Optimization of network configuration for the entities in reverse logistics through MILP

Introduction and background

The previous chapter dealt with evolution of possible network framework for the product returns and their subsequent processing or disposal. We discussed typical flow of returns and also the alternatives exercised by the industrial set ups for the collection, scrutiny and processing of returns, before it heads again to either the original customer (after repair), or secondary customer (after remanufacture) or to the scrap or disposal facility.

An important ultimate outcome of the present work, further, is to optimize the reverse logistics network, in terms of facility establishment and processing operations and cost of transportation for all movements of product returns. While the mathematical formulation can adapt to varied individual entities of reverse logistics, like remanufacturing, recycle, and disposal, but we follow a network configuration that features a mathematical formulation that involves all three reverse logistics operations. We primarily adapt a mixed integer linear programming formulation [183] with an added provision for incorporation of entity for retreading facility at the location of recycling center, by additional formulation. We present a composite solution that optimizes the total cost of the reverse logistics network.

Subsequently, we use this formulation to optimize the cost and location-decisions by LINGO optimization software application, in upcoming chapter.

We consider the case of tire and rubber product returns, which is a real representative sector for the returns’ management, for, it involves all key attributes of logistics, repair, remanufacture and also, the crucial environmentally safe disposal. Especially, the environmental importance of this
produce, owing to its carbon and metal constituents gains significance in the state of UP, India, that strives and struggles for up keeping clean and pollution-free air.

We begin with formulating the problem as a mixed-integer linear programming problem involving eight entities involved in the reverse logistics network, including incorporated entity of retreading.

**Optimization of return flows**

The present work intends to recommend and model a generalized multi-stage reverse supply chain and analyze it under different situations. We consider a reverse supply chain for a global major tire production, distribution, and remanufacturing organization, having manufacturing plant based in state of UP. The company has 4 manufacturing plants across India, and we limit our focus to reverse logistics and returns management framework for the manufacturing location catering primarily to the region of UP, Haryana, and NCR.

We model the reverse logistics practices for the existing entities namely customer zones, collection centers, remanufacturing centers, disassembly centers, recycling and retreading centers, primary markets, secondary markets and disposal centers with collected industrial data for the number and location of different existing facilities present in the network and the quantity of flow of products, components and materials between each stage of the reverse supply chain, with an objective to minimize the total cost comprising of transportation cost, processing cost, disposal cost and fixed facility cost.
We first adapt mathematical formulation of the automobile reverse logistic network using mixed-integer linear programming, and go on further to solve a real-life network design problem using Solver Lingo (v. 15 running on Intel i-5, 2.20 GHz, 4 GB RAM computer) to obtain the optimum design of the returns’ network. We obtain and propose a framework with optimized numbers and locations for the facilities for different entities, and also, optimized flow quantity between each stage of this reverse supply chain.

Primary take-away from the exercise is to obtain the optimal locations and numbers of the entities, and optimized inter-facility flow, that minimizes the total cost of the returns’ management activity for the original manufacturer, so as to aid him with the decision support for returns classified into end-of-life (heading to disposal) and end of economic use (heading to remanufacturing).

**MILP formulation for the reverse logistics networks for tire manufacturing industry**

Figure 4.1 represent typical flow of the existing seven stage reverse supply chain for the tire manufacturing organization under study. The network has different entities such as customer...
zones, collection centers, and remanufacturing centers, disassembly centers, recycling centers, primary markets, secondary markets and disposal centers.

We partly adapt the formulation by [183] for the following existing operating conditions:

1. The returns have been recorded for a single period (as per the prevalent schedule), and for multi-products.

2. The returns flow only sequentially/hierarchically.

3. Capacities at different entities as per existing situation, and inter-facility transportation cost is determinable, and

4. We limit our work to existing transportation mean and its optimization, rather than exploring other transportation modes for cost-effectiveness.

5. The manufacturing company intends to add retreading option to their existing recycle facilities. Our formulation is suitably modified to incorporate costs for retreading facilities, which would further be cost and location optimized.

The products from the customers from customer zones are collected at the collection centers, having provisions to classify the returns into remanufacturable or recyclable/disposable. Recyclable or those classified to be heading to disposal are further sorted to disassemble usable components out of them. In sequence, they had to either recycle plant or disposal site.

Returns classified as remanufacturable are further remanufactured at remanufacturing centers, and finally head to the secondary markets for a fresh sale.

We reiterate that with an objective of minimizing the total cost comprising of transportation cost, processing cost, disposal cost and fixed facility cost, we propose an optimum configuration of reverse networks with location and numbers of different facilities already established in the existing network and also the optimized returns’ flow between each stage of the reverse supply chain. For this, the formulated MILP model will be subjected to Lingo optimization modelling, in the next section.
Nomenclature:

- Z set of market zones
- C set of collection centers
- R set of remanufacturing centers
- RT set of retreading centers
- D set of disassembly centers
- L set of recycling centers
- M set of primary markets
- S set of secondary markets
- K set of disposal sites
- P products returned
- EU end-of-use products
- EL end-of-life products
- RC recyclable components
- DI disposable items
- RM recycled materials
- RP remanufactured products
- Rt retreaded products
- PR\textsubscript{m} returned product from customer zone m, m ∈ Z
- HC\textsubscript{n} handling cost per unit at collection center n, n ∈ C
- PC\textsubscript{n} \textsuperscript{i} processing cost of product, component or material per unit at facility n, where n∈R, D, L and I ∈ EU, EL, RC, RT
- U\textsubscript{i} unit cost of disposal of material i, where i∈ DI
- d\textsubscript{mn} distance between facilities m and n, where m, n ∈ Z × C, C ×R, C ×D, R × S, RT × S, D × L, D × K, L ×M
- t\textsubscript{ci} Transportation cost per unit product/ component/material i
- f\textsubscript{n} fixed cost of facility n, where n∈ C, R, D, L
- Cap\textsubscript{i} \textsuperscript{n} capacity of facility n, for product/ component/material i
- α maximum flow rate of the collected products to the remanufacturing centers
- β number of recyclable components produced from the product at disassembly center
• γ number of retreaded tires produced from products at disassembly center

**Decision variables**

• $X_{m:n}^{i}$ quantity of product/component/ material $i$ shipped from facility $m$ to facility $n$, where $m, n \in \{Z \times C, C \times R, C \times D, R \times S, RT \times S, D \times L, D \times K, L \times M\}$ and $i \in \{P, EU, EL, RC, RT, DI, RM, RP\}$

• $Y_{C}$ 0-1 variable, $Y_{C} = 1$ if collection center $C$ is used else $Y_{C} = 0$

• $Y_{R}$ 0-1 variable, $Y_{R} = 1$ if remanufacturing center $R$ is used else $Y_{R} = 0$

• $Y_{Rt}$ 0-1 variable, $Y_{Rt} = 1$ if retreading center $R$ is used else $Y_{Rt} = 0$

• $Y_{D}$ 0-1 variable, $Y_{D} = 1$ if disassembly center $D$ is used else $Y_{D} = 0$

• $Y_{L}$ 0-1 variable, $Y_{L} = 1$ if recycling center $L$ is used else $Y_{L} = 0$

**Objective function:**

The objective for the reverse logistics network is to minimize the total cost of the multi-stage reverse supply chain. We consider inter-facility transportation cost, processing costs at different facilities (operating and establishment costs).

Minimise:

$$\sum_{m \in Z} \sum_{n \in C} \sum_{i \in P} X_{mn}^{i} \times (tc_{i} \times d_{mn} + HC_{n}) + \sum_{m \in C} \sum_{n \in R} \sum_{i \in EU} X_{mn}^{i} \times (tc_{i} \times d_{mn} + PC_{n}^{i}) +$$

$$\sum_{m \in C} \sum_{n \in L} \sum_{i \in EL} X_{mn}^{i} \times (tc_{i} \times d_{mn} + PC_{n}^{i}) + \sum_{m \in R} \sum_{n \in S} \sum_{i \in RP} X_{mn}^{i} \times (tc_{i} \times d_{mn}) +$$

$$\sum_{m \in D} \sum_{n \in K} \sum_{i \in DI} X_{mn}^{i} \times (tc_{i} \times d_{mn} + U_{i}) + \sum_{m \in R} \sum_{n \in S} \sum_{i \in RP} X_{mn}^{i} \times (tc_{i} \times d_{mn} + U_{i}) \quad (1)$$

Subject to constraints as described below:

• Collection of returns through collection centers:
\[
\sum_{n \in C} X_{mn}^i = PR_m, \forall m \in Z, \forall i \in P \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \ cd
• Processing capacity constraint at collection centers

\[ \sum_{m \in Z} x_{mn}^i \leq C_{ap_n}^i \times Y_n , \forall n \in C, \forall i \in P \] (9)

• Processing capacity constraint at remanufacturing centers

\[ \sum_{m \in C} x_{mn}^i \leq C_{ap_n}^i \times Y_n , \forall n \in R, \forall i \in EU \] (10)

• Processing capacity constraint at remanufacturing centers

\[ \sum_{m \in Z} x_{mn}^i \leq C_{ap_n}^i \times Y_n , \forall n \in D, \forall i \in EL \] (11)

• Processing capacity constraint at recycling centers (for recyclable components)

\[ \sum_{m \in Z} x_{mn}^i \leq C_{ap_n}^i \times Y_n , \forall n \in L, \forall i \in RC \] (12)

\( Y_n \) is binary, \( \forall n \in C, R, D, L, RT \) ................................................................. (13)

\( x_{mn}^i \geq 0 \) and integer in product flow \( \forall m, n \) and \( i \) ..................................................... (14)

• Constraint (13) represents the binary variables.
• Constraint (14) ensures the non-negative flow of products, components and materials.

Also, understandably, the variables are restricted to an integer value, when the flow is in product level.

Tire recovery can be done by three ways: tire retreading, recycling or combustion in cement facilities for energy recovery. In the existing logistics network framework of the company, the company wishes to investigate profitability of launching retreading facility embedded in to the existing facility created for recycling. The model can be solved for different volumes of retreadable tires. Also, tires collected back from customers are directly sent to either recycling facility or cement facility without controlling whether the incoming tires are retreadable. After recycling, the
main products obtained are granule and steel wire at respective rates of 65% and 25%.

This formulated model for optimization is subjected to optimization modelling using Lingo R1 in the next chapter, for the existing scenario of arrangement of facilities and inter-entity returns’ flow, the inter-facility distance and transportation costs. We also incorporate the fixed facility costs and unit processing costs at different entities. We optimize the model to find optimized cost and locational decision support for the different entities in the reverse logistics network of a rubber and tire manufacturing organization in Delhi NCR and Gurugram region in India.