# Optimization Model of Remanufacturing Reverse Logistics Network Based on the Impact of Green Environment Protection and Carbon Tax

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**Abstract.** With economic development, human development of resources intensifies, leading to natural resource tension and environmental problems. As an important part of the remanufacturing industry, the reverse logistics network has a significant impact on helping enterprises reduce the cost of each transportation link and reduce energy loss. This paper proposes a mixed-integer linear programming model based on the optimization of the existing remanufacturing reverse logistics network, with the aim of minimizing the sum of the investment in remanufacturing logistics sites, operating costs, and transportation costs in each link.

**Keywords:** Reverse logistics, carbon tax, MILP modeling.

## 1. Introduction

With the rapid development of science and technology, the speed of replacement is accelerated, the products that are eliminated and discarded by the people are also more and more, which brings about a rapid increase in the output of waste materials[1]. As low carbon and environmental protection issues are getting more and more attention, the concept of green logistics has been put forward[2]. Remanufacturing is the process of turning end-of-life items into fully functional ones through recycling[3]. Since used products retain much of the value embedded in them at the time of initial production, remanufacturing is one of the key elements in realizing resource-efficient manufacturing and the circular economy[4]. But although China's remanufacturing industry is developing rapidly and has great potential, it should also be noted that the foundation of China's remanufacturing industry is relatively weak and the industrial chain is not mature enough[5, 6].

Remanufacturing logistics includes the reverse logistics of transporting waste products from the place of consumption back to the place of production and the forward logistics of transporting remanufactured products from the place of production to the place of consumption, which involves the collection, testing and classification of waste products, waste treatment, remanufacturing, redistribution and so on, and is a kind of closed-loop logistics system, and in accordance with the implementation of the current carbon Consider adding a carbon tax as a variable in light of the implementation of the current carbon reduction policy.[7]. In traditional production and distribution logistics management, cost is an important variable in business operations[8], And logistics network design is of strategic importance. Similarly, the rationality of logistics network design fundamentally determines the efficiency and effectiveness of remanufacturing logistics management.

This paper proposes a MILP model for the optimal design of a remanufacturing logistics network, which takes into account four levels of recycling facilities: testing centers, reprocessing plants, distribution centers, and waste recycling stations, and introduces the variable of carbon tax.[9, 10]. As a result, there is a high degree of generalizability.

## 2. Fundamentals of Reverse Logistics Modeling for Remanufacturing

### 2.1. Structure of the remanufacturing reverse logistics model

The reverse logistics is from a number of consumers to send the used products back to the distribution center and the testing center, where the waste materials can be examined for recyclability, and the non-recyclable waste materials are transported to the corresponding waste disposal station of the waste materials, and the materials that can be reused twice are transported to the original factory or to the new remanufacturing The reusable materials are shipped to the original factory or the newly built remanufacturing factory. The network structure is shown in Figure 1.

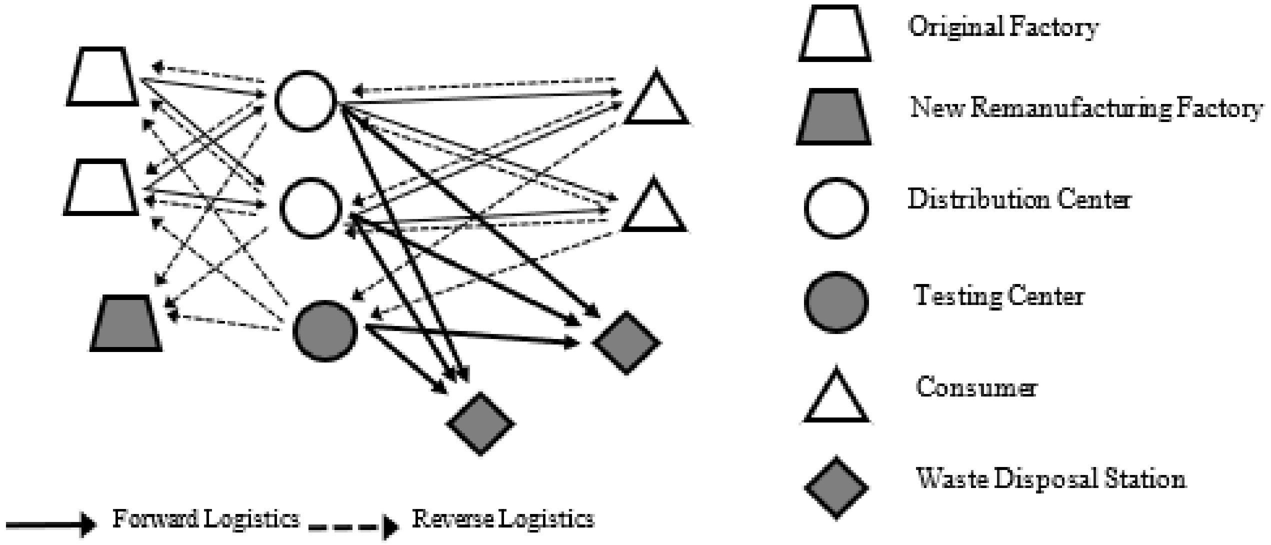

**Figure 1.** Reverse logistics network structure for remanufacturing

For the purpose of the model, the following assumptions are made: (1) only one type of waste product is recycled, and the amount of waste product recycled, the processing capacity of the various facilities, as well as the investment and operating costs, and the transportation costs between the facilities are known with certainty; and (2) new remanufacturing factories or testing centers are considered only in a number of alternative locations with known geographic locations;

### 2.2. Description of symbols

$I=I', I''$,$I'$,Indicates a new testing center,$I''$,Indicates original distribution center,$i\in I$;
$J=J', J'', J'$,Indicates a new remanufacturing plant,$J''$,Indicates original manufacturer,$j\in J$;
H,Indicates a collection of waste disposal station areas, $h\in H$.
K,Represents the set of regions where consumers are located, $k\in K$.

**Table 1.** Symbol description

| Notation | Meanings | Unit of measure |
|---|---|---|
| $X_{ki}$ | Transportation from region K to region I | t |
| $X_{ij}$ | Transportation from region I to region J | t |
| $X_{ih}$ | Transportation from region I to region H | t |
| $Y_i$ | Whether to select region I | Yes,1,No,0 |
| $Y_j$ | Whether to select region J | Yes,1,No,0 |
| $Y_h$ | Whether to select region H | Yes,1,No,0 |
| $TC_{ki}$ | Unit transportation costs from region K to region I | CNY/t |
| $TC_{ij}$ | Unit transportation costs from region I to region J | CNY/t |
| $TC_{ih}$ | Unit transportation costs from region I to region H | CNY/t |
| $OC_i$ | Operating costs per unit in Region I | CNY |
| $OC_j$ | Operating costs per unit in Region J | CNY |
| $OC_h$ | Operating costs per unit in Region H | CNY |
| $FC_i$ | Fixed costs of new construction or expansion in Region I | CNY |
| $FC_j$ | Fixed costs of new construction or expansion in Region J | CNY |
| $FC_h$ | Fixed costs of new construction or expansion in Region H | CNY |
| $P_i$ | Region I Energy consumption per unit of product treated | kWh/t |
| $P_j$ | Region J Energy consumption per unit of product treated | kWh/t |
| $P_h$ | Region H Energy consumption per unit of product treated | kWh/t |
| $R_i$ | Fixed Energy Consumption for New Construction or Expansion in Region I | MWh |
| $R_j$ | Fixed Energy Consumption for New Construction or Expansion in Region J | MWh |
| $R_h$ | Fixed Energy Consumption for New Construction or Expansion in Region H | MWh |
| $A_k$ | Total amount of product recovered in Region K | t |
| $\mu$ | Carbon emission factor for in-plant energy consumption( t·$CO_2$ /MWh) | t·$CO_2$/MWh |
| $\lambda$ | Carbon tax coefficient | CNY/t·$CO_2$ |
| $U_i$ | Maximum capacity of Area I for material handling | t |
| $L_i$ | Minimum capacity of Area I for material handling | t |
| $U_j$ | Minimum capacity of Area I for material handling | t |
| $L_j$ | Maximum capacity of Area I for material handling | t |
| $U_h$ | Minimum capacity of Area I for material handling | t |
| $L_h$ | Maximum capacity of Area I for material handling | t |
| $ZI$ | Maximum number of new testing centers in Region I | pcs |
| $ZJ$ | Maximum number of new remanufacturing plants in Region J | pcs |
| $ZH$ | Maximum number of new waste recycling stations in Region H | pcs |

The parameters and notation in this paper are presented in Table 1.The remanufacturing reverse logistics model is as follows:

$$\min Z = \sum_{k\in K}\sum_{i\in I} TC_{ki}X_{ki} + \sum_{i\in I}\sum_{j\in J} TC_{ij}X_{ij} + \sum_{i\in I}\sum_{h\in H} TC_{ih}X_{ih} + \sum_{i\in I}\sum_{k\in K} OC_i X_{ki} +$$

$$\sum_{j\in J}\sum_{i\in I} OC_j X_{ij} + \sum_{h\in H}\sum_{i\in I} OC_h X_{ih} + \sum_{i\in I} FC_i Y_i + \sum_{j\in J} FC_j Y_j + \sum_{h\in H} FC_h Y_h +$$

$$\lambda\mu(\sum_{i\in I}\sum_{k\in K}P_i X_{ki}+\sum_{j\in J}\sum_{i\in I}P_j X_{ij}+\sum_{h\in H}\sum_{i\in I}P_h X_{ih}+\sum_{i\in I}R_i G_i+ \sum_{j\in J}R_j G_j+\sum_{h\in H}R_h G_h) \tag{1}$$

$$\text{s.t. } \sum_{i\in I}X_{ki}=A_k \tag{2}$$

$$\sum_{k\in K}X_{ki}=\sum_{j\in J}X_{ij}+\sum_{h\in H}X_{ih} \quad (i\in I) \tag{3}$$

$$\sum_{k\in K}X_{ki}\le U_iY_i \quad (i\in I) \tag{4}$$

$$\sum_{k\in K}X_{ki}\ge L_iY_i \quad (i\in I) \tag{5}$$

$$\sum_{i\in I}X_{ij}\le U_jY_j \quad (j\in J) \tag{6}$$

$$\sum_{i\in I}X_{ij}\ge L_jY_j \quad (j\in J) \tag{7}$$

$$\sum_{i\in I}X_{ih}\le U_hY_h \tag{8}$$

$$\sum_{i\in I}X_{ih}\ge L_hY_h \tag{9}$$

$$\sum_{i\in I'}Y_i\le ZI \tag{10}$$

$$\sum_{j\in J'}Y_j\le ZJ \tag{11}$$

$$\sum_{h\in H}Y_h\le ZH \tag{12}$$

$$X_{ki},X_{ij},X_{ih}\ge 0 \quad (k\in K,i\in I,j\in J,h\in H) \tag{13}$$

$$Y_i,Y_j,Y_h\in\{0,1\} \tag{14}$$

(1)is the objective function and the constraints,(2)(3)describes the conservation of physical quantities,(4)—(9)describes the operating capacity constraints of plant equipment,(10)—(12)describes constraints for new sites,(13)(14)specifies a range of values for the variable. $\lambda$=60,$\mu$=0.8044.

The above model is a MILP model that can be solved using specialized software for solving linear programming problems, such as LINDO 18.0.

## 3. Results

### 3.1. The establishment of simulation model

A remanufacturing logistics network based on a production and distribution logistics network is being considered for the recovery of a used product. The network has nine recycling sites (consumer areas), seven alternative sites for testing centers, and four sites for scrap processing stations. It is assumed that the recycling rate of the scrap is 80% (80% of the recycled material can be used for remanufacturing, with the remaining 20% going to the scrap manufacturing station).Other proposed parameters are shown in Table 2-14

**Table 2.** Volume of used products recovered at recycling points($A_k$)

| Recovery point | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | $K_7$ | $K_8$ | $K_9$ |
|---|---|---|---|---|---|---|---|---|---|
| $A_k$ | 30 | 10 | 40 | 80 | 50 | 60 | 20 | 70 | 90 |

**Table 3.** Minimum treatment capacity of used products in each testing center($L_i$) and maximum processing capacity($U_i$)

| Processing capability | Testing center | | | | | | |
|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ | $I_7$ |
| $L_i$ | 45 | 60 | 110 | 50 | 135 | 70 | 90 |
| $U_i$ | 60 | 110 | 165 | 90 | 160 | 120 | 145 |

**Table 4.** Minimum treatment capacity of used products in each testing center($L_j$)and maximum processing capacity($U_j$)

| Processing capability | Factory | | | |
|---|---|---|---|---|
| | $J_1$ | $J_2$ | $J_3$ | $J_4$ |
| $L_j$ | 40 | 60 | 155 | 180 |
| $U_j$ | 85 | 95 | 225 | 250 |

**Table 5.** Minimum capacity of each waste treatment station for used and end-of-life products($L_h$) and maximum processing capacity($U_h$)

| Processing capability | Waste disposal station | | | |
|---|---|---|---|---|
| | $H_1$ | $H_2$ | $H$ | $H_4$ |
| $L_h$ | 90 | 125 | 155 | 140 |
| $U_h$ | 155 | 205 | 250 | 200 |

**Table 6.** Unit Transportation Costs from Recycling Points to Testing Centers($TC_{ki}$)

| Testing center | Recycling station | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | $K_7$ | $K_8$ | $K_9$ |
| $I_1$ | 7 | 27 | 50 | 32 | 41 | 59 | 39 | 22 | 30 |
| $I_2$ | 10 | 10 | 37 | 29 | 23 | 10 | 44 | 7 | 24 |
| $I_3$ | 47 | 7 | 27 | 49 | 51 | 12 | 24 | 22 | 13 |
| $I_4$ | 56 | 27 | 44 | 22 | 34 | 23 | 19 | 17 | 8 |
| $I_5$ | 10 | 33 | 43 | 23 | 49 | 9 | 23 | 46 | 38 |
| $I_6$ | 49 | 18 | 12 | 30 | 52 | 34 | 56 | 37 | 54 |
| $I_7$ | 56 | 20 | 18 | 48 | 14 | 53 | 17 | 53 | 12 |

**Table 7.** Unit transportation cost from testing center to factory($TC_{ij}$)

| Factory | Testing center | | | | | | |
|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ | $I_7$ |
| $J_1$ | 21 | 18 | 11 | 39 | 14 | 21 | 9 |
| $J_2$ | 6 | 29 | 37 | 38 | 35 | 7 | 45 |
| $J_3$ | 26 | 38 | 9 | 14 | 24 | 37 | 26 |
| $J_4$ | 5 | 14 | 14 | 9 | 33 | 48 | 24 |

**Table 8.** Unit transportation costs from testing centers to waste disposal stations($TC_{ih}$)

| Waste disposal station | Testing center | | | | | | |
|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ | $I_7$ |
| $H_1$ | 9 | 17 | 7 | 13 | 14 | 27 | 27 |
| $H_2$ | 20 | 14 | 27 | 15 | 11 | 9 | 7 |
| $H_3$ | 11 | 21 | 9 | 21 | 6 | 21 | 25 |
| $H_4$ | 25 | 19 | 17 | 12 | 18 | 15 | 18 |

**Table 9.** Fixed investment in testing centers($FC_i$)and unit operating costs($OC_i$)

| Costs | Testing center | | | | | | |
|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ | $I_7$ |
| $FC_i$ | 100000 | 140000 | 120000 | 100000 | 130000 | 110000 | 140000 |
| $OC_i$ | 21 | 35 | 24 | 33 | 29 | 31 | 27 |

**Table 10.** Fixed investment in remanufacturing plants($FC_j$)and unit operating costs($OC_j$)

| Costs | Factory | | | |
|---|---|---|---|---|
| | $J_1$ | $J_2$ | $J_3$ | $J_4$ |
| $FC_j$ | 410000 | 350000 | 270000 | 380000 |
| $OC_j$ | 72 | 89 | 83 | 79 |

**Table 11.** Fixed investment in waste treatment stations($FC_h$)and unit operating costs($OC_h$)

| Costs | Waste disposal station | | | |
|---|---|---|---|---|
| | $H_1$ | $H_2$ | $H$ | $H_4$ |
| $FC_h$ | 40000 | 60000 | 35000 | 55000 |
| $OC_h$ | 37 | 21 | 49 | 31 |

**Table 12.** Energy consumption per unit product processed in testing centers($P_i$)and fixed energy consumption($R_i$)

| Energy consumption | Testing center | | | | | | |
|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ | $I_7$ |
| $P_i$ | 6 | 12 | 14 | 7 | 10 | 7 | 12 |
| $R_i$ | 21 | 16 | 37 | 29 | 29 | 31 | 27 |

**Table 13.** Factory energy consumption per unit of product treated($P_j$)and fixed energy consumption($R_j$)

| Energy consumption | Factory | | | |
|---|---|---|---|---|
| | $J_1$ | $J_2$ | $J_3$ | $J_4$ |
| $P_j$ | 24 | 36 | 29 | 42 |
| $R_j$ | 49 | 32 | 48 | 53 |

**Table 14.** Energy consumption per unit of product treated at waste treatment stations($P_h$)and fixed energy consumption($R_h$)

| Energy consumption | Waste disposal station | | | |
|---|---|---|---|---|
| | $H_1$ | $H_2$ | $H_3$ | $H_4$ |
| $P_h$ | 7 | 3 | 5 | 9 |
| $R_h$ | 12 | 19 | 16 | 13 |

### 3.2. Analysis of experimental results

The solution was performed using LINDO 18.0 and the results are shown in Tables 15-17

**Table 15.** Transportation from recycling sites to testing centers($X_{ki}$)

| Testing center | Recycling station | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | $K_7$ | $K_8$ | $K_9$ |
| $I_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $I_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $I_3$ | 0 | 10 | 0 | 0 | 0 | 10 | 0 | 70 | 55 |
| $I_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $I_5$ | 30 | 0 | 0 | 80 | 0 | 50 | 0 | 0 | 0 |
| $I_6$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $I_7$ | 0 | 0 | 40 | 0 | 50 | 0 | 20 | 0 | 35 |

**Table 16.** Transportation from testing centers to factories($X_{ij}$)

| Factory | Testing center | | | | | | |
|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ | $I_7$ |
| $J_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $J_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $J_3$ | 0 | 0 | 52 | 0 | 128 | 0 | 0 |
| $J_4$ | 0 | 0 | 64 | 0 | 0 | 0 | 116 |

**Table 17.** Transportation from testing centers to waste disposal stations($X_{ih}$)

| Waste disposal station | Testing center | | | | | | |
|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ | $I_7$ |
| $H_1$ | 0 | 0 | 29 | 0 | 32 | 0 | 29 |
| $H_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $H_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $H_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The total cost is calculated to be 2056734 RMB.

## 4. Conclusions

This paper proposes a MILP model for the optimal design of remanufacturing logistics network based on the traditional production and distribution logistics network, in which four levels of recycling and processing facilities, namely, testing center, reprocessing plant, distribution center and waste recycling station, plus a new variable, carbon tax, are taken into account in the model. Thus, it is highly generalizable. Further research will consider the integrated design of remanufacturing logistics networks and traditional production and distribution logistics networks. In addition, the remanufacturing logistics system has a high degree of uncertainty. Thus further research will also address the optimal design of the remanufacturing logistics network in an uncertain environment.

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