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Optimization Model of Closed-loop Logistics Distribution Network with Double-channel Collection Inspection

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Abstract

With the coexistence of two channels, the operation among collecters, remanufacturers and wholesalers in the closed-loop logistics distribution network system is facing new challenges. At the same time, there are some problems such as the quality difference of collection inspection. In this case, considering the change of the quality difference of the double-channel collection inspection, a closed-loop logistics distribution network optimization model is constructed, aiming at maximizing the total operating income, and LINGO11.0 is applied to solve the problem, and the optimal transportation scheme and profit of supply chain members are given. By solving the model, the influence of the quality difference of collection inspection on the profit of supply chain members is further analyzed. The given model can choose a reasonable channel for the flow of used products, and effectively solve the operation optimization problems of collecters, remanufacturers and wholesalers.

Keywords

Quality Difference of Recovery Test; Closed Loop Logistics Network Model; Network Optimization Model.

1. Introduction

With the increasing number of used products and the development of science and technology, enterprises at home and abroad are faced with the problem of recycling and selling used products, and the collection of used products is not limited to offline recycling points. Therefore, there are new challenges in the research of the distribution model of double-channel closed-loop logistics network with collection inspection error. In the research of closed-loop logistics distribution network, Xie et al.(2008) constructed a single-cycle closed-loop supply chain network location model which comprehensively considered raw material suppliers, producers, recycling centers, reverse warehouses and remanufacturers[1]. Ma et al.(2008) considered the incentive system of deposit return, built a closed-loop logistics distribution network model and obtained the position of the payback when the profit was maximum[2]. Zhou et al.(2010) constructed a closed-loop supply chain network equilibrium model composed of manufacturers, retailers, consumers and recycling companies, and considered the form of online transactions, and discussed the independent behaviors and interactions of decision makers at all levels in the network and the conditions for reaching equilibrium [3]. Fan et al.(2011) based on the game theory, built a decision-making model of used product recycling outsourcing with or without incentive factors, and got the conclusion that for used product recycling outsourcing, the introduction of incentive factors will help improve the recycling efficiency of used products and increase the income of manufacturers [4]. Shao et al.(2011) adopted the recycling model of MT-CLSC, established a profit model of two-level remanufacturing closed-loop supply chain, and analyzed the changes of supply chain members' profits. Finally, the critical value of the government's minimum recycling constraint was given [5].Guo et al. (2013) built a closed-loop supply chain system

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network optimization model with the dual objectives of minimizing the cost and environmental pollution, and used random opportunity constraint and fuzzy expected value method to optimize and solve the problem of transforming the uncertain model into an equivalent deterministic model [6]. Aiming at the recycling and sales of used products, Sun et al.(2013) have constructed the recycling quantity function related to both the sales quantity and the recycling price, aiming at the shortcomings of the existing recycling quantity function of closed-loop supply chain, and analyzed the optimal decision-making problem of members in the supply chain [7]. Xu (2013) built a decision-making model of closed-loop supply chain by using game theory, and reached the conclusion that government recycling and remanufacturing subsidies can promote enterprises to raise the recycling price, improve the recycling amount and rate of used products, and the closed-loop supply chain and the target income of all parties [8]. Sun et al.(2014) used the game theory as the research method to investigate the closed-loop supply chain model of electronic product manufacturers under the leadership of network and entity sales channels and the third party responsible for recycling, and made a comparative analysis, thus realizing the coordination of the system [9]. Xia et al.(2021) built a game model of collecters and processors under different government subsidy strategies based on two kinds of recycling modes through game theory, and came to the conclusion that under the government subsidy, double-channel recycling will gain greater profits [10].

2. Problem Description

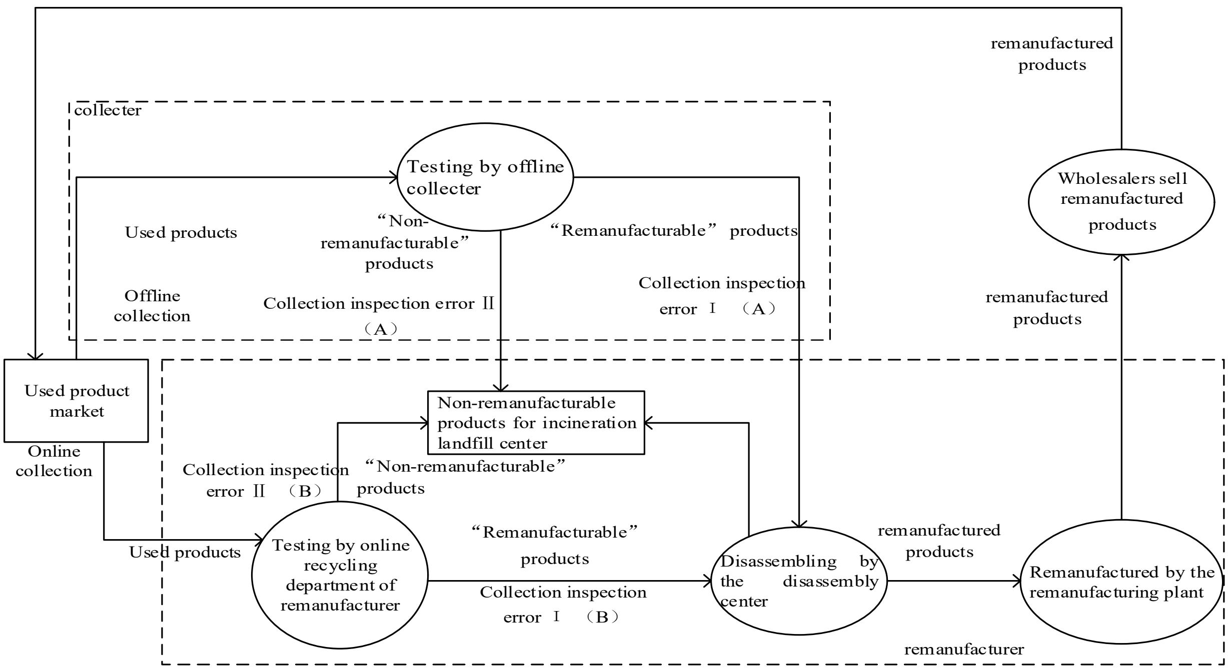

Figure 1. Conceptual Framework of Closed-loop Logistics Distribution Network with Double-channel Collection Inspection

The conceptual framework of the closed-loop logistics distribution network for the dual channel recycling detection of used products, see Figure 1 (A refers to traditional channel, B refers to online channel), and the closed-loop logistics distribution network for the dual channel recycling detection, see Figure 2. Among them, there are three members, collecters, wholesalers and remanufacturers. The used products are composed of the used products submitted by consumers at offline recycling points in the used product market and the used products recovered by online recycling and disposal departments. The online inspection and disposal departments of collecters and remanufacturers are responsible for collection the used products from consumers and conducting inspection. The tested "remanufactured products" are handed over to the disassembly center for disassembly, and the "non remanufactured products" are discarded. The disassembly center disassembles the "remanufactured

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products", after which the truly remanufactured products are transported to the remanufacturing factory for remanufacturing, and the products that cannot be remanufactured are discarded. Finally, the remanufacturer will ship the remanufactured products to the wholesaler and the wholesaler will be responsible for selling them back to the used product market.

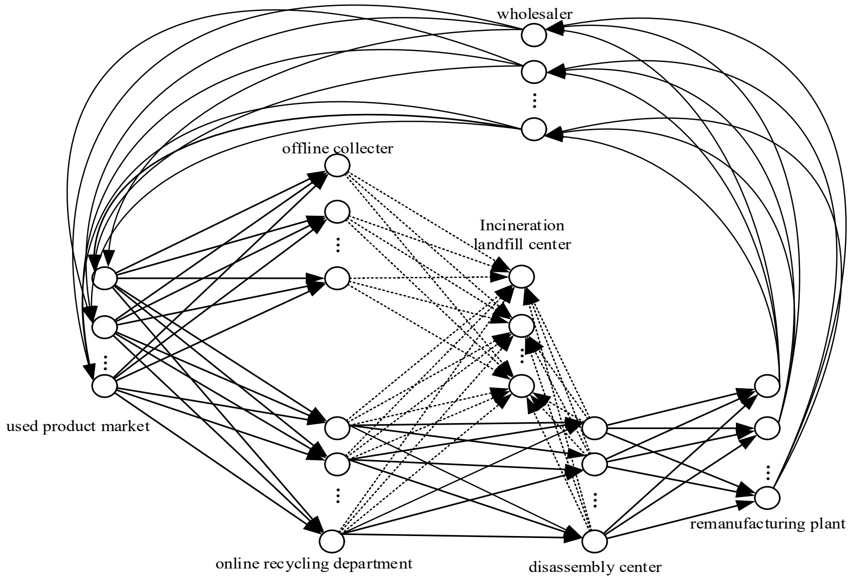

Figure 2. Closed-loop Logistics Distribution Network of Double-channel Collection Inspection

3. Model Building

3.1 Symbol Description

The sets, parameters and decision variables involved in this model are described below.

(1) Sets

l is the set of used product market;i is the set of disassembly centers;j is the set of remanufacturing plants;m is the set of offline collecters;n is the set of departments for online recycling;y is the set of incineration and landfill centers;t is the set of wholesalers.

(2) Parameters

L_n is the demand of used product market for remanufactured products;

α_m is the collection inspection error rate of the offline collecters m who mistakenly checks the non-remanufacturable used products as "remanufacturable products" and delivers them to the disassembly centers;

β_m is the collection inspection error rate of the offline collecter m who mistakenly checks the remanufacturable products as "non-remanufacturable products";

γ_m is the maximum remanufacturability of all used products transported by the offline collecters;

δ_m is the probability that the used products that can be disassembled in the offline channel will go to the remanufacturing plants;

α_n is the collection inspection error rate that the online recycling department n mistakenly checks the non- remanufacturable used products as "remanufacturable products" and sends them to the disassembly centers;

β_n is the collection inspection error rate that the department for online recycling n mistakenly checks the remanufacturable products as "non-remanufacturable products";

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γ_n is the maximum remanufacturability of all used products transported by the online recycling department n;

δ_m is the proportion of used products that can be disassembled from offline channel going to the remanufacturing plants, δ_n is the proportion of used products that can be disassembled from online channel to remanufacturing plants;

C_{lm} is the unit transportation cost from used product market l to offline collecter m;C_{mi} is the unit transportation cost from offline collecter m to disassembly center i;C_{ij} is the unit transportation cost from disassembly center i to remanufacturing plant j;C_{ln} is the unit transportation cost from the used product market l to the online recycling department n;C_{ni} is the unit transportation cost from the online recycling department n to the disassembly center i;C_{my} is the unit transportation cost from offline collecter m to incineration and landfill center y;C_{ny} is the unit transportation cost from online recycling department n to incineration and landfill center y; C_{iy} is the unit transportation cost from the disassembly center i to the incineration and landfill center y;C_l is the unit cost of each piece of used product recovered from the used product market;C_j is the unit cost of each remanufactured product obtained by the wholesalers from the remanufacturers;C_m is the unit cost of "remanufacturable products" obtained by the remanufacturers from the collecters;P_t is the unit price of new products sold by wholesalers;D_{lm} is the distance from used product market l to offline collecter m; D_{mi} is the distance from offline collecter m to disassembly center i; D_{ij} is the distance from disassembly center i to remanufacturing plant j; D_{ln} is the distance from the used product market l to the online recycling department n; D_{ni} is the distance from the online recycling department n to the disassembly center i; D_{my} is the distance from offline collecter m to incineration landfill center y; D_{ny} is the distance from online recycling department n to incineration landfill center y; D_{iy} is the distance from the disassembly center to the incineration and landfill center; D_{jt} is the distance from remanufacturer j to wholesaler t.

(3) Decision Variables

X_{lm} is the quantity of used products transported from the used product market l to the offline collecter m; X_{mi} is the quantity of "remanufacturable products" delivered by offline collecter m to disassembly center i; X_{ij} is the quantity of remanufactured product transported by the disassembly center i to the remanufacturing plant j; X_{ln} is the quantity of used products transported to the online recycling department n from the used product market l; X_{ni} is the quantity of "remanufacturable products" transported by the online recycling department n to the disassembly center i; X_{my} is the quantity of "non-remanufacturable products" transported by offline collecter m to incineration and landfill center y; X_{ny} is the quantity of "non-remanufacturable products" transported by online recycling department n to incineration and landfill center y; X_{jy} is the quantity of non-remanufactured products transported from the disassembly center j to the incineration and landfill center y; X_{jt} is the quantity of new products after remanufacturing transported by the remanufacturers to the wholesales; X_t is the quantity of new products after remanufacturing sold by wholesalers; X_l is the quantity of used products to be dealed; X_j is the quantity of remanufactured products traded by remanufacturers to wholesalers; X_m is the quantity of "remanufacturable products" traded by collecters to remanufacturers.

3.2 Model

According to the relevant symbols of the remanufacturing closed-loop logistics network structure of the double channel collection inspection, the following model is obtained.

The objective function as follows:

$$\max \pi = \sum_{t\epsilon T} X_t P_t - \left(\sum_{l\epsilon L} C_l X_l + \sum_{m\in M} C_m X_m + \sum_{j\in J} C_j X_j\right) -$$

$$(\sum_{l\in L}\sum_{m\in M}X_{lm}\,C_{lm}D_{lm}+\sum_{n\in N}\sum_{l\in L}X_{nl}\,C_{nl}D_{nl}+\sum_{m\in M}\sum_{i\in I}X_{mi}\,C_{mi}D_{mi}\sum_{i\in I}\sum_{l\in L}X_{il}C_{il}D_{il}) \quad (1)$$
$$-\left(\sum_{m\in M}\sum_{y\in Y}X_{my}\,C_{my}D_{my}+\sum_{n\in N}\sum_{y\in Y}X_{ny}\,C_{ny}D_{ny}+\sum_{j\in J}\sum_{t\in T}X_{jt}\,C_{jt}D_{jt}\right)$$
$$-\left(\sum_{m\in M}\sum_{y\in Y}X_{my}\,C_{my}D_{my}+\sum_{n\in N}\sum_{y\in Y}X_{ny}\,C_{ny}D_{ny}+\sum_{j\in J}\sum_{t\in T}X_{jt}\,C_{jt}D_{jt}\right)$$

$$Z_m=\sum_{m\epsilon M}X_m\,C_m-\sum_{l\epsilon L}\sum_{m\epsilon M}X_{lm}\,C_l-\sum_{m\epsilon M}\sum_{i\epsilon I}X_{mi}\,C_{mi}D_{mi}-\sum_{i\epsilon I}\sum_{y\epsilon Y}X_{iy}\,C_{iy}D_{iy} \quad (2)$$

$$Z_j=X_jC_j-X_{ln}C_l-X_{ny}C_{ny}D_{ny}-X_{ni}C_{ni}D_{ni}-X_{ij}C_{ij}D_{ij}-X_{iy}C_{iy}D_{iy}-X_{jt}C_{jt}D_{jt} \quad (3)$$

$$Z_t=\sum_{t\epsilon T}X_t\,P_t-\sum_{j\epsilon J}X_j\,C_j-\sum_{t\epsilon T}\sum_{l\epsilon L}X_{tl}C_{tl}D_{tl} \quad (4)$$

Among them, (1) is the objective function of total profit, (2) is the profit function of the collecter, (3) is the profit function of the remanufacturer, and (4) is the profit function of the wholesaler. The constraints on the used product market, wholesalers, offline collecters, online recycling departments, disassembly centers and remanufacturers are as follows.

Constraints on used product market l as follows:

$$X_l{=}X_{lm}+X_{ln}\;\;\forall l\in L \quad (5)$$

$$\sum_{n\epsilon N}X_{nl}\le L_n\;\;\;\forall l\epsilon L \quad (6)$$

Formula (5) indicates that the used products to be dealed in double channel are equal to the used products in online channel plus the used products in offline channel. Formula (6) indicates that the transportation volume from wholesalers to the used product market shall not be greater than the demand for remanufactured products in the used product market.

Constraints on wholesale t as follows:

$$X_t=\sum_{j\epsilon J}X_{tj}\quad\forall t\in T \quad (7)$$

Formula (7) indicates that the quantity of remanufactured products received by the wholesaler is equal to the quantity of remanufactured products transported to the wholesaler by the remanufacturer.

Constraints on offline collecter m as follows:

$$\sum_{l\in L}X_{lm}=X_m\;\;\forall m\in M \quad (8)$$

$$\sum_{\forall i\in I}X_{mi}=[(1-\beta_m)\gamma_mX_{li}+\alpha_m(1-\gamma_m)]X_m\;\;\;\forall m\in M \quad (9)$$

$$\sum_{y\in Y}X_{my}=[\beta_m\gamma_mX_{lm}+(1-\alpha_m)(1-\gamma_m)X_m\;\;\forall m\in M \quad (10)$$

$$\sum_{l\in L}X_{lm}\le MP_m\;\;\forall m\in M \quad (11)$$

Equation (8) indicates that the used products received by the offline collecter from the used product market are equal to the total number of used products to be recycled and tested by the offline collecter; Equation (9) indicates that the quantity of remanufacturable products by offline collecters to all

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disassembly centers is equal to the quantity of "remanufacturable products" after inspection; Formula (10) indicates that the quantity of non-remanufactured products transported by offline collecters to all incineration and landfill centers is equal to the quantity of "non-remanufactured products" after inspection; Equation (11) indicates that the quantity of used products transported to offline collecters in the used product market cannot exceed the maximum detection capacity of offline collecters.

Constraints on the online recycling department n as follows:

$$\sum_{l\in L} X_{ln} = X_n \quad \forall n\epsilon N \tag{12}$$

$$\sum_{j\in J} X_{nj} = [(1-\beta_n)\gamma_n + \alpha_n(1-\gamma_n)]X_n \quad \forall n\epsilon N \tag{13}$$

$$\sum_{y\in Y} X_{ny} = [\beta_n\gamma_n + (1-\alpha_n)(1-\gamma_n)]X_n \quad \forall n\epsilon N \tag{14}$$

$$\sum_{l\in L} X_{ln} \le MP_n \quad \forall n\epsilon N \tag{15}$$

Equation (12) indicates that the quantity of used products transported to the online recycling department is equal to the total quantity of used products to be disposed in the online recycling department; Equation (13) indicates that the quantity of remanufacturable products transported by the online recycling department to all disassembly centers is equal to the quantity of "remanufacturable products" after inspection; Equation (14) indicates that the quantity of "non-remanufacturable products" transported by the online recycling department to all incineration and landfill centers is equal to the quantity of non-remanufacturable products after inspection; Equation (15) indicates that the quantity of used products transported to the online recycling department cannot exceed the maximum detection capacity of offline collecters.

Constraints on disassembly center i as follows:

$$X_i = \sum_{m\epsilon M} X_{mi} + \sum_{n\epsilon N} X_{ni} \quad \forall i\epsilon I \tag{16}$$

$$X_i = \sum_{j\in J} X_{ij} + \sum_{y\epsilon Y} X_{iy} \quad \forall i\epsilon I \tag{17}$$

$$\sum_{j\epsilon J} X_{ij} = \delta_m \sum_{m\epsilon M} X_m\delta_m(1-\beta_m) + \delta_n \sum_{n\epsilon N} X_n\delta_n(1-\beta_n) \quad \forall i \in I \tag{18}$$

$$\sum_{y\epsilon Y} X_{iy} = \sum_{m\epsilon M} X_m(1-\gamma_m)\alpha_m + (1-\delta_m)\sum_{m\epsilon M} X_m\gamma_m(1-\beta_m) + \sum_{n\epsilon N} X_n(1-\gamma_n)\alpha_n + (1-\delta_n)\sum_{n\epsilon N} X_n\gamma_n(1-\beta_n) \quad \forall i\epsilon I \tag{19}$$

$$X_i \le MP_i \quad \forall i\epsilon I \tag{20}$$

Equation (16) indicates that the quantity of used products accepted by the disassembly center is equal to the sum of used products transported to the disassembly center by offline collecter and online recycling department; Equation (17) indicates that the sum of remanufactured products transported by the disassembly center to the remanufacturing plant and non-remanufactured products transported to the incineration and landfill center is equal to the quantity of remanufactured products received by the disassembly center; Equation (18) indicates that the quantity of remanufactured products transported to the remanufacturing plant through double channels is equal to the proportion of used products that can be disassembled in offline channel to the remanufacturing plant multiplied by the quantity of used products that can be remanufactured under the inspection error rate of offline collecter; Equation (19) indicates that the quantity of used products transported from the double channel disassembly center to the incineration and landfill center is equal to the sum of the quantity of non-remanufacturable products incorrectly detected as remanufacturable products and the quantity that cannot be disassembled through the disassembly center; Equation (20) indicates that the maximum quantity of "remanufacturable products" accepted by the disassembly center cannot exceed the maximum processing capacity of the disassembly center.

Constraints on remanufacturing factory j as follows:

$$\sum_{i\epsilon I} X_{ij} \leq MP_j \tag{21}$$

$$X_j = \sum_{i\epsilon I} X_{ij} \tag{22}$$

$$X_j = \sum_{t\epsilon T} X_{jt} \tag{23}$$

Equation (21) indicates that the transportation volume from the disassembly center to the remanufacturing plant shall not exceed the maximum collection capacity of the remanufacturing plant; Equation (22) indicates that the total quantity of remanufactured products transported by the disassembly center to the remanufacturing plant; Equation (23) indicates that the remanufactured products received by the wholesaler are equal to the remanufactured products received by the remanufacturer.

4. Numerical Example

4.1 Related Parameter Settings

In the model, it is assumed that there are 4 used product markets, 3 offline collecters, 3 online recycling departments, 3 disassembly centers, 2 remanufacturing plants, 1 incineration landfill center and 3 wholesalers.

The maximum collection/inspection/processing capacity of each node is in pieces, and the unit transportation cost is yuan/km. The relevant parameters are set as follows: there are 12000 pieces of waste products in used product markets; The maximum collection inspection capacity of offline collecters is 10000, the maximum collection inspection capacity of online recycling departments is 5000, the maximum disassembly capacity of disassembly centers is 5000, and the maximum processing capacity of remanufacturers is 5000; The unit transportation cost from the used product market to the offline collecter is 0.4; The unit transportation cost of offline collecter to the disassembly center is assigned as 0.3; The unit transportation cost from the disassembly center to the remanufacturing plant is assigned as 0.4; The unit transportation cost from the used product market to the online recycling department is 0.4; The unit transportation cost from the online recycling department to the disassembly center is assigned as 0.5; The unit transportation cost of offline collecters to the incineration and landfill center is 0.4; The unit transportation cost from the online recycling department to the incineration and landfill center is assigned as 0.2; The unit transportation cost from the disassembly center to the incineration and landfill center is 0.7; The unit transportation cost from the wholesaler to the used product market is assigned as 0.5; The inspection error rate of offline collecters is 0.4; The inspection error rate of the online recycling department is 0.3; The demand for remanufactured products in the used product market is 4000, 5500, 7000 and 6200.

The distance (unit: km) is set as follows: the distance from the used product market $(l_1 - l_4)$ to the offline collecter $(m_1 - m_3)$ is 252,136,145;137,148,48;145,62,145;260,45,239,the distance from used product market ($l_1 - l_4$) to online recycling department ($n_1 - n_3$) is 88, 60,38;

145,79,156;139,58,60;58,146,38;the distance from the offline collecter $(m_1 - m_3)$ to the disassembly center $(i_1 - i_3)$ is 75,160,80;140,126,92;58,96,75;the distance from the online recycling department $(n_1 - n_3)$ to the disassembly center $(i_1 - i_3)$ is 112,88,76;115,113,67;110,120,55; the distance from the disassembly center ($i_1 - i_3$) to the remanufacturing plant ($j_1 - j_2$) is 125,120,118;78,121,215,the distance from the incineration landfill center $(y)$to the offline collecter $(m_1 - m_3)$ is 118,210,86 ;the distance from the incineration and landfill center (y) to the online recycling department $(n_1 - n_3)$ is 92,126,74;the distance from incineration and landfill center (y) to the remanufacturing plant $(j_1 - j_2)$ is 120,78,139;the distance from the remanufacturing plant $(j_1 - j_2)$ to the wholesaler is 118,120;129,70;35,128;the distance from the wholesaler $(t_1 - t_3)$ to the used product market $(l_1 - l_4)$ is 178,52,116;126,185,190;78,214,98;256,133,141.

4.2 Transportation Scheme and Profit of Each Member of the Supply Chain

In the initial state, according to the above parameter settings, the transportation scheme obtained by using LINGO11.0 to optimize the above model is shown in Figure 3. The letter in the figure is the optimized transportation route, the subscript of the letter is the selection of routes, and the superscript number is the quantity of distribution.

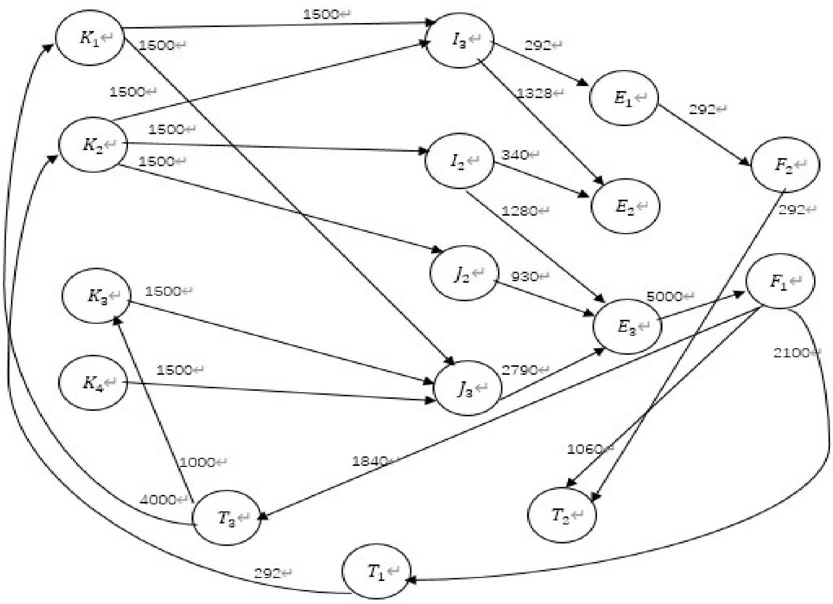

Figure 3. Transportation scheme in initial state

According to the relevant parameter settings, it can be concluded that:

$$Z_m = 96366.8(yuan),\ Z_j = 566436.8(yuan)$$
$$Z_t = 3544528(yuan)\ ,\pi = 286997.6(yuan)$$

When the transportation plan is optimal, the total profit is 286997.6 yuan, the profit of the collecter is 96366.8 yuan, the profit of the remanufacturer is 566436.8 yuan, and the profit of the wholesaler is 3544528 yuan.

4.3 When the Error Rate Changes the Transportation Scheme S and the Profits of Each Member of the Supply Chain

Other conditions remain unchanged, when the inspection error rate of offline collecters is 0.3 and the inspection error rate of the online recycling department is 0.2, the optimal solution can lead to the transportation scheme as shown in Figure 4.

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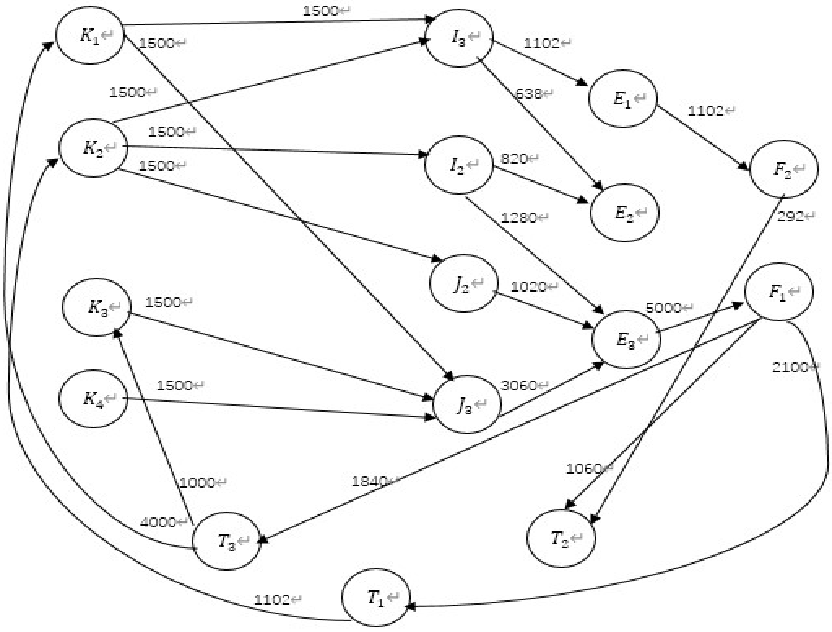

Figure 4. When the inspection error rate changes transportation scheme

According to the relevant parameter settings, it can be concluded that:

$$Z_m = 261304.4(yuan), Z_j = 717924.8(yuan)$$
$$Z_t = 3790766(yuan), \pi = 702803.6(yuan)$$

When the inspection error rate changes, according to the optimal transportation scheme, the total profit is 702803.6 yuan, the profit of the collecter is 261304.4 yuan, the profit of the remanufacturer is 717924.8 yuan, and the profit of the wholesaler is 3790766 yuan.

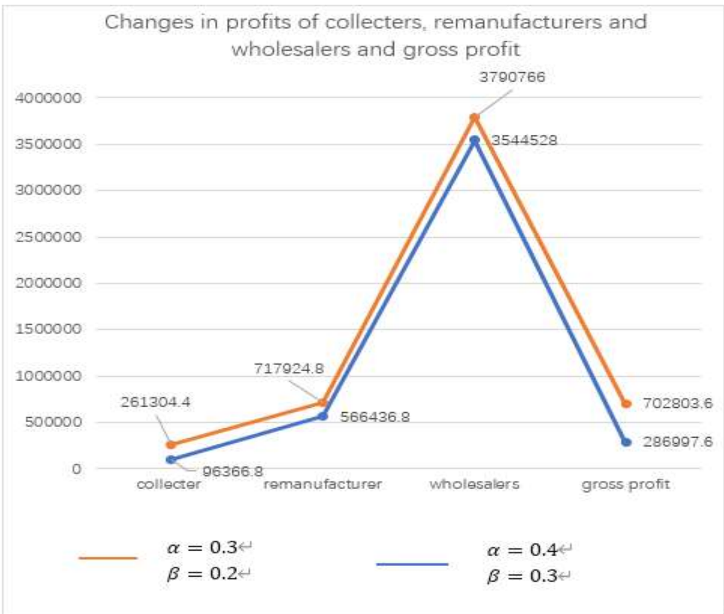

Figure 5. Changes in profits of collecters, remanufacturers and wholesalers and gross profit in both cases

According to the initial state and the state when the inspection error rate changes, the profit changes of the collecter, remanufacturer and wholesaler can be obtained as shown in Figure 5 (unit: yuan).

5. Conclusion

On the basis of previous research, this paper builds an optimization model of closed-loop logistics distribution network with double-channel collection inspection, and uses LINGO11.0 to make numerical calculation, which can get the optimized related transportation scheme. The analysis shows that when the inspection error rate is reduced, the profits of collecters, remanufacturers, wholesalers and the whole closed-loop logistics distribution network are all improved, and the profit of recyclers is the most significant, which provides an optimization strategy for the operation of related enterprises and makes the application of the model more practical.

Acknowledgments

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