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Research on the site selection of recycling network of packaging with integrating forward and reverse logistics under the guidance of government

Shuai Liu [a], Jiankun Hu [b]

Research Institute of Logistics Science and Engineering. Shanghai Maritime University. Shanghai 201306, China

[a] 1484963320@qq.com, [b] jkhu@shmtu.edu.cn.

Abstract

The rapid development of e-commerce leads to a large number of packaging waste, but most of the packaging waste is still valuable, and it is treated as municipal garbage because the low recycling value. On the other hand, with the introduction of circular economy, more and more people have realized the importance of reverse logistics, but most enterprises regard forward and reverse logistics as separate logistics systems and build a large amount of logistics resources respectively, resulting in serious waste of resources. Consider the influence of government behavior for packaging forward and reverse logistics integration, based on the supermarket chain enterprises as the research background, focused on the forward and reverse logistics integration of retail packaging waste recycling network location problem, by introducing the government subsidies function, build the total logistics cost minimization recycle supermarket site selection model of target, and the effectiveness of the model and Yalmip tool is proved through a scale example. Finally, sensitivity analysis is used to analyze that the government's positive subsidy strategy is more meaningful to network site selection, which provides further support for network decision-making.

Keywords

forward and reverse logistics integration, government subsidy, packaging waste recycling, site selection, retailer dominated recycling model.

1. Introduction

With the development of e-commerce, China's express delivery business has reached 83.4 billion [22] pieces in 2020.The rapid development of the express industry has led to the corresponding rapid growth of the demand for express packaging in the industry. Excessive packaging of goods and the one-time use of transport packaging have brought serious problems of resource waste and environmental pollution. According to the experience of developed countries in packaging waste recycling, the government is the backbone of packaging recycling network construction. Although the government has issued a series of policies to effectively promote the development of green packaging, the current packaging industry focuses on the development of green packaging technology, and the government's support and enterprises' attention to packaging recycling and reuse aren't enough. In addition, most domestic enterprises take forward logistics as the center of logistics work and spend a lot of logistics resources to improve the forward logistics network. Compared with reverse logistics, the focus is less on reverse logistics, and the uneven distribution of a large number of logistics resources leads to serious waste of resources. To a large extent, some nodes in forward and reverse logistics can be converted to each other, and logistics resources can be shared. It can be

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considered to integrate forward and reverse logistics into a complete logistics network. The existing facilities and equipment can be borrowed to recycle packaging waste while carring out forward distributione, so as to reduce the total cost of packaging waste recycling logistics network. Therefore, in the packaging waste recycling, with the aid of the backbone of the government, how to effectively integrate forward and reverse logistics ,form a complete logistics network, maximize the use of logistics resources and minimize waste of packaging resources into a problem to be resolved.

At present, there have been many researches on waste packaging recycling for domestic and foreign researchers. Scholars mainly studied the recycling model, recycling network and other aspects. C.W. Tallentire [1] established a life cycle assessment model, it is concluded that high collection performance of packaging material is crucial for efficient utilization of resources. Pankaj Dutta et al. [2] established a multi-objective reverse logistics network model for Indian e-commerce products and used weighted goal programming (WGP) technology to balance different objectives. Yuan Shi [3] built a reverse logistics model with retailers, manufacturers and third parties as subjects by adopting the method of sharing responsibility for recovery. He compared the non-sharing responsibility for collection and quantified the effectiveness of sharing responsibility. From the perspective of different subjects, he concluded that the different cost parameters would affect the network optimization results of different subjects as builders. Based on the concept of Extended Producer Responsibility and ERP system, Yuping Wu [4] summarized and analyzed the influencing factors of packaging waste recycling mode of enterprises, constructed mathematical models of different recycling modes, and solved and analyzed them respectively, and provided suggestions and support for packaging waste recycling mode of enterprises.

In the study of packaging waste recycling network system, Caimei Zou [5] proposed that in the construction of packaging waste recycling network, the government, enterprises and consumers should jointly participate in the whole waste packaging reverse logistics network system and independently undertake the responsibilities in the system. Lina Jiang [6] revealed that the uncertainty of recovery rate and reuse rate had a significant impact on the site selection and target value of the whole reverse logistics network through the sensitivity analysis under the model of packaging recycling network with certain environment and uncertain environment. Xiadan Dong [7] took express package as the research object and studied and designed both the express package recycling system and the express package recycling system. When the recycling system was optimized, he adopted the two-stage heuristic improvement method to solve the problem of "location-path-arrangement - inventory" proposed by her. Sisi Zhang [8] took the recycling rate and uncertainty of packaging waste as the starting point to plan the layout of the reverse logistics network facilities of packaging waste, and detailed the flow distribution of each logistics path. Through the combination of 16 different scenarios, the optimal site selection was analyzed.

On the other hand, in the research on the integration of forward and reverse logistics, Jinshun Ding [9] took SDN enterprises (multi-functional and open enterprise supply and demand network) as the research subject, analyzed the current situation of the drawbacks of the separation of logistics resources within and between enterprises, came out with forward and reverse logistics resource integration strategies, and drew a resource integration framework by taking SDN enterprises as a case. Xuanjing Fangc, Haishun Ruan [10] [11] based on the logistics distribution network of express packing boxes, The former builds LRP model to optimize the forward and reverse logistics network integration of e-commerce enterprises, and designs an improved genetic algorithm to solve the results. The latter optimizes the path problem of simultaneously taking delivery package boxes for forward and reverse logistics, and solves the problem through ant colony algorithm. Yang Xiwen [12] considered the combination of forward and reverse logistics, built a dual-objective location model to study the location problem of recycling and processing center in the forward and reverse logistics network during goods recycling and second distribution, and designed two algorithms to solve the problem respectively. Lijun Zhao and Yun Xu [13] [14] both studied the vehicle distribution problem in forward and reverse logistics integration. The former mainly solves the demand of delivery vehicles in forward and reverse logistics network, providing a scientific calculation method for specific distribution problems of enterprises. The latter is specific to the vehicle distribution problem of home appliance retail industry, using the dynamic real-time theory to put forward the optimization method of vehicle distribution problem. XiaoLi Su [15], etc are put forward to use RFID technology as the key technology of to set up reverse logistics resources integration platform.

In the study of the government's participation in the construction of logistics network, some studies have concluded that the government subsidy incentive strategy can better promote the construction of reverse logistics network [16] [17]. Wenbin Wang [13] took the target recovery rate and the intensity of rewards and punishments as parameters to study the government reward and punishment mechanism of the reverse recovery supply chain of electronic products. Without considering the complete symmetry of information, he compared and analyzed four situations in which rewards and punishments were different. Jiayi Joey Yu [14] proposed a simple model to determine the optimal government subsidy scheme under different environments, and discussed the case of subsidizing consumers, subsidizing manufacturers and subsidizing both, and finally reached the optimal government subsidy scheme. Yuyu Li et al. [15] took the recovery of expired drugs as the research problem and took the government as the core, established a three-layer planning model, and applied the model to the logistics network of the recovery of expired drugs, and adopted HGSAA to seek the optimal solution of the model. It is concluded that the government subsidy policy is the best and the hybrid genetic simulated annealing algorithm are effective algorithms to solve the problem.

In this context, considering that the retail industry has a strong forward logistics resources, and the forward and reverse logistics resources can be converted to each other under certain conditions, this paper takes chain supermarket enterprise as the builder of the optimization of the forward and reverse logistics integrated network, and studies the retailer-oriented recycling mode for packaging waste recycling. Considering the government incentives and subsidies and the active participation of residents, the location model with the minimum total cost of logistics network is constructed to solve the location problem of retailer recycling network. The purpose is to drive the combination of forward and reverse logistics integration and packaging waste recycling in the retail industry, give play to its social role, and make the total cost of packaging waste recycling the lowest.

2. Model construction

2.1 Problem description and model hypothesis

Based on the research background of chain supermarket enterprises, this paper focuses on the location of recycling supermarket in the packaging recycling logistics network composed of residential areas, recycling supermarkets and distribution centers under the integration of forward and reverse logistics. Fig. 1 shows the schematic diagram of the forward and reverse logistics network of packaging waste. Unlike traditional recycling channels, this article envisaged the traditional recycling channels the first node (recycling point) is set to the existing supermarket in the area, which is to integrate the forward and reverse logistics of the supermarket industry and utilize the existing forward logistics system of the supermarket to recycle and reuse packaging waste, so as to better play the role of the supermarket as a node. The recycling supermarket is only used as a temporary storage place. Packaging Waste collected from residential areas will be classified, stored and done some simple processing in a certain supermarket distribution cycle, then the packaging waste will be send to the distribution center by the delivery vehicles when the supermarket takes place forward logistics, and carry on recycling treatment in the distribution center. The solid line represents the forward logistics, representing the flow trajectory of packaging with commodities, while the dashed line represents the reverse logistics, representing the flow trajectory of recycling discarded packaging materials.

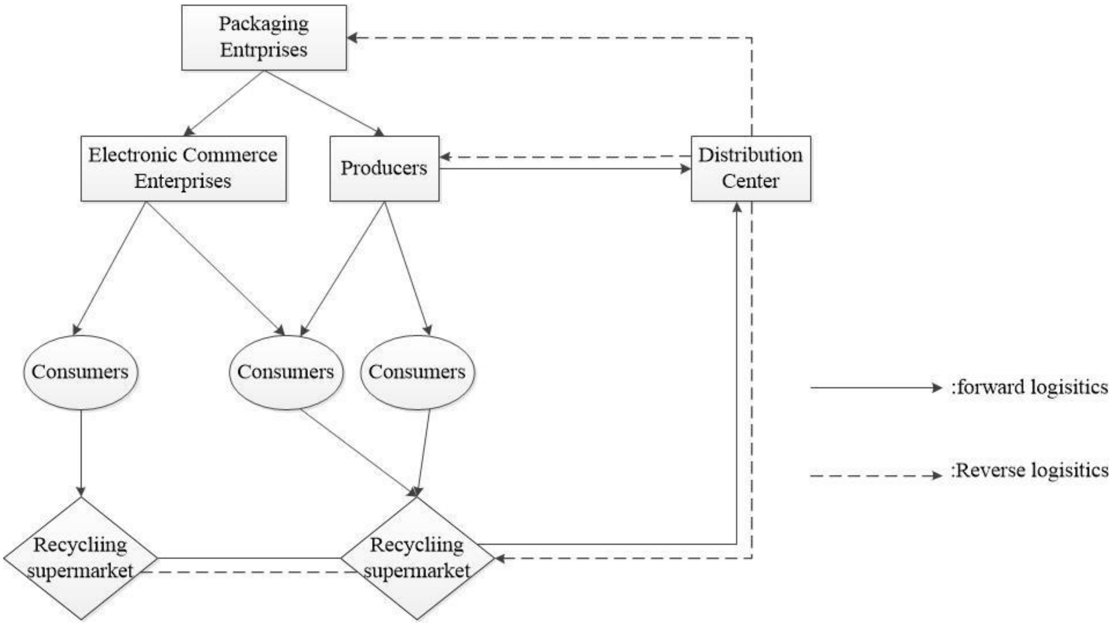

Figure 1. Schematic diagram of waste packaging recovery network

The government subsidy function studied in this paper belongs to subsection function, which mainly carries out incentive subsidy for enterprises that meet the government subsidy quota, and carries out corresponding punishment for enterprises that do not meet the government recovery rate requirement. Therefore, quote the following government subsidy function:

$$\mathbf{f}(r) = \begin{cases} \beta_1 (R-r), r<R \\ \beta_2 (r-R), r>=R \end{cases} \tag{1}$$

Where, R is the subsidy fixed number decided by the government, and r is the recovery rate. Due to the large uncertainty of the recovery quality, random parameters are considered in this paper to facilitate calculation and meet the normal distribution. β_1, β_2 are the subsidized price of government units.

To simplify the model, the following assumptions and explanations are made:

Hypothesis:

1. Since residents choose the nearest supermarket, the transportation cost of the residential area to the recycling supermarket not considered.

2. Due to the influence of various uncertain factors in the recovery process and the uncertainty of the recovery quality, it is assumed that the recovery rate should be random parameters.

3. The alternative supermarkets all have the basic conditions to become the recycling supermarkets, due to the same ability, the disposal cost and storage cost of waste packaging products are not considered.

4. The alternative coordinates and capacity of the alternative supermarket and the distance between the settlement and the alternative supermarket are known.

5. Coordinates and capacity of the distribution center are known.

2.2 Model parameters and decision variables

The subscript notation used in this paper are as follows:

i: The serial number of the residential area, $i \in I$, I represents a collection of all settlements.

j: The serial number of the alternative recycling supermarket, $j \in J, J$ represents a collection of all recycling supermarket.

k: The serial number of the distribution center, $k \in K, K$ represents a collection of the distribution centers.

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The parameters of the symbol used in this paper are as follows:

P: Total cost of packaging recycling logistics network.

D_{ij}: The distance between residential areas *i* and alternative supermarket *j.*

D_{jk}: The distance between alternative supermarket *j* and distribution center *k.*

L: Maximum permissible distance from residential areas *i* to recycling supermarket *j.*

N: Determine the maximum number of recycling supermarkets in the area.

r: The recovery rate takes a random parameter and follows a normal distribution, i.e $r \sim N(\mu,\sigma^2)$.

Q_i*:* The amount of packaging waste possessed by residential areas *i*.

Q_{ij}*:* The amount of packaging waste recycled from residential areas *i* to recycling supermarket *j.*

C_1*:* Recycling price per unit of packaging waste.

C_2*:* The unit freight from the recycling supermarket *j* to distribution center *k.*

q_k*:* Capacity of distribution center *k.*

q_j*:* The capacity of alternative recycling supermarket *j.*

$\beta_{1,2}$*:* unit subsidy price from the government.

The decision variable symbol used in this paper are as follows:

Y_j*:* 0-1 variables, 1 means the selection of the alternative recycling supermarket, 0 is the opposite.

Xij: 0-1 variable, 1 means that the residential area *i* is allocated to alternative recycling supermarket *j*.0 is the opposite.

2.3 Mathematical model

$$MinP = \sum_i \sum_j (D_{ij}Y_j)/r + \sum_i \sum_j c_1 Q_{ij} + \sum_j \sum_k c_2 Q_{jk} D_{jk} - f(r)\sum_j Q_{jk} \tag{2}$$

S.t:

$$\sum_j X_{ij} = 1, \forall i \in I \tag{3}$$

$$X_{ij} \le Y_j, \forall i \in I, j \in J \tag{4}$$

$$Q_{ij} = Q_i X_{ij}, \forall i \in I, j \in J \tag{5}$$

$$Q_{jk} = \sum_i Q_{ij}, \forall j \in J \tag{6}$$

$$\sum_j Y_j \le N \tag{7}$$

$$\sum_i Q_{ij} \le q_j, \forall j \in J \tag{8}$$

$$\sum_j Q_{jk} \le q_k, \forall k \in K \tag{9}$$

$$\sum_i Q_{ij} \le q_j X_{ij}, \forall j \in J \tag{10}$$

$$D_{ij} X_{ij} \le l, \forall i \in I, \forall j \in J \tag{11}$$

$$Y_j, X_{ij} \in (0,1), \forall i \in I, \forall j \in J \tag{12}$$

In the above model, (2) is the objective function of the logistics network of packagin-g recycling, in order to minimize the total cost of the recycling network (social cost, tran-sportation cost, recovery cost).Among them, $\sum_i \sum_j D_{ij} Y_j / r$ represents the social cost of th-e alternative recycling supermarket,

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$\sum_{\mathrm{i}}\sum_{j}c_1Q_{ij}$ represents the cost of recycling packaging waste, $\sum_{\mathrm{j}}\sum_{\mathrm{k}}\mathrm{c}_2\mathrm{Q}_{\mathrm{jk}}D_{jk}$ represents the cost of transporting packaging waste from recycling s-upermarkets to distribution centers, $\mathrm{f}(r)\sum_{j}Q_{jk}$ represents subsidy income. Constraint (3) me-ans that every resident corresponds to a recycling supermarket. Constraint (4) means that u-nselected supermarkets cannot be selectd to recycle. Constraints (5) and (6) are the calcula-tion of intermediate variables, representing the outflow capacity is balanced with the inflo-w capacity. Constraint (7) indicates the limit on the number of recycled supermarkets. Const-raint (8) and constraint (9) represent the capacity limit of recycling supermarket and distri-bution center respectively. Constraint (10) means that Only if the recycling supermarket is selected can the amount of recycling be found in the path.Constraint (11) refers to the dis-tance limit between the recycling supermarket and the residential area. Constraint (12) me-ans that all decision variables are 0-1 integers.

3. Simulation examples and results analysis

The data in paper makes corresponding adjustments based on the case data given in literature [21]. Table 1 shows the locations of alternative recycling supermarkets and distribution centers. Table 2 shows the location of residents and the amount of packaging waste in each period. Table 3 shows other parameters related to recycling supermarkets and distribution centers. It is assumed that the transport distance is Euclidean distance, which is obtained by matlab program.

Table 1. Locations of alternative recycling supermarkets and distribution centers

Alternative recycling supermarket locations			Alternative supermarket capacity	distribution centers locations		
Surpermarket *J*	Ascissa *X*	Ordinate*Y*	*qj*	Distribution centers *K*	Abscissa *X*	Ordinate *Y*
1	19.8592	38.8201	125	1	41.3454	32.4533
2	20.6814	24.4673	120			
3	32.7606	9.2952	140			
4	41.8793	35.0318	120			
5	18.5804	49.1354	120			
6	21.2627	40.3319	130			
7	29.7332	35.1784	120			
8	28.2869	24.2482	150			

Table 2. Location of residents and amount of packaging waste

Residential area *I*	Ascissa *X*	Ordinate*Y*	*Qi*
1	46.0906	34.0639	7
2	36.9104	18.9741	8
3	8.8133	41.5898	32
4	20.2853	25.1406	95
5	46.7735	35.4736	99
6	45.8452	21.4446	56
7	20.5135	15.2309	99
8	44.6825	9.4827	70
9	2.8946	9.6716	25
10	17.6434	34.1112	81

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Table 3. Other parameters related to the node

Parameter	Symbol	The numerical
Government subsidy parameters	*β1*	-30
	β2	30
	R	0.6
Capacity of the distribution center	*qk*	3000
Per unit freight for recycling packaging waste	*c1*	3
Per unit recycling cost of packaging waste	*c2*	0.5
The maximum number of recycling supermarkets	*N*	6
Maximum distance between the customer and the recycling supermarket	*l*	20
Recovery rate	*r*	$N(0.7,1^2)$

The yalmip tool is used to solve the problem, and the results obtained are listed in Table 4.

Table 4. Optimal solution

variable	solution							
Xij	0	0	0	0	0	0	1	0
	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	1	0
	0	0	0	1	0	0	0	0
	0	1	0	0	0	0	0	0
	0	0	0	0	0	0	0	1
	0	0	0	0	0	1	0	0
	0	0	0	1	0	0	0	0
	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	1	0
Yj	0	1	0	1	0	1	1	1
P	203511.4287							

According to the result table, supermarkets 4, 7 and 8 covered more residents, and supermarkets 2 and 6 only covered one residential area. Since every residential area needed to be covered, supermarkets 2, 4, 6, 7 and 8 were selected as the packaging waste recycling supermarket, and the total cost of the recycling network was 203511.4287.

4. Sensitivity analysis

After the results of network optimization are obtained, sensitivity analysis is needed to provide support for the decision of network optimization. Under the condition that the subsidy fixed R given by the government is unchanged at 0.6, the influence of different government subsidy strategies on network decision-making is analyzed by changing the government subsidy price.

1) No incentive and no punishment

When the government advocates the recycling of packaging waste, it does not take any measures to encourage or punish enterprises, that is β_1, $\beta_2 = 0$, under the condition that the subsidy price is 0. The site selection and related results of the recycling network of packaging waste are shown in Table 5.

Table 5. Impact of no incentive and no penalty strategy on packaging waste recycling network

Subsidized prices	Subsidies income	The total cost	Location decision
β_1, β_2=0	0	278521	01010111

Since the government has not taken any measures to encourage or punish the recyclin-g, the subsidy income is 0, so the total cost is the social cost, transportation cost and recy-cling cost of the supermarket enterprises to build the recycling network of packaging wast-e. With the decrease of subsidy income, if enterprises want to carry out packaging recyclin-g, they will also reduce the selection of facilities for recycling supermarkets. Therefore, th-e site selection of recycling supermarkets in the site selection scheme will also decreas-e a-ccordingly.

2) No incentive but punishment

The government will punish the enterprises that fail to meet the recovery rate stipulated by the government, and take no measures for the enterprises that meet the recovery rate. The penalty price will be changed from 10 to 30 to 50, and the changes of the network planning under the punishment measures are analyzed. The calculation results are shown in Table 6.

Table 6. Effects of non-incentive and penalty strategies on packaging waste recycling network

Subsidized prices	Subsidies income	The total cost	Location decision
β_1=0, β_2=-10	-6292	349946	01110111
β_1=0, β_2=-30	0	278291	11010111
β_1=0, β_2=-50	-44044	663106	01110111

After the government penalizes the enterprises that fail to meet the stipulated recovery rate, the total cost increases significantly with the strengthening of the punishment intensi-ty. This is because the government penalizes the enterprises accordingly, resulting in an a-dditional penalty cost. Under the uncertain change of recovery rate, when the recovery rate is higher than the stipulated recovery rate, the subsidy price is 0, so the subsidy income- is 0.On the whole, the government's punishment increases the cost of enterprises to build recycling network, and high intensity punishment is not conducive to enterprises to build recycling network.

3) Incentive without punishment

In contrast to the second situation, the government provides corresponding incentive compensation for enterprises that meet the stipulated recovery rate, and the subsidy price is increased by 10, 30 and 50, while no penalty is imposed on enterprises that do not meet the recovery rate. The changes of network planning under the incentive measures are analyzed, and the results are shown in Table 7.

Table 7. Impact of incentive and non-penalty strategies on packaging waste recycling network

Subsidized prices	Subsidies income	The total cost	Location decision
β_1=10, β_2=0	572	272588	01110111
β_1=30, β_2=0	18876	89609	01110111
β_1=50, β_2=0	0	291780	01110111

As incentive strength enhancement, the total cost of the network is down, this is due to the increase in subsidies income, led to a decline in the total cost, when the subsidy price is small, the total cost differs little from that without measures. This is because although there is a certain subsidy price, the cost advantage is not obvious when the recovery rate is not high and the corresponding facility location and other costs remain unchanged. On the whole, when the government increases the subsidy price, the decrease trend of cost is obvious, and when the recovery rate is far higher than the stipulated recovery rate, it will greatly encourage enterprises to recycle packaging waste. Under the incentive measures, the network location did not change.

4) Incentives and penalties

In the case of both punitive measures and incentive measures, that is, β_1 >0, β_2 <0, the changes of the packaging recycling network are analyzed, and the results are shown in Table 8.

Table 8. The impact of incentive and penalty strategies on packaging waste recycling network

Subsidized prices	Subsidies income	The total cost	Location decision
β_1=10, β_2=-10	-573	284585	01110111
β_1=30, β_2=-30	572	271987	01110111
β_1=50, β_2=-50	-5720	336476	11010111

By the table 8, the two strategies exist at the same time, when strategy is, namely β_1 = 10, β_2 = - 10 cases, as same as the situation of no subsidy and no penalty, there is n-o obvious promotion effect on the incentive enterprises to build packaging recycling netw-ork, but with the increase of intensity, the total cost changes greatly, and the location of facilities also changes a little.

From the analysis of the above situation, it can be concluded that in the construction of the network of packaging waste recycling, the relevant measures of the government af-fect the network decision-making of enterprises to a certain extent. Among them, the gover-nment's subsidy-oriented strategy is more meaningful for enterprises to build networks. Es-pecially in the case of the increase of the stimulus recovery rate, the cost of enterprise n-etwork construction is greatly reduced, which is conducive to the enterprise to undertake social responsibility independently.

5. Conclutions

Most of the previous scholars who study packaging waste recycling logistics problems study this problem from the angle of the reverse logistics, In this paper, considering government subsidy strategy and the integration of forward and reverse logistics, packaging waste recycling as the research object, building the packaging waste recycling supermarket location model with the supermarket enterprises as the main body. Because the commodity category is too complex, when adding the government subsidy function, the recovery rate is expressed as a random function. In the subsequent research, this part still needs to be further improved. Finally, through sensitivity analysis, it is concluded that the positive incentive subsidy strategy adopted by the government is more meaningful than other strategies for supermarket enterprises to recycle packaging waste. In this paper, YALMIP + MATLAB + Cplex tool is used to solve the model, the solver has the advantages of fast and accurate in solving small scale mixed integer programming model, which is of great reference significance for solving small scale model problems. But at the same time, it is suitable for small-scale integer programming model, and finally solve the recycling supermarket location, when the model is more complex, there should consider the comparison heuristic algorithm. Due to the large number of uncertain factors and subjects involved in the reverse logistics network, next research direction:1.Considering the multiple categories of commodities ,the impact of government subsidies on packaging waste recycling with different high and low values for the packaging waste recycling network.2. Considering the optimal path optimization problem of forward and reverse vehicle distribution. By adding the time constraint and the forward logistics distribution demand uncertainty constraint into the path planning model, the forward and reverse logistics network will be integrated more completely.

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Conflicts of Interest

The authors declare no conflict of interest.

Dataset

Part of the data in this paper is based on the data in literature [21].

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