfied by the customers, returned at the retailer distribution center. The LSPs pick-up the scrap/defective product and transported to the respective manufacturing plants. The challenges of the proposed work are to consider all the pick-up, delivery points of retailers/customers within the promising range of time window.

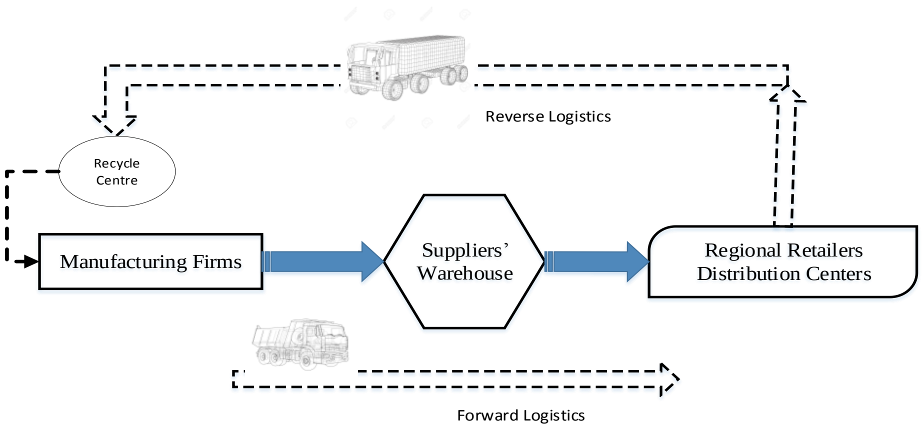

Figure 1. Forward-reverse logistics supply chain network

3.2 Assumptions

1. Considered scenario is a multi-period and multi-echelon
2. The cost is fixed for each facility layout and time period
3. The capacity of the products at each location is limited
4. The remaining inventory level decides the holding cost of the products
5. The Disposal Centre is near to disassembly location and distance is negligible.
6. The demand capacity at first customer zone are known Sets

3.3 Mathematical Model

Index

m Number of manufacturers' (m=1,2……..M)
w Number of warehouse (w =1,2……..W)
$\tilde{w}$ Number of warehouse store ($\tilde{w}$ =1, 2,……….. $\tilde{W}$)
$\tilde{r}$ Number of recycle centre ($\tilde{r}$ =1, 2,……….. $\tilde{R}$)
t Time period (t=1,2………T)
c Distribution centre (c =1,2………C)
d Disassembly centres (d=1,2…….D)

Parameters

C_M The cost of raw material / unit supplied by the manufacturer
C_p Manufacturing cost/unit product
C_r The cost of recycling products / unit recycled
C_p^l The purchasing cost associated with recycling (per unit)
$P_{i,j}$ Shipping cost to transport the products from *i* node to *j* node (location)

Decision Variables

$Q_{t,m,w}$ = The products flow from manufacturer (m) to warehouse (w) in time period t

$Q_{t,w,c}$ = The products flow from warehouse (w) to distributor centers (c) in period 't'

$I_{\tilde{w},c,t}$ = The flow of products from warehouse store($\tilde{w}$) to distributor center (c) in period 't'

$Q_{d,w,t}$ = The quantity of products flow from disassembly (d) to warehouse (w) in period t

$Q_{u,d,t}$ = The products transported from first user (u) to disassembly location (d) in period 't'

$Qr_{r\sim,w,t}$ = The products transported from recycling center($r^{\sim}$) to warehouse (w) in period 't

$Qrd_{d,r\sim,t}$ = The number of products move from disassembly d to recycling location $r^{\sim}$ in period 't'

$R_{w^{\sim},t}$ = Remaining inventory at $w^{\sim}$ warehouse stores

$R_{c,t}$ = Remaining inventory at distribution center c

$$z_{i,j} = \begin{cases} 1 \text{ if the transportation service occurs between manufacturer } i \text{ to location } j \\ 0 \text{ otherwise} \end{cases}$$

Objective function (Minimize)

Z $_{\min}$= Total expected cost

Total expected cost $(T_{ec})_{\min}$ = material cost + production cost + material cost (for return units) + shortage cost + purchasing cost + recycling cost + inventory holding cost + repairing cost + disposal cost + transportation cost

Flow of goods from manufacturer to warehouse in t time-period. Cost of material

$(T_{ec})_{\min}$ =

$$\sum_{t}^{T}\sum_{m=1}^{M}\sum_{w=1}^{W} Q_{t,m,w}C_M + \sum_{t=1}^{T}\sum_{w=1}^{W}\sum_{c=1}^{C} Q_{t,w,c}C_p + \sum_{\tilde{w}=1}^{\tilde{W}}\sum_{c=1}^{C}\sum_{t=1}^{T} I_{\tilde{w},c,t}C_p + \sum_{d=1}^{D}\sum_{w=1}^{W}\sum_{t=1}^{T} Q_{d,w,t}(C_R - C_M) + \sum_{u=1}^{U}\sum_{d=1}^{D}\sum_{t=1}^{T} Q_{u,d,t}C_p^l$$

$$+\sum_{r^{\sim}=1}^{R}\sum_{w=1}^{W}\sum_{t=1}^{T} Qr_{r^{\sim},w,t}(C_R) + \sum_{w^{\sim}=1}^{W^{\sim}}\sum_{t=1}^{T} R_{w^{\sim},t}.C_H + \sum_{d=1}^{D}\sum_{t=1}^{T} R_{c,t}.C_{Hd} + \sum_{d=1}^{D}\sum_{r^{\sim}=1}^{R^{\sim}}\sum_{t=1}^{T} Qrd_{d,r^{\sim},t}C_{rep} + \sum_{d=1}^{D}\sum_{g=1}^{G}\sum_{t=1}^{T} Q_{d,g,t}C_{dis}$$

$$+\sum_{i=1}^{I}\sum_{j=1}^{J} P_{i,j}.z_{i,j}$$

Constraints

The equation 10 & 11 describe the transportation service occurs between depot i to Manufacturer depot j

$$\sum_{i=1\, j\neq 1}^{T_1+M} z_{i,j} = 1, \forall j \in (1,2.......M)$$

$$\sum_{j=1 i\neq 1}^{T_1+M} z_{i,j} = 1, \forall i \in (1,2.......T_1)$$

Supplier to warehouse path

$$\sum_{i=1\, j\neq 1}^{M+W} z_{i,j} = 1, \forall j \in (1,2.......W)$$

$$\sum_{j=1 i\neq 1}^{M+W} z_{i,j} = 1, \forall i \in (1,2.......M)$$

Warehouse store to distribution centres

$$\sum_{i=1\, j\neq 1}^{\tilde{W}+C} z_{i,j} = 1, \forall j \in (1, 2.......C)$$

$$\sum_{j=1 i\neq 1}^{\tilde{W}+C} z_{i,j} = 1, \forall i \in (1, 2.......\tilde{W})$$

Distribution centres to users'/customers' locations

$$\sum_{i=1\, j\neq 1}^{C+U} z_{i,j} = 1, \forall j \in (1, 2.......U)$$

$$\sum_{j=1 i\neq 1}^{C+U} z_{i,j} = 1, \forall i \in (1, 2.......C)$$

User's locations to disassembly location

$$\sum_{i=1\, j\neq 1}^{D+L} x_{i,j} = 1, \forall j \in (1, 2.......L)$$

$$\sum_{j=1 i\neq 1}^{D+L} x_{i,j} = 1, \forall i \in (1, 2.......C)$$

Disassembly to recycling and repair centres

$$\sum_{i=1\, j\neq 1}^{L+R_1} x_{i,j} = 1, \forall j \in (1, 2.......R_1)$$

$$\sum_{j=1 i\neq 1}^{L+R_1} x_{i,j} = 1, \forall i \in (1, 2.......L)$$

Repair centres to facility centres

$$\sum_{i=1\, j\neq 1}^{R_1+F} x_{i,j} = 1, \forall j \in (1, 2.......F)$$

$$\sum_{j=1 i\neq 1}^{R_1+F} x_{i,j} = 1, \forall i \in (1, 2.......R_1)$$

The quantity of products supply from the suppliers to the warehouse and recycling is equal to the sum of total quantity of products existing from this warehouse-to-warehouse store and distributor.

$$\sum_{s=1}^{S}\sum_{f=1}^{F} Q_{t,m,f} = \sum_{f=1}^{F}\sum_{d=1}^{D} Q_{f,d,t} + \sum_{f=1}^{F}\sum_{f^{\sim}=1}^{F^{\sim}} I_{f,f^{\sim},}, \forall t \in \{1, 2.....T\}$$

The sum of the total products flow existing from each destined customer point to disassembly locations does not exceed the sum of entering each destined customer location.

$$\sum_{l=1}^{L} Q_{c,l,t} \leq \left(\sum_{d=1}^{D} Q_{d,c,t} \right) R_r, \forall t \in (1, 2.......T), \forall c \in (1, 2.......C)$$

4. SOLUTION APPROACH

The proposed work dealt with the forward-reverse logistics network design for the new (satisfactory products) and returned (unsatisfied products). The model has been formulated as mixed integer non-linear programing (MINLP) and problem is broadly classified in vehicle routing problem, which is a NP hard problem. IBM CPLEX is used to determine the total revenue generated by the system. CPLEX is flexible optimizer tool, which can solve the linear and non-linear models. CPLEX gives the exact optimal solution and obtained results can be used for planning in resources and business analysis of firms.

5. RESULTS & DISCUSSIONS

We have used CPLEX on i5 processor (8.0 GHz) in Windows 10 platform and determined the minimum total expected cost incurred in the logistics network. Computation experiments reveal that in all considered cases, the dataset increases the computation time. We have conducted tests on 5 instances as described in table 1.

Table 1. Computation Experiments (five instances)

Instances	*m, w, t, c ,d*	CPLEX	
		Objective function (Million $)	Computation Time (Seconds)
I	3,2,1,2	1.85	69
II	3,3,2,2	2.1	76
III	4,3,1,2	3.5	81
IV	4,4,2,3	4.2	89
V	5,4,2,4	5.8	102

6. CONCLUSIONS AND FUTURE RESEARCH SCOPE

In this paper, we have considered the forward-reversed logistics network design from the manufacturer to customer and vice-versa. The proposed scenario is formulated as mixed integer nonlinear programming, which captures the total expected costs associated with production, transportation cost, recycling costs, inventory and shortage cost, material cost for forward-reverse network, disposal cost and repairing cost. The CPLEX optimization tool is used to minimize the total expected cost incurred in the manufacturing firms. The model has been tested on five test instances and it is found that when the number of parameters increases, which also increases the complexity of the problem and computational time. In future scope, these models can be extended for new and refurbished products with social sustainable factors.

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