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Logistics network planning of medical waste recycling

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Abstract: *Medical waste has the characteristics of direct or indirect infection, toxicity and harmfulness, and is listed as "top risk" internationally, and is listed as No.1 hazardous waste in China's Hazardous Waste List. Therefore, it is particularly important to recycle and treat medical waste. The reasonable design of medical waste recycling and disposal logistics network can effectively solve this problem, among which, the location planning of related facilities is an important activity. For medical waste recycling logistics facilities (i.e., collection points) location optimization design, this paper according to the different levels of service collection point, has carried on the classification of medical units, and then according to the different collection point location method of classification is put forward. Finally using MATLAB for data experiment and analysis of the results to verify the validity of the model. The model is instructive and referential to reality.*

Keywords: *Medical waste, location planning, logistics network*

1. Introduction

The management of medical waste and its associated health and environmental risks is a global concern and its disposal needs to be carried out in a manner that does not endanger the environment or human health. Rahman [1] pointed out that the problem of the base value of medical waste was growing rapidly around the world, which was the direct result of rapid urbanization and population growth and required professional treatment and management. In addition, the WHO says medical waste can also expose people in contact with it and entire communities to infection. Al-habash, Al-Zubi [2] and Nwachukwu [3] suggest that this may also lead to environmental pollution and degradation risks. At the same time, Hossain [4] also realized that improper medical waste management could lead to many diseases and work injuries, which increased the risk of medical waste recycling and disposal.

Campion et.al. [5] Concluded that the importance of hospital waste management lies in reducing its possible negative impact and the negative impact caused by improper disposal of medical waste on human beings and the environment. Therefore, it is particularly important to make a reasonable planning for the recovery network of medical waste, among which the location of medical treatment and related facilities is the most critical link. A reasonable layout can effectively reduce the negative impact of medical waste. Pu and Xia [6]. Considered location planning and distribution plan in the design of medical recycling network to build an efficient logistics network under the environment of discrete random parameters. Alagoz [7] optimized and improved the recovery of medical waste by comprehensively considering the recovery points and treatment points of the recovery logistics system. Shi and Fan [8] combined the characteristics of medical waste different from general waste to establish a recycling logistics network with limited capacity. Li [9] put forward the network planning structure of medical waste treatment in view of the demand of recycling and treatment under the new situation, which provides a reference for the reality.

2. Medical waste recycling network planning

2.1 Problem description

Due to the different objects of medical institutions, there are different location methods. In this paper, it is assumed that all medical institutions are divided into two categories, one is a hospital above level 1 and medical institutions within 500m, and the other is other medical institutions. Hospitals above level 1 produce a large amount of medical waste every day, so the rule of setting waste collection points within the hospital remains unchanged. In addition, the medical waste of all other medical institutions, such as the community, outpatient clinic and clinic, within 500 meters of the first level or above hospital can be transferred to the hospital. Other medical facilities, except hospitals at or above level 1 and their medical

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facilities at 500m, are located on the principle that all medical facilities at 500m within the collection point can transfer waste to the collection point.

(1) Location planning for collection points of hospitals at or above level-1 and medical institutions within 500m

For such medical institutions, site planning is very simple, that is, waste collection points are directly established in hospitals above level-1. If the specific location of level-1 or higher hospitals is known, the distance between each hospital and nearby medical institutions is calculated, and the waste of medical institutions within 500m shall be transferred to the collection point of the hospital. In addition to the above decision, this paper also proposed to take the capacity size of waste collection point as a decision variable. In the establishment of facilities, if the scale of facilities is too large, not only more capital investment is needed, but also resources may be wasted. If the facility is too small, it may not be able to meet all the needs, so it is equally important to determine a reasonable facility capacity. Specific steps to determine facility capacity are:

1) Determine the classification standard of collection point capacity scale;

2) Collect daily production information of medical waste, identification information of medical institutions, and category information of medical institutions of the hospital where the collection point is located and the institutions it serves;

3) For different types of medical institutions, there are different collection frequency, so it is necessary to calculate the amount of medical waste actually stored in the collection point. Hospitals at or above level-1 collect waste once a day, so the amount of waste stored at the collection point of a hospital at or above level-1 is equal to the amount of waste generated by the hospital plus the daily waste generated by all medical institutions served by the collection point.

IV. Because of the uncertainties, the daily production of medical facilities is different, so the amount of waste stored at collection points also shows irregular changes over time. The capacity size of the collection point can be determined by a multiple or maximum of the average daily storage of waste at the collection point. It is assumed that the size of each collection point's capacity is determined by the maximum daily storage capacity at that collection point during the year. For example, there are three optional collection point capacity scale classes available, with reserves of 3, 5 and 10 tons respectively. The maximum possible daily storage capacity of collection site A in A year is 7.5 tons, so the capacity scale of collection site A to be built is 10 tons.

(2) Location planning of collection points of other medical institutions

Other medical institutions here may include level-1 hospitals, outpatient clinics, community hospitals, clinics, medical departments of large and medium-sized universities and enterprises, pet clinics, medical cosmetology, etc. In this paper, a mathematical model (1) is proposed to plan the location of such medical institutions. By solving mathematical model (1), the location and capacity scale of medical waste collection points are obtained. Medical waste causes serious environmental pollution and has strict requirements for its storage. Therefore, it is impossible to set up collection points randomly at every location in a city. We consider all the objects targeted at the current location planning model of collection points as alternative collection points. On the one hand, they can meet stringent environmental requirements; on the other hand, medical personnel are responsible for medical waste storage in a more professional way. As different hospital institutions produce different amounts of medical waste, in addition to determining the location of collection points, we also consider the level of capacity and scale of collection points as decision variables. For the capacity scale level, we assume that there are multiple collection points with different capacity levels. Finally, the network planning also attaches great importance to the cost problem, hoping to save more costs while being more environmentally friendly, so we will minimize all costs as the decision goal of location planning.

2.2 Model

In order to better describe the problem, this paper makes specific assumptions and puts forward the corresponding mathematical model.

(1) Basic assumptions

1) The geographical location of all medical institutions is known, and the amount of waste produced is also known.

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2) The medical waste of each medical institution can only be temporarily stored at one collection point.

3) The waste of all institutions should be covered by the collection point, and the covering distance of the collection point is known.

4) There are a variety of capacity scale grades, and the capacity of each grade is known.

5) Whether the existing medical institutions have collection points and the capacity of collection points are known.

(2) Description of parameters and variables

Table 1: Index, parameter and variable

Index	
i, I	waste generation point and generation point set
j, J	alternative waste collection point and corresponding set
l, L	Alternate capacity number and capacity number set, and $L = \{0,1,2 \ldots, l^{max}\}$,When l=0, it means that the capacity of the alternative collection point is 0, which also means that the alternative collection point has not been selected
Parameter	
q_i	the amount of waste at waste generation point $\boldsymbol{i}$
Q_l	capacity of the collection point whose capacity number is l
$c_{j,l}$	fixed cost under capacity number l of collection point j
R	The service radius (i.e. coverage) of the collection point, and is assumed as 500m
(x_i, y_i)	coordinate of i
(x_j, y_j)	coordinate of j
$d_{i,j}$	The distance between i and j
Variable	
$X_{j,l}$	binary variable, $X_{j,l}$=1 means that the alternative waste collection point j with capacity Q_l is selected as the collection point; otherwise, it is 0
$Y_{i,j}$	binary variable, $Y_{i,j}$=1 means that the waste at the waste generation point l is stored at the collection point j; otherwise, it is 0

(3) Specific model

$$\begin{cases} \min \sum_{j \in J} \sum_{l \in L} c_{j,l} X_{j,l} \\ s.t.: \\ \sum_{i \in I} Y_{i,j}\, q_i \leq \sum_{l \in L} Q_l X_{j,l}, \quad \forall j \in J \qquad (1.1) \\ Y_{i,j} d_{i,j} \leq R, \qquad \forall i \in I, j \in J \qquad (1.2) \\ \sum_{j \in J} Y_{i,j} = 1, \qquad \forall i \in I \qquad (1.3) \\ \sum_{l \in L} X_{j,l} = 1, \qquad \forall\, j \in J \qquad (1.4) \\ \sum_{l=1}^{l^{max}} X_{j,l} = Y_{i,j}, if\ i = j\,, \ \forall\, j \in J \qquad (1.4) \\ X_{j,l}, Y_{i,j} \in \{0,1\}, \qquad \forall i \in I, j \in J \qquad (1.5) \end{cases} \tag{1}$$

Where, $d_{i,j} = \omega_{i,j}\sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}$, and $\omega_{i,j}$ is the circuitous coefficient. The circuitous coefficient is set as 1.3 in this problem.

The objective function of model (1) is to minimize the total cost, i.e. the fixed cost of replanning the collection points. Constraint (1.1) is a capacity constraint. Constraint (1.2) is the service radius constraint of the collection point. Constraints (1.3) only one collection point can be used to store waste for medical facilities. Constraint (1.4) indicates that only one capacity state can be selected for each collection point. Constraint (1.5) indicates that the decision variable is a binary variable.

Note that $c_{j,l}$, which represents the fixed cost for each capacity number l at the alternative collection point j, is given in order to present a concise model (1). $c_{j,l}$ is not information obtained directly, but is obtained by processing some raw data and results that the model may solve. In order to show the

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calculation process of $c_{j,l}$ more clearly, first of all, we take the existing state of the alternative collection point as the horizontal axis, and the state of the alternative collection point solved by the model as the vertical axis, and give the value of fixed cost c under all possible interaction states, as shown in the figure below:

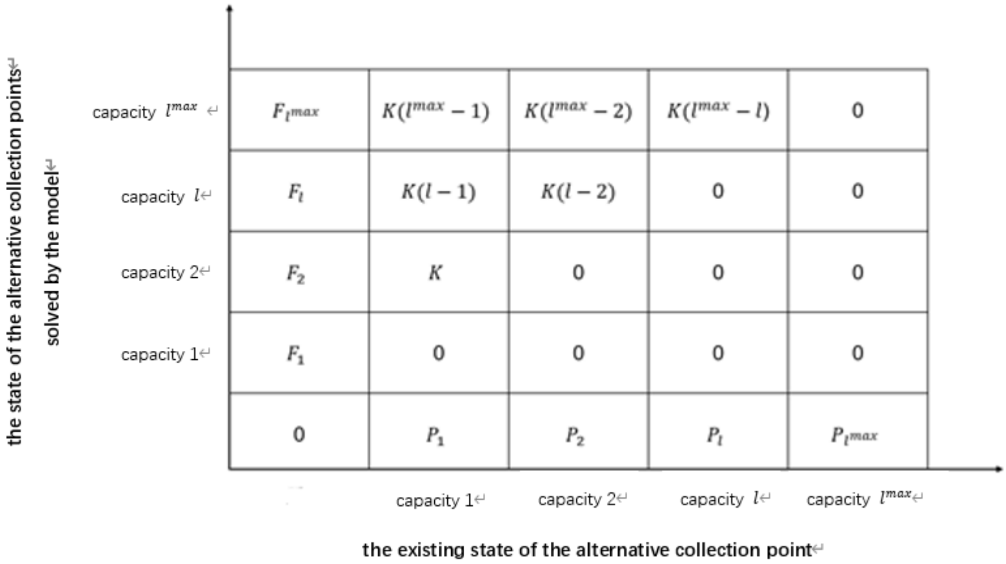

Figure 1: All possible fixed costs of collection points j under the interaction between the existing and solved state c

Where: F_l means the fixed cost of creating a new collection point of capacity Q_l; P_l means the penalty cost of shutting down an existing collection point with capacity Q_l and K means that expand the collection point to add a level of fixed cost to the capacity scale level of the existing collection point.

Secondly, the $\mu_{j,l}$ of each alternative collection point can be determined from the collected information, that is, the horizontal axis information in the graph is definitely determined. If $\mu_{j,l}$=1, it indicates that backup collection point j has capacity as Q_l collection point.

Finally, based on the known existing state of the alternative collection point j, the value corresponding to this state is the value of $c_{j,l}$.

3. Model solving and experimental analysis

3.1 Solving steps

To make the solution procedure clearer, the solution procedure is for the collection point location planning of level-1 or higher hospitals and medical institutions within 500 meters and for other medical institutions.

The procedure for calculating the site selection of the collection points for hospitals at or above level-1 and medical institutions within 500 meters is as follows: On the basis of preparing all required input known information, select all hospitals at or above level 1 as collection points. Second, the distance between other medical institutions and all hospitals above level I was calculated separately. Then, medical institutions within 500m from each level-i or higher hospital were selected and assigned to corresponding hospital collection points. Finally, the capacity scale decision of each hospital collection point is made according to the specific steps of determining facility capacity described above.

The solution steps of site selection planning of collection points of other medical institutions are as follows:

Step 1: Delete all hospitals above level-1 and the information of medical institutions within 500m. All the remaining medical institutions were numbered to determine the waste generation point set I. Since this paper assumes that all waste generation points can be used as alternative collection points, the collection of waste collection points $J = I$.

Step 2: Data processing. The value of $\mu_{j,l}$ is determined according to the information of collection point and capacity scale of each waste generating point, and then the value of $c_{j,l}$ is calculated according to the above method. Based on the location information of the waste generation point and the alternative collection point, the distance matrix $D=\left(d_{i,j}\right), \forall i \in I, j \in J$ is obtained. It should be noted that the amount of waste q_i at the waste generation point i in this model is twice the amount of daily production, as the level-2 and above hospitals collect it once a day, and level-1 hospitals and communities, outpatient departments, factories and schools collect it once every two days.

Step 3: Model (1) is a mixed integer programming model, which can be solved directly by using existing solving tools, such as MATLAB, CPLEX, LINGO, GAMS, etc. It is very convenient to obtain results by using these solving tools. We encode and run on MATLAB R2016a software to obtain the results of model (1). Detailed numerical experiment results and some site planning suggestions are given below.

3.2 Numerical experiment and analysis

In this paper, the relevant data of Wang [10] are cited for example experiments. A total of 153 medical units were selected, including 8 level-1 plus hospitals, 20 level-1 hospitals, 8 community hospitals, 17 out-patient clinics and 100 clinics. It is assumed that there are 5 different capacity scales, i.e. $L=\{0,1,2,3,4\}$, and the corresponding $\{Q_l\}$ is $\{0,10,50,100,200\}$, in Kg. Assume that the cost of upgrading a capacity scale is $K=1000$; The corresponding relation between F_l and P_l and l is shown in the following table:

Table 2: The correspondence between F_l and P_l

l	F_l	P_l
0	0	0
1	$2 \cdot K$	$0.5 \cdot K$
2	$4 \cdot K$	$1 \cdot K$
3	$6 \cdot K$	$1.5 \cdot K$
4	$8 \cdot K$	$2 \cdot K$

Then, the value of fixed cost c in all possible interaction states is shown in Figure 2:

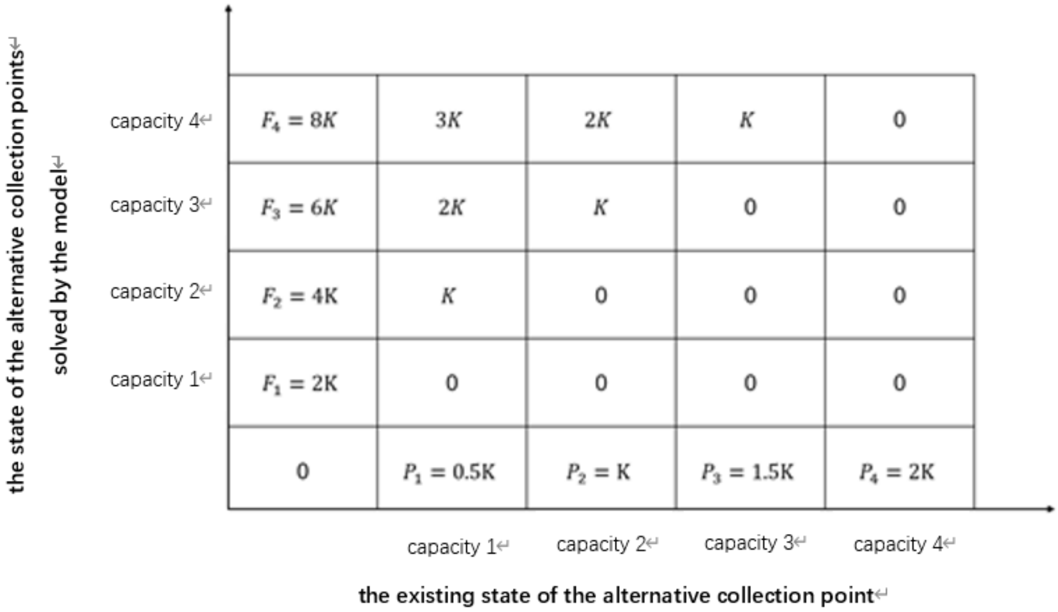

Figure 2: The values of fixed cost c for all possible interaction states in the example

There is no information about existing collection points in the reference data, and we assume the number of collection points is 35. Then locations of collection points are randomly generated.

First of all, the site selection planning of 8 hospitals above level-1 was calculated, as shown in the following table:

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Table 3: The location planning scheme for hospitals at or above the level-1

The medical unit number chosen for the collection point	Number of medical units covered by the collection point	Capacity scale (Kg)
1	16	200
2	78	200
3	70	200
4	42,75	200
5	-	200
6	20,28	200
7	120	200
8	19,118,130	200

It can be seen from the table that the position of each collection point and its corresponding set of coverage points:

Collection point 1 is located in medical unit 1, covering 16 medical units with a capacity of 200Kg.

Collection point 2 is located in medical unit 2, covering medical unit 78 with a capacity of 200Kg.

Collection point 3 is located in medical unit 3, covering 70 medical units with a capacity of 200Kg.

Collection point 4 is located in medical unit 4, covering 42,75 medical units with a capacity of 200Kg.

Collection point 5 is located in medical unit 5, no covered medical unit, with a capacity of 200Kg.

Collection point 6 is located in medical unit 6, covering medical unit 20,28, with a capacity of 200Kg.

Collection point 7 is located in medical unit 7, covering 120 medical units with a capacity of 200Kg.

Collection point 8 is located in medical unit 8, covering 19,118,130 medical units with a capacity of 200Kg.

Table 4: Location planning for other medical institutions

The medical unit number chosen for the collection point	Number of medical units covered by the collection point	Capacity scale (Kg)	The medical unit number chosen for the collection point	Number of medical units covered by the collection point	Capacity scale (Kg)
9	55,58	100	77	--	10
10	--	100	79	64,69	10
11	22	200	84	21,34,40,82	100
12	39	100	85	81, 88	10
13	--	50	87	61,67	10
14	--	100	93	--	10
15	62	100	95	135	10
17	--	100	97	36, 100,145	50
23	--	50	99	--	10
25	--	50	101	109,151	10
26	--	50	102	--	10
27	24,	50	106	--	10
29	60,90,136	50	107	98, 127	10
30	--	50	108	92	10
33	73	50	111	--	10
38	37, 83	50	115	96,110	10
41	--	50	116	--	10
43	--	50	121	45,91,112	50
44	52,117,125,143	100	122	--	10
46	--	50	123	114,	10
48	35,47, 133	100	124	152	10
50	94	50	126	105, 146	10
51	31,49	100	129	113	10
53	104	50	131	119, 148	10
54	63	10	132	138	10
57	——	10	139	128,137	10
59	56	10	141	--	10
65	86	10	142	--	10
66	--	10	144	--	10
68	80,89	10	147	--	10
71	--	10	149	18,32,	100
72	76	10	150	--	10
74	--	10	153	103,134	10

Then, the information of the medical units where the collection points are located and the medical units covered are removed, and the site selection of the remaining medical units is planned. We coded on MATLAB R2016a. The location planning results obtained from the operation are shown in the following table:

The results of site selection planning for collection points of other medical institutions show that the total cost of this planning scheme is 139,000 yuan, and there are 66 collection points in total, among which 28 collection points are independent collection points, and the number of collection points is relatively large in general. In order to further explore the reason, sensitivity analysis was carried out on the value of coverage radius R. The influence of coverage radius on total cost and number of collection points is shown in the figure below:

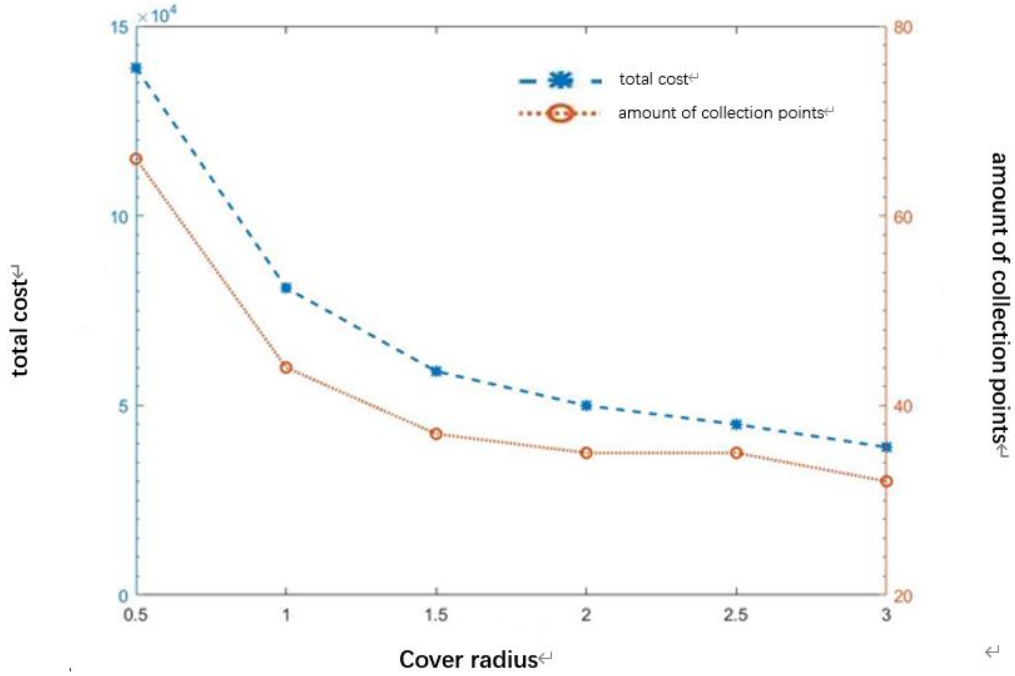

Figure 3: Sensitivity analysis of coverage radius

When the coverage radius R increases from 0.5km to 3Km, the total cost of site selection decision decreases from 139,000 to 39,000, and the number of collection points decreases from 66 to 32, indicating that the coverage radius has an important impact on site selection planning scheme. In addition, when the coverage radius reaches 1.5Km, the reduction rate of total cost and collection points slows down, probably because the distance between medical units is generally greater than 1.5Km where there are few medical units.

Large coverage radius can save a lot of collection point construction costs, but also reduce storage, transportation and other daily operating costs. However, it will greatly reduce the consciousness of medical institutions, increase the burden of medical institutions, and may lead to medical waste mixed with household garbage flowing into the society, so that it can not be treated innocently. Therefore, when making planning decisions in practice, decision-makers should take into account the situation of themselves and the medical institutions, determine the coverage radius based on the satisfactory coverage radius of the medical institutions, or improve the charging system considering the distance, so as to maximize the interests of both sides.

Through the analysis of the above experimental results, it can be seen that the collection point location model proposed in this paper can scientifically plan the layout of collection points and the objects served by each collection point for the company under the condition that all constraints are satisfied. And through different cost rules, the original collection point is utilized to minimize the cost of the new program. In addition, the size of facilities at different collection points is set based on the needs of each medical unit to reduce the waste of resources.

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4. Conclusion

In this paper, the recycling logistics network of medical waste is designed and planned. Starting from the practical problems, the location of relevant facilities in the recycling network is determined by establishing a mathematical model, and then the feasibility of the model is verified by numerical experiments. This has certain guiding significance for the actual logistics network planning of medical waste recycling and treatment. The main contributions of this paper are as follows:

First, on the basis of integrating many data, this paper theoretically expounds the classified recycling of medical waste, and puts forward some suggestions for enterprises to do a good job in classified recycling.

Secondly, this paper not only stays at the theoretical level, but also considers the actual situation in the process of model construction, such as the different capacity and scale of collection points, the construction of original collection points and so on.

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