# Automobile Tire product reverse supply chain: Configuration of networks

**Corresponding author: Uday K. Chhaya,**
Shantilal Shah Engineering College, Bhavnagar-364060, Gujarat state, India

*Abstract*— **Presented work discusses an industrial field study carried out in the State of Haryana and NCR, and studies configuration of physical reverse logistics networks for automobile tire. Further, the determination of the number and location of different facilities like collection centres, re-manufacturing centres, disassembly centres, recycling centres, disposal centres is demonstrated through real-field data of returns-flow and transportation costs of the products, and also for the intra-stage quantity-flow between facilities in the reverse supply chain. MILP is used to optimize the mathematical model and Lingo solver is used to determine numbers and locations of different key constituting facilities for the reverse logistics network, with an objective of minimising the supply chain cost.**

*Index Terms*—**Reverse Logistics, MILP**

## I. Introduction

Developing economies are observing a large and diverse market vouching to extend productive life of goods and products through reuse and thereafter, a safe disposal. According to the Environmental Protection Agency, there are 20-50 million metric tons of waste electrical and electronic products generated worldwide every year, comprising more than 5 per cent of all municipal solid waste [1].

Relative profitability of processing returns being lesser in general, economics and control over product return is far more complicated than that of the forward flow. Contributing factors to this could be skewed ratio of capacity utilization of transport facility to the frequency of [1] availability requirement of the product. Another aspect could be uncertainty over the quality variations of the returned products. Due to this, all the products collected cannot be remanufactured or sometimes, more advanced operations are required for making the returned product resalable [2]. This will necessitate bringing the total cost down so as not to let it consume profit margin.

Researchers have established that well-managing reverse logistics network provides cost savings in procurement, recovery, disposal, inventory holding and transportation over and above helping in customer retention. Proper modelling could help reduce total reverse supply chain cost [6]. An increased thrust on environmental implications is also well documented [4]. Companies focus on remanufacturing and recovery activities, thereby achieving significant gains [5].

The returned products can be classified into a number of categories. In this paper, we consider two types of product returns: One that have come to end of economic use (which can be refurbished and can be resold into secondary market); and the other, that have reached end of life (to be safely disposed-off). A framework based on the economic value analysis concept has been suggested by [6].

A mathematical programming model with heuristic solution methodology for problem solving was proposed [7]. A genetic algorithm to design a reverse logistics network involving products returned was proposed by [8]. [9] Proposed a reverse distribution network design with the repairing and remanufacturing options.

Mixed-integer programming has been the most adopted modelling technique by researchers [1] [2] [10] [11] [12] [13] [14] [15] [16], focusing on varied components of supply chain like location-allocation of repair facilities with a TPL provider. Also, an integrated, multi echelon, multi period, multi-product mixed-integer linear programming model is suggested to optimise the distribution and inventory level for a closed loop supply chain network. These contributions take examples from different sectors like lead acid batteries, tumble driers, end-of-life vehicles, etc.

The review of the literature shows that there is a relative dearth of publications addressing development of a general framework for the network design, with most work in this area are limited to either a single type of product return (e.g. end-of-life) or a single type of recovery option (e.g. remanufacturing) [2].

## II. METHODOLOGY

Presented work examines key reverse supply chain constituents contributing to sector-specific network have been examined through industrial survey for both types of product returns: end-of-life; and end-of-economic use. Further, the determination of the number and location of different facilities like collection centres, remanufacturing centres, disassembly centres, recycling centres, disposal centres is demonstrated, through real-field data of returns-flow and transportation costs of the products, components and materials between each stage in the network and also for the intra-stage quantity-flow between facilities in the reverse supply chain.

## III. Reverse logistics constituents

In reverse logistics, it has been established that there are three fundamental stages of flow [17] [19] [20]:

1) Collection, 2) sort-test, where decisions like whether to recycle/dispose-off, or remanufacture for secondary market are taken, and 3) processing (Done at recycling or remanufacturing centers)

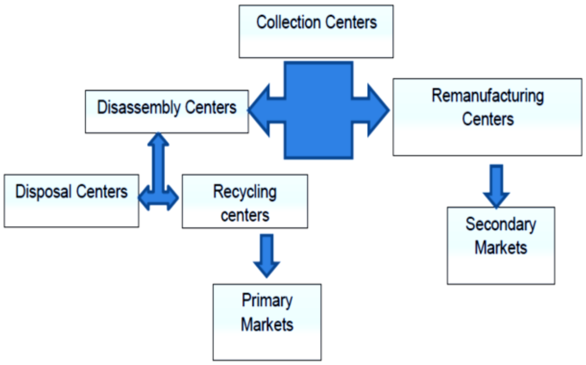


Figure 1. Reverse Logistics constituents

As [20] observes, companies need to choose how to collect recoverable products from their former users, where to inspect collected products in order to separate recoverable resources from worthless scrap, where to re-process collected products to remarket them, and further, how to distribute recovered/remanufactured products to primary/secondary customers.

For our case, the determination of the number and location of different facilities like collection centres, remanufacturing centres, disassembly centres, recycling centres, disposal centres for the reverse logistics of tire industries is demonstrated, along with the quantity of flow of products, components and materials between each stage to be established in the network and the quantity of flow of products, components and materials between each stage of the supply chain.

A reverse supply chain, existing in Haryana and NCR industrial zones, consisting of four market clusters, four locations for collection centres, three locations for remanufacturing centres, four locations for disassembly centres, three locations for recycling centres, one disposal centre, two secondary markets and two primary markets are considered. The problem involves the determination of the number and location of different facilities to be established in the network and the quantity of flow of products, components and materials between each stage of the supply chain. The objective minimises the total cost comprising of transportation cost, processing cost, fixed facility cost and disposal cost. The network is modelled (adapted from [2]) and optimized using mixed-integer linear programming formulation with minor customizations, that minimizes the total cost of the multi- stage reverse supply chain and further solved using solver Lingo.

## IV. Industrial Case and Input Data

A real reverse supply chain consisting of four market clusters, seven potential locations for collection centres, three potential locations for remanufacturing centres, four potential locations for disassembly centres, three potential locations for recycling centres, one disposal centre, two secondary markets and two primary markets are considered. The coordinates of the different facilities are generated by Google maps (not shown, used only for generating distance-matrix).

In Exhibits 1 through 8, flow, cost and distance data between existing facilities is shown. The quantity of used products available for collection at market clusters are shown in Exhibit I. Exhibit II shows the distance matrix between market clusters and collection centres.

Exhibit III shows the distance matrix of collection centres with disassembly centres and remanufacturing centres. Exhibit IV shows the distance matrix between remanufacturing centres and secondary markets.

Exhibit V shows the distance matrix of disassembly centres with recycling centres and disposal centre. Exhibit VI shows distance (in KM) between recycling centers and primary markets.

## V. Results and Discussions

The problem is solved for a realistic situation on the pre-modelled MILP formulation. Solution tables 1 through 6 (R-1 through R-6) show the values of optimized flow and locational decisions for facilities to carry out constituent activities. Also shown in R-1 is the optimized cost figures.

The application of the model to the real industrial scenario provides optimum decisions for the said industrial cluster, and can be applied to cluster of similar industries. Also, through some customizations, it can further be extended for other industrial domains engaged in reverse logistics activities.

## VI. Future Work

The proposed model is a general one and with the proper analysis of the results obtained, it helps to analyse the long-term operation of a reverse supply chain. Further, only a single product-variants, single-period situation has been considered, and it could be further extended by considering a multi-product, multi-period situation. The uncertainty in data can also be incorporated into the study as a future research.

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**Exhibit 1**: Unitized quantity of product returns (Unit time frame)

| Market clusters | Market cluster 1 | Market cluster 2 | Market cluster 3 | Market cluster 4 |
|---|---|---|---|---|
| Product returns | 66 | 51 | 39 | 44 |

**Exhibit 2**: Distance (in KM) between market clusters (using Google maps)

| Collection centers/ Market clusters | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 9.5 | 37 | 63 | 66 |
| 2 | 59 | 9 | 43 | 51 |
| 3 | 66.8 | 44 | 7.6 | 49 |
| 4 | 32 | 31 | 44 | 29.7 |

**Exhibit 3**: Distance (in KM) between market clusters and collection centres (using Google maps)

| Collection clusters/ Market clusters | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 6.6 | 49.8 | 71 | 61 |
| 2 | 54 | 9 | 44 | 42 |
| 3 | 81.5 | 57 | 9 | 55 |
| 4 | 26.6 | 31.2 | 66 | 37 |

**Exhibit 4**: Distance (in KM) of collection centres with disassembly centers and remanufacturing centers

| DAs/ Collection centres | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| DA 1 | 11 | 75 | 95 | 36 | 65 |
| DA 2 | 55 | 21 | 39 | 16 | 5 |
| DA 3 | 53 | 32 | 40 | 14 | 11 |
| DA 4 | 77 | 42 | 16 | 37 | 10 |
| RM 1 | 88 | 76 | 44 | 54 | 41 |
| RM 2 | 61 | 75 | 71 | 38 | 46 |
| RM3 | 97 | 73 | 30 | 60 | 40 |

**Exhibit 6**: Distance (in KM) between recycling centers and primary markets

| | Primary Market 1 | Primary Market 2 |
|---|---|---|
| RC 1 | 66 | 61 |
| RC 2 | 39 | 17 |
| RC 3 | 40 | 20 |

**Exhibit 5**: Distance (in KM) between remanufacturing centers and secondary markets

| | Secondary Market 1 | Secondary Market 2 |
|---|---|---|
| RM 1 | 45 | 35 |
| RM 2 | 14 | 39 |
| RM 3 | 58 | 36 |

**Exhibit 7**: Capacity, unit processing and fixed costs (in Rs. '000s) of collection centers

| | Collection centers | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Capacity (no. of units) | 76 | 102 | 88 | 98 | 79 |
| Fixed facility cost (in Rs. '000s) | 83 | 98 | 87 | 105 | 70 |
| Unit processing cost (in Rs. '000s) | 70 | 71 | 79 | 76 | 65 |

**Exhibit 8**: Capacity, unit processing and fixed costs (in Rs. '000s) of disassembly centers

| | Disassembly centers | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Capacity (no. of units) | 120 | 170 | 70 | 150 |
| Fixed facility cost (in Rs. '000s) | 200 | 190 | 150 | 165 |
| Unit processing cost (in Rs. '000s) | 186 | 195 | 190 | 182 |

## Results

**R- 1)** Cost components (in Rupee value) of the objective function

| Performance criteria | Value (in Rs. ) |
|---|---|
| Total cost | 6367442 |
| Total transportation cost | 239560 |
| Total fixed facility cost | 172356 |
| Total disposal cost | 22880 |
| Total processing cost | 154690 |

**R- 2)** Facilities opening decisions

| Type of facility | Decision (Open at locations) |
|---|---|
| Collection center | 1,2, 4,5 |
| Disassembly center | 1,2 |
| Remanufacturing center | 2 |
| Reycling center | 1,3 |

**R- 3)** Optimized flow from market clusters to CCs

| Market clusters/ Collection centers | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Market cluster 1 | 77 | 0 | 0 | 0 |
| Market cluster 2 | 0 | 67 | 0 | 0 |
| Market cluster 3 | 0 | 0 | 85 | 0 |
| Market cluster 4 | 0 | 0 | 0 | 52 |
| Market cluster 5 | 0 | 0 | 19 | 9 |

**R- 4)** Optimized flow from CCs to disassembly centers

| | Disassembly 1 | Disassembly 2 | Disassembly 3 | Disassembly 4 |
|---|---|---|---|---|
| CC 1 | 81 | 0 | 0 | 0 |
| CC 2 | 0 | 50 | 0 | 0 |
| CC 3 | 0 | 56 | 0 | 0 |
| CC 4 | 39 | 4 | 0 | 0 |
| CC 5 | 0 | 49 | 0 | 0 |

**R- 5)** Optimized flow from collection centers to remanufacturing centers

| | Remanufacturing 1 | Remanufacturing 2 | Remanufacturing 3 |
|---|---|---|---|
| CC 1 | 0 | 0 | 0 |
| CC 2 | 0 | 22 | 0 |
| CC 3 | 0 | 37 | 0 |
| CC 4 | 0 | 18 | 0 |
| CC 5 | 0 | 21 | 0 |

**R- 6)** Optimized flow from remanufacturing centers to secondary markets

| | Secondary Market 1 | Secondary Market 2 |
|---|---|---|
| RC 1 | 0 | 0 |
| RC 2 | 0 | 69 |
| RC 3 | 0 | 0 |