Study of Municipal Solid Wastes Transfer Stations Locations Based on Reverse Logistics Network

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Abstract: Location of the refuse transfer stations need to consider the cost-effectiveness for minimizing the cost and minimal impact on the surrounding residents in social benefits. This paper builds a multi-objective mathematical model, through using the logistics system location theory. For ease of calculation, give the corresponding weights to the economic and social benefits, and make it into a single objective function. Solve it with the corresponding example. Finally, determine the reasonable place for the refuse transfer stations.

Keywords: Municipal Solid Wastes (MSW); Reverse Logistics Network; Refuse Transfer Station; Location;

I. Introduction

Municipal Solid Wastes (MSW) refers to the divisions within the urban people in daily life and activities of the solid refuse, including households, public places and street sweeping refuse, hospital refuse, business life refuse. With the rapid urbanization and economic development, municipal solid wastes problem has become increasingly prominent. Refuse is growing at average rate of 8.42 percent currently in the world annually; while China's growth rate is over 10%.China has become one of the most serious countries in which the cities are surrounded by the refuse in the world. At present the cumulative stock pile of municipal solid wastes have accumulated over 70 billion tons, covering about 80 million mu in recent years, and at an average annual rate of 4.8% growth. About 688 cities nationwide, in addition to the county seat, there are existing 2/3 of the medium-sized cities surrounded by refuse, and there is 1/4 of the city has no suitable places for refuse piling up[1].

The community consumes a large amount of manpower and material resources for refuse removal, transportation and disposal every year, in particular the issue of refuse transfer. The difficulty of refuse transfer caused a number of local construction authorities attentions. Refuse transfer station is the life of the masses need to be built. If built in a place far away from residential areas, refuse collection would become inconvenient, and would lose the meaning of transfer. Everyone wants to throw refuse, but all would not want to build a refuse transfer station near their houses. So where the refuse transfer stations should be built becomes a problem.

The refuse collection, transportation, transfer and a series of related processes are the primary link of municipal solid waste management system. It is a process that the refuse from scattered to the centralized, which belongs to the scope of reverse logistics. From the social point of view, refuse processing and recycling are a key component of sustainable development. The refuse transfer station separates the collection and disposal of municipal solid wastes. Therefore, location of the refuse transfer station becomes a crucial element of municipal solid waste reverse logistics network optimization. This paper build a mathematical model through using the logistics facilities location theory, and solve it through the relevant algorithms to determine the optimal location of refuse transfer stations, in order to make the cost present value of the municipal solid wastes system to be minimum, while also achieving the goal to minimize the impact on the surrounding residents, which called the social benefits. This is critical to the domestic refuse recycling reverse logistics network optimization.

II. Reviews

The municipal solid wastes reverse logistics system mainly includes collection points, transfer stations and disposal sites. These three parts, as well as complicated transport routes between them form the whole of municipal solid wastes reverse logistics network structure. In the reverse logistics network, the refuse transfer station connects collection points with disposal sites, as a bridge among them. It plays an important role in the logistics system.

In recent years, municipal solid wastes reverse logistics network optimization problems have aroused much attention of domestic and abroad scholars. In the refuse transfer station location optimization, Hu Shuanghai and He Bo (2007)[2] analysed the factors which should be considered during the establishment of refuse transfer stations, and set a location evaluation index system. Based on their research into the field, Wang Jinhua, Sun Kewei and Fang Zhen（2008）[3]developed the theory of site selection of municipal refuse transfer stations and named such basic necessary community facilities as “non-expected facilities”, for their environment effect on people’s daily life. They pointed out that location bicriteria in the non-expected-type facility are minimum and maximum criterion. However, the paper did not establish the appropriate model based on the actual situation to verificate. He Bo, Yang Chao and Zhang Hua(2007)[4] studied the design and optimization problems of refuse recycling multi-layer of reverse logistics network, including the location selection of transfer stations and disposal sites, at the same time established of multi-target pure Integer Programming model to meet the wishes of the public. Designed a two-phase decomposition algorithm based on heuristic to construct a refuse recycling multi-layer reverse logistics network. However, the paper did not make a discount for the model. Jia Chuanxing, Peng Xuya and Liu Guotao(2006) [5]established a model to make the present value of the system total cost to be minimum through using the Integer Programming method after determining the refuse transfer station to be the choice of site, and achieved the overall optimization. At the same time they elected the optimal combination of transfer stations from the choice of sites, and determined the amount of refuse transfer stations accepted of them. But the article made the present value of the whole system to be minimized with view of the economic perspective.

The existing literatures consider the building reverse logistics network problem basically from the economic perspective, and always build single-objective. Mixed Integer Programming model, objective function of which generally is to minimize the total cost of building logistics network system. But the refuse transfer stations are really a kind of public facilities. This means that in location not only the cost-effectiveness should be considered, but also the social benefits. This kind of location problems becomes a multi-objective optimization problem.

III. Building the Municipal Solid Wastes Transfer Station Location Model

Description of the problem

Municipal solid wastes reverse logistics network should be the highest level of general acceptance by the public, which means the smallest impact on the environmental and the lowest cost.

This paper uses the cost of transfer stations construction, operation fee and transportation cost to reflect the cost-effectiveness. The purpose is that minimize the economic cost. As the refuse transfer station has unpredictable effects on the surrounding environment, it should be away from residential areas as far as possible to make the social benefits under consideration. The two objectives, Economic and social benefits, are interlinked and influence each other, which form a target system. Therefore municipal solid wastes transfer station location is a multi-objective programming problem. It must be co-ordinate the planning and reasonable arrangement, in order to achieve the best results. This is the ultimate goal of the model building.

After set the related evaluation index system, we use the analytic hierarchy process to evaluate comprehensively and get the transfer stations alternative addresses. Using Integer Programming method to establish a model, in which the total present value cost of refuse reverse logistics system is minimum while social benefit is maximized. Then optimal points of refuse transfer station are selected out from alternative addresses to achieve the overall optimization.

Model Assumptions

(1) The number of refuse collection points has been identified. Each collection point is located near residential areas, while refuse disposal sites are built by the government in the designated locations.

(2) The capacity of each refuse collection point and transfer station is a certain size.

(3)The refuse in the collection point can only be transported directly to the transfer station, and then transported to the disposal site from the transfer station, and can not be directly transported to the disposal sites. The refuse in the collection points can only be transported to a nearest refuse transfer station, but a refuse transfer station can accept refuse from many collection points. The refuse in the transfer station can be shipped to more than one disposal sites, and disposal sites can accept refuses from a number of refuse transfer stations.

(4)The refuse shipping cost of unit distance is known as a constant.

(5)The transportation cost of domestic refuse has simple linear relation with its transportation distance.

In this case, in the process of the entire refuse reveres logistics, the cost from the economic perspective depends largely on transport costs of refuse from collection points to the transfer station and from the transfer station to the disposal site, the transfer station fixed investment costs and the transfer station operating costs during the using period. The three kinds of costs above-mentioned are interlinked and mutual constraint with each other. All of them are closely related to the location and the size of the transfer stations.

Definition of Parameters and Decision Variables Definition in the Model

(1)$i \in I$ the subscripts of collection points; $k \in K$ subscripts of transfer stations; $j \in J$ subscripts of disposal sites;

(2) T means the lifespan of the transfer stations;

(3) r represents present value discount rate;

(4)A is operating costs of the transfer station(Yuan per Ton), including depreciation charges and maintenance fees of equipment and facilities, staff costs of transfer station operations, utilities supporting materials fee and operating cost of the transport trucks;

(5) B_{ik} means the transportation costs involved in transporting one ton refuse for one kilometer over the delivery route from the refuse collection point "i" to the transfer station "k",(yuan $\cdot t^{-1} \cdot km^{-1}$).

(6)C_{kj} means the transportation costs involved in transporting one ton refuse for one kilometer over the delivery route from the transfer station "k" to the disposal site "j", (yuan $\cdot t^{-1} \cdot km^{-1}$).

(7)X_{ik} is the unit amount of refuse transported from collection point "i" to refuse transfer station "k" per day ($t \cdot d^{-1}$);

(8)Y_{kj} is the unit amount of refuse transported from refuse transfer station "k" to disposal site "j" per day ($t \cdot d^{-1}$);

(9) L_{ik} is the transport distance between collection point "i" and refuse transfer station "k" (km);

(10) S_{kj} is the transport distance between refuse transfer station "k" and disposal site "j" (km);
(11) F_k is the fixed investment of transfer station "k" to be constructed during the planning period (yuan);
(12) Q_k is the capacity size of refuse transfer station "k";
(13) q_i is the refuse capacity of collection point "i";
(14) M is a large number

Mathematical model

Based on the above analysis, mathematical models can be built as follows:
Objective function:

$$\min R=\sum_{i=1}^{m}\sum_{k=1}^{p}\sum_{t=1}^{T}\frac{L_{ik}\times B_{ik}}{(1+r)^t}\times(365X_{ik})\times U_{ik}$$
$$+\sum_{i=1}^{m}\sum_{k=1}^{p}\sum_{t=1}^{T}\frac{S_{kj}\times C_{kj}}{(1+r)^t}\times(365Y_{kj})\times V_{kj}$$
$$+\sum_{k=1}^{p}F_k\times W_k+\sum_{k=1}^{p}\sum_{j=1}^{n}\sum_{t=1}^{T}\frac{365\times Y_{kj}\times A}{(1+r)^t}\times W_k \quad (1)$$

$$\min P=\sum_{i=1}^{m}q_i\times\sum_{k=1}^{p}\frac{Q_k\times W_k}{L_{ik}} \quad (2)$$

Subject to:

$$\sum_{i=1}^{m}X_{ik}\times U_{ik}=\sum_{j=1}^{n}Y_{kj}\times V_{kj} \quad (3)$$
$$\sum_{k=1}^{p}X_{ik}\le q_i \quad (4)$$
$$\sum_{k=1}^{p}\sum_{j=1}^{n}Y_{kj}\le Q_k \quad (5)$$
$$\sum_{k=1}^{p}U_{ik}=1 \quad (6)$$
$$\sum_{k=1}^{p}U_{ik}\le M\times W_k \quad (7)$$
$$\sum_{i=1}^{m}X_{ik}\times U_{ik}\le Q_k \quad (8)$$
$$X_{ik},Y_{kj}\ge 0 \quad (9)$$
$$i=1,2\cdots\cdots m;$$
$$k=1,2\cdots\cdots p;\ j=1,2\cdots\cdots n$$

$$W_k=\begin{cases}1 & \text{build the k waste transfer station}\\ 0 & \text{otherwise}\end{cases} \quad (10)$$

$$U_{ik}=\begin{cases}1 & \text{waste in the i collection point transport to the k transfer station}\\ 0 & \text{not}\end{cases} \quad (11)$$

$$V_{kj}=\begin{cases}1 & \text{waste in the k transfer station transport to the j disposal site}\\ 0 & \text{not}\end{cases} \quad (12)$$

Expression (1) is model that the minimum of the present value during the lifespan, including the costs of transfer station construction, operation, and transportation refuse among the collection points, transfer stations and disposal sites in the reverse logistics network. Discount them through the discounting approach, calculate 365d for one year. Expression (2) indicates that the negative effect arising from transfer station establishing is proportional to its scale, inversely proportional to the distance from the residential area. Constraint equation (3) that is the amount of refuse balance between transfer stations in and out. Constraint equation (4) that is the amount of refuse shipped out of collection point "i" should be less than its capacity; Constraint equation (5) that the amount of refuse shipped out of transfer station "k" should be less than its size; Constraint equation (6) that the refuse in a collection point is only shipped to one transfer station; Constraint equation (7) means ensure that only when the transfer station is built, it can receive refuse from collection points; Constraint equation (8)represent the restrictions on the size of the transfer stations; Constraint equation (9) ensure that the amount of refuse on the transport is non-negative. Constraint equation (10) is the decision variable whether to establish a refuse transfer station; Constraint equation (11) is the decision-making variable that whether the refuse is transported from some one collection point to certain transfer station. Constraint equation (12) is a decision variables that whether refuse from one transfer station is transported to some one disposal site.

For ease of operation, we can put the multi-objective programming problem into a single objective. On the economic and social benefits are given a certain weight W_1 and W_2. W_1 and W_2 can generally be organized by experts' discussion, W_1 that is the weight of cost-effective share. The general value of it is 0.6- 0.8, and it is defined as 0.6 in the text. The objective function becomes min F=0.6minR+0.4minP.

IV. Numerical Examples Analysis

This paper use the case which in He Bo,Yang Chao and Yang Jun's paper that "A Multi-objective Optimization Model of Reverse Logistics for Solid Refuses". There are 10 transfer stations to be chosen, and their locations coordinates and construction costs are given in Table 1. Disposal site locations coordinates are shown in Table 2. Values of each parameter are shown in Table 3. Table 4 gives the locations coordinates and population of 30 collection points. This paper assumes that one person would produce 1.1 Kg refuse per day.

Table 1 The Location and Cost of Alternative Transfer Station

NO.	horizontal coordinate	vertical coordinate	cost(ten thousand yuan)
1	20.58	27.25	50
2	32.36	28.59	55
3	9.58	6.51	60
4	37.54	19.31	45
5	10.14	46.21	50
6	25.97	40.89	55
7	43.57	38.65	55
8	25.23	20.25	60
9	43.04	4.97	65
10	16.08	21.71	60

Table 2 Location of Disposal Sites

No.	horizontal coordinate	vertical coordinate
1	8.58	88.25
2	50.36	73.59
3	30.58	85.51
4	72.54	60.31
5	75.14	26.21

Table 3 Model Parameter Values

Lifespan T	Discount	Transfer station Operation cost A/yuan·t^{-1}	Unit cost of transportation (yuan·t^{-1}·km^{-1})
15	8%	20	35

In order to facilitate the calculation, rectangle distance is used to measure the distance between refuse collection points, transfer stations and disposal sites.

$$L_{ik} = |x_i - x_k| + |y_i - y_k| \quad (13)$$

$$S_{kj} = |x_k - x_j| + |y_k - y_j| \quad (14)$$

In formulae (13) and (14), x_i, y_i, x_k, y_k, x_j, y_j indicate the horizontal and vertical coordinates of the collection points, transfer stations, disposal sites on the map. Finally, put the above-mentioned values into the model of the objective function. Compile algorithm programs for Optimization through using MATLAB. The beneficial economic and social effects will be maximized by building No. 3, No.6, No.7 and No.9 transfer stations, as the research result suggests. Using MATLAB can easily do this, and this result is more accurate than that paper.

Table 4 Location and Population of the Collection Points

No.	Horizontal coordinate	vertical coordinate	Population(Ten thousand)
1	15.69	3.80	1.2
2	18.67	14.28	0.3
3	12.6	9.13	1.4
4	7.43	11.27	2.1
5	5.08	5.43	1.9
6	11.14	10.85	1.0
7	28.62	20.00	2.7
8	24.86	29.39	2.2
9	33.42	35.85	1.5
10	27.23	21.9	2.9
11	37.32	27.23	2.2
12	46.37	36.36	2.1
13	14.93	32.6	1.1
14	18.07	43.38	2.7
15	9.77	40.5	1.4
16	18.61	31.99	1.1
17	12.8	41.71	2.6
18	7.13	37.98	2.2
19	15.78	46.81	3.7
20	5.69	37.24	0.5
21	33.51	16.72	3.2
22	40.38	9.07	1.6
23	45.29	7.87	2.2
24	39.51	13.92	0.6
25	42.82	46.24	1.8
26	39.28	42.90	2.9
27	40.68	48.38	1.4
28	27.30	36.77	1.7
29	30.59	38.45	2.1
30	28.43	41.33	2.3

Ⅴ.Conclusion

This paper studies the municipal solid wastes transfer station location issues in reverse logistics network. From the management point of view, the construction and operation cost are requested to be the minimum. However, from the public point of view, require transfer station away from the living area as far as possible, so establish a bi-objective integer programming model. By solving the model, we can decide a reasonable location of the refuse transfer stations. Further studies include:

(1) The municipal solid wastes may deposit at the transfer station, so that this become a problem with inventory of the location.

(2) For the amount of collection points is uncertain, that is, random variables or fuzzy variables situation. stochastic programming and fuzzy programming model can be used to build a reverse logistics network system.

(3)Because of the requirements of operational economies of scale in the real environment, the time of refuse collection and transportation needs to be taken into account. Therefore, the problem can be turned into a model with time windows constraints, it will be more in line with the actual situation. Time window constraints can be divided into two categories, hard and soft time windows constraints. The so-called hard time window constraint is that the service must be carried out in a given period of time. And the soft time windows constraint is that the transfer station can provide services in the specified period. However, during this time provided services, it must compensate for the resulting loss. This problem can be addressed through the introduction of penalty factor.

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