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Modeling a Recovery Network Optimization Problem with Multi-objective in Remanufacturing Reverse Supply Chain

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Abstract:

This paper introduces a recovery network optimization problem with total cost and service satisfaction objective, a multi-objective optimization model is established and the membership degree function of each objective is constructed separately. Based on the objective weight value and satisfactory degree theory, the multi-objective optimization model is transformed into a single objective mixed integer programming model. An Example in Shaanxi province is given, the optimization models with different weight value is solved by computer, and the final location of the recycling centre and the optimal transportation capacity of each recovery facility are determined.

Keywords: *Reverse supply chain, Waste products recovery network, Multi-objective optimization, Membership degree function, Objective weight, Service satisfaction degree.*

I. INTRODUCTION

In today's world, rapid economic development led to a large number of waste products, according to statistics, European Union countries have produced 540~600 million tons of waste household appliances every year at the end of 1990s. Sweden produced 200 thousand tons of waste electrical appliances per year and an average of more than 20 kg per person [1], Japan's waste appliances reached 600 thousand tons per year, in the United States more than 315 million computers scrapped from 1997 to 2004 [2]. If these large quantities of waste products are simply buried or incinerated, it will cause a great waste of resources, for example, e-waste contains precious metals, such as copper, gold, platinum, tin, and many other components that can be recycled directly, the Danish researchers published the results of a study shows that 1 tons of circuit board can be separated out of 286 pounds of copper, 1 pounds of gold, 44 pounds of tin. Moreover, a large number of waste products will also cause serious environmental pollution and immediately harm human health, for example, the United States Massachusetts states have occurred poly (PBB) pollution event in 1973.

In order to resolve the increasingly serious problems of resource wasting and environmental pollution, various countries in the world have proposed to establish reverse supply chain and implement remanufacturing. Recycling of waste products is the most important part in the implementation of remanufacturing, which has a very important impact on the establishment and operation of the reverse supply chain, Optimization of waste recycling network not only affects every member in the reverse supply chain, such as customers, recyclers, manufacturers and other interests, but also has a very important significance for the establishment and operation of the reverse supply chain.

II. LITERATURE REVIEW

Tognetti A, Pan G R and Wagner S M researched the Green Supply Chain network optimization considering the trade-off between environmental and economic objectives [3]. Shuihua Han et al. established a robust optimisation model for hybrid remanufacturing and manufacturing systems under uncertain return quality and market demand [4]. Majid Eskandarpour et al. designed a comprehensive seven-layer recovery network and developed a new Tabu search-based heuristic method for computing optimal or near-optimal solutions for the recovery system [5]. Yarui Zhang, Xuelin Liu and Jun Ma established a network model with for multi-objective reverse logistics under fuzzy environment in order to minimize the total cost and maximize the recovery rate [6]. Yuxiang Yang et al. developed the remanufacturing closed-loop supply chain network design model extends the aforementioned models to consider competition among closed-loop supply chains and the model can handle nonlinear costs[7]. Meili Lu et al. put forward a two-stage stochastic linear programming model with compensation considering randomness both quantities of recycling and refurbishing proportion in the optimal design of reverse logistics network [8]. Changbing Li and Feimin Zhang built a mixed integer programming model with location-routing-inventory control optimization by combining with the batch transportation of recycle products and proposed a two-phase heuristics algorithm [9]. Changsheng Yi and Xuebin Guan established a Recovery Logistics network optimization model by using a mixed method of random chance-constrained programming and fuzzy chance-constrained programming [10]. Zhong Wan, Jie Guo, Xinbo Zhang constructed a new recycling network optimization model with uncertain daily recovery quantity and the possibility of reusing the garbage disposed by an urban refuse treatment sites[11]. Qi Feng, Weimin Di, Guiyin Cheng developed a mixed integer programming model for multilevel, multi-product, constrained processing capacity reverse logistics network of scraped agricultural machinery[12]. In recent years, some researchers began to pay attention to resource consumption and environmental protection in Remanufacturing Reverse Supply Chain. Rui Huang, Ling Yan, Zhendong Zhang constructed a reverse logistics network model, including location problems, the choice of recycling routes and the allocation problem of the client demands[13]. Tao Wang, Jing Ni, Yixuan Wang set up a two-stage reverse logistics network model considering the carbon emission factor [14]. Faxin Cheng, Li Li, Ting Pan established a mixed integer programming model for minimum total cost and carbon emission, multi-objective particle swarm optimization algorithm was used to solve the model [15]. Botang Li and Gang Zhao established a robust mixed linear programming of remanufacturing logistics network to minimize the sum of carbon trading revenue and expenditure and logistics costs [16]. Weida Chen and Shaodong Cui set up a new model with the objectives of minimum carbon emission, maximum capacity utilization and customer satisfaction, designed a genetic algorithm to solve the model [17].

It can be concluded from the above literature that the research on optimization of reverse supply chain recycling network mainly pay attention to the overall interests of the supply chain, and requires all members to make decisions simultaneously, but each enterprise often operate and make decisions independently, the establishment and implementation of reverse supply chain must be carried out in sequence, all enterprises do not make decisions at the same time. Therefore, it is necessary to research the independent decision problem of different members in the supply chain. On the other hand, most of the existing network optimization models are single objective optimization model, the only goal of the optimization is to minimize the total cost. In recent years, some researchers begun to pay attention to multi-objective optimization problems on reverse supply chain, but only carbon emissions was considered, the influence of the service capacity of the recycling centre on the facility location was ignored. In fact, the competition of modern enterprises is not only the cost of competition, service quality is also a very important competitive factor. Thus, considering the total cost of each recycling centre and the distribution service satisfaction of waste products, this paper will establish a double-objective optimization model of waste products recycling network.

III. METHODOLOGY

3.1 Problem Description

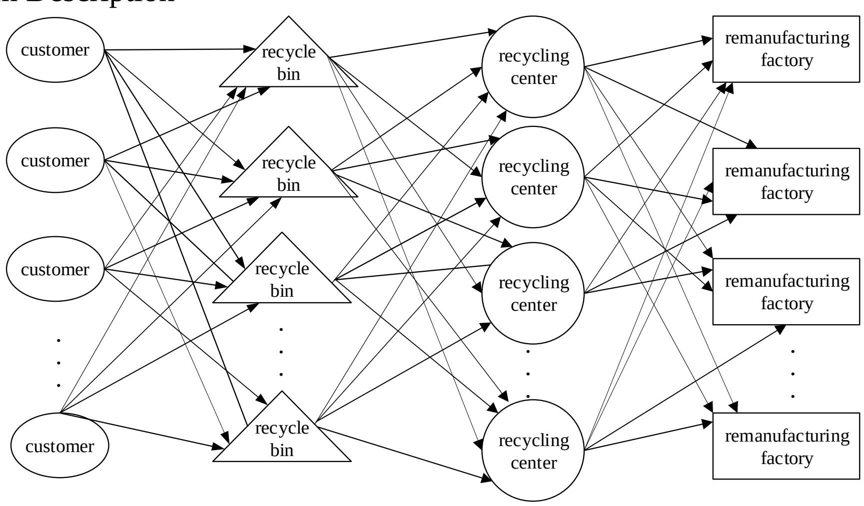

Fig 1: The structure of waste products recycling network

The recycling network of waste products is generally composed of the main facilities such as the recycle bin, recycling centre and remanufacturing factory, its network structure is shown in Figure 1. The problem to be solved in this paper is that how to establish and solve the quantitative location model for selecting the location of the recycling centre from a limited

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number of alternatives, and determine the amount of logistics between the recycle bin to the recycle bin, the recycling centre and the remanufacturing plant under the assumption of the self-decision of third party recyclers and the location of the recycling and remanufacturing plants determined.

In order to reduce the complexity of the location problem and make the solution and application of model conveniently, the following assumptions are made:

Assumption 1: Recycling and remanufacturing of single cycle and various waste products should be considered.

Assumption 2: When selecting the location of the recycling centre in a region, it can be divided into a number of fixed consumption areas, and the location and quantity of recycle bin have been determined according to the data of each consumption area.

Assumption 3: The recycling of waste products is divided according to the consumption area, and the amount of recovery in each consumption area has been determined.

Assumption 4: The number and location of alternative recycling centres are known, and the recycling centres are selected only in a limited number of alternatives.

Assumption 5: All kinds of transportation cost, fixed cost and unit variable cost is known, transportation distance and average speed between all kinds of different facilities is known, and the transportation cost and the transport distance per unit of product satisfy a simple linear relationship.

Assumption 6: Unit transportation cost of various waste products are equal.

Assumption 7: There are capacity constraints for recycling centres and remanufacturing plants, and the processing capacity and the production capacity have be got.

Assumption 8: The total amount of waste products recycling is greater than demand.

3.2 Explanations of the Symbols in Models

The parameters' definition and typical values can refer to TABLE I and TABLE II, respectively.

TABLE I. Common parameter definition

Notation	Description	Span
i	Sequence number of recycle bin	$i \in \{1,2,...,I\}$
j	Sequence number of recycling centre	$j \in \{1,2,...,J\}$
k	Sequence number of remanufacturing factory	$k \in \{1,2,...,K\}$
l	Sequence number of waste products	$l \in \{1,2,...,L\}$

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TABLE II. Specific parameter definition

Notation	Description	Span
q_{il}	Recovery quantity of waste products from recycle bin	Nonnegative
n_{kl}	Demand for waste products from Remanufacturing factory	Nonnegative
d_{ij}^{sc}	Distance between recycle bin and recycling centre	Nonnegative
d_{jk}^{cm}	Distance between recycling centre and remanufacturing factory	Nonnegative
v_{ij}^{sc}	Average speed between recycle bin and recycling centre	Nonnegative
v_{jk}^{cm}	Average speed between recycling centre and remanufacturing factory	Nonnegative
t_k	Delivery time with maximum satisfaction	Nonnegative
$t_k^{'}$	Delivery time with zero satisfaction	Nonnegative
w_j	Fixed investment cost of recycling centre	Nonnegative
e_{ij}^{sc}	Unit transportation cost between recycle bin and recycling centre	Nonnegative
e_{jk}^{cm}	Unit transportation cost between recycling centre and emanufacturing factory	Nonnegative
u_{jl}	Unit variable cost of disposal of waste products	Nonnegative
p_{jl}^{c}	Maximum processing capacity of recycling centre	Nonnegative
p_{kl}^{m}	Production capacity of remanufacturing plant	Nonnegative
z_j	Decision variables for location of recycling centres	0 or 1
x_{ijl}	Traffic volume between recycle bin and recycling centre	Nonnegative
y_{jkl}	Traffic volume between recycling centre and remanufacturing factory	Nonnegative

3.3 Representation of Service Satisfaction

Service satisfaction is defined as the degree of satisfaction with the quantity and time required, it reflects the rapid response capability of the third party recyclers' recycling facilities and the operating system for remanufacturing enterprises demand. In order to simplify the problem and build the model easily, In order to simplify the problem and establish the model, this paper defines the service satisfaction as the product of the distribution and time satisfaction, as shown in Eq. (1).

$$b_{jk} = y_{jk} \times f_s(t_{jk}) \tag{1}$$

In Eq. (1), b_{jk}, y_{jk}, t_{jk} represents the recycling centre’s service satisfaction , total distribution and delivery time of waste products respectively, and $f_s(t_{jk})$ is defined as the Time Satisfaction Function. In this paper, we assume that the time satisfaction is a continuous linear function of delivery time, as shown in Figure 2.

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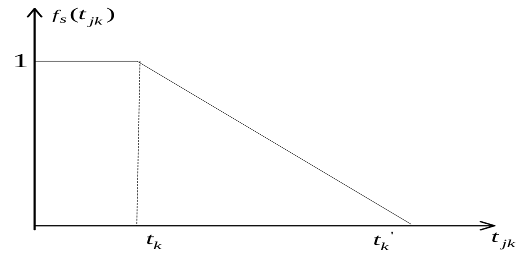

Fig 2: The time satisfaction function

According to Fig.2, the time satisfaction function can be expressed as shown in Eq. (2).

$$u_{f_{ts}}(x)=\begin{cases}0 & t_{jk}\geq t_k' \\ \dfrac{t_k'-t_{jk}}{t_k'-t_k} & t_k<t_{jk}<t_k' \\ 1 & t_{jk}\leq t_k\end{cases} \tag{2}$$

The total distribution satisfaction of recycling centre can be calculated by the Eq. (3).

$$\sum_{k=1}^{K} b_{jk}=\sum_{k=1}^{K}\sum_{l=1}^{L} y_{jkl}\times f_s\left(\frac{d_{jk}^{cm}}{v_{jk}^{cm}}\right) \tag{3}$$

3.4 Establishment of Recycling Centre Location Model

The completed formulation for the proposed problem can be represented as follows:

$$\min f_{tc}(z_j,x_{ijl},y_{jkl})=\sum_{j=1}^{J}(w_j\times z_j) \tag{4.a}$$

$$+\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L}(x_{ijl}\times d_{ij}^{sc}\times e_{ij}^{sc}\times z_j) \tag{4.b}$$

$$+\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L}(u_{jl}\times x_{ijl}\times z_j) \tag{4.c}$$

$$+\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L}(y_{jkl}\times d_{ij}^{cm}\times e_{jk}^{cm}\times z_j) \tag{4.d}$$

$$\max f_{ts}(z_j,y_{jkl})=\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L}\left[y_{jkl}\times f_{jk}\left(\frac{d_{jk}^{cm}}{v_{jk}^{cm}}\right)\times z_j\right] \tag{5}$$

Subject to

$$\sum_{j=1}^{J}(x_{ijl}\times z_j)\leq q_{il} \quad \forall\ i,l \tag{6}$$

$$\sum_{i=1}^{I}(x_{ijl}\times z_j)\leq p_{jl}^{c} \quad \forall\ j,l \tag{7}$$

$$\sum_{k=1}^{K}(y_{jkl}\times z_j)\leq\sum_{i=1}^{I}(x_{ijl}\times z_j) \quad \forall\ j,l \tag{8}$$

$$\sum_{j=1}^{J}(y_{jkl}\times z_j)\leq p_{kl}^{m} \quad \forall\ k,l \tag{9}$$

$$\sum_{j=1}^{J}(y_{jkl}\times z_j)=n_{kl} \quad \forall\ k,l \tag{10}$$

$$x_{ijl},y_{jkl}\geq 0 \quad \forall\ i,j,k,l \tag{11}$$

$$z_j\in\{0,1\} \tag{12}$$

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There are two objective functions in this model, the first objective comprises four parts: (4.a) total fixed investment cost, (4.b) total transportation cost between recycle bin and recycling centre , (4.c) total treatment cost, and (4.d) total transportation cost between recycling centre and remanufacturing plant, the second goal is to maximize service satisfaction. Constraints (6) to (12) respectively expresses the flow constraints between recycle bin and recycling centre, processing capacity constraints of recycling centres, flow constraints between recycling centre and remanufacturing plant, production capacity constraints in remanufacturing plants, demand constraints in remanufacturing plants, decision variable value constraint.

3.5 Model Solution

The model established in this paper contains two objective functions, which belongs to multi-objective mixed integer optimization problem, the solution of multi-objective optimization problem is a decision-making process, the results of which should be based on the decision maker's expectations [18], or the decision maker's satisfaction as the standard. However, it is difficult to express the expectation and satisfaction of decision makers that belongs to the category of fuzzy concept [19]. Therefore, through the fuzzy satisfaction-maximizing method, this paper will introduce the concept of membership degree to express the satisfaction of decision maker, and find a optimal solution to satisfy the decision maker. The process of solving the model is as follows:

Determine the membership function of the objective of the total cost and total distribution service satisfaction, as shown in Figure 3 and Figure 4.

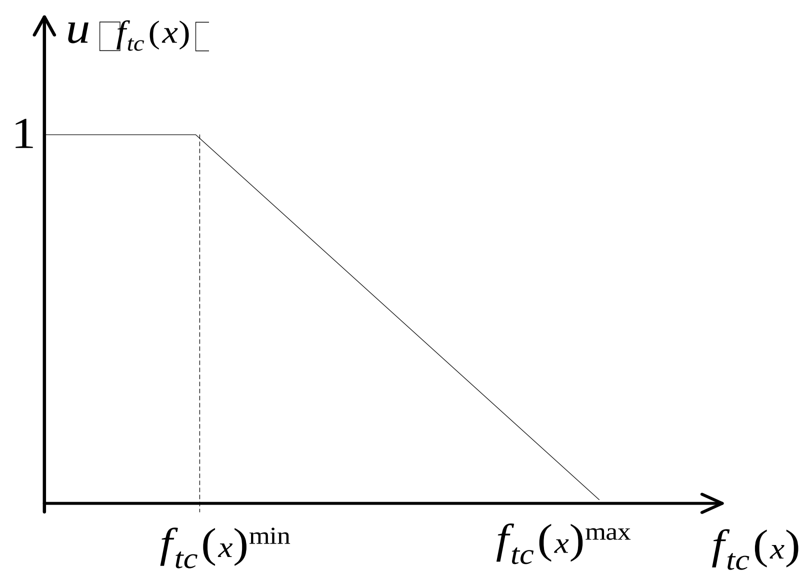

Fig 3: membership function of total cost

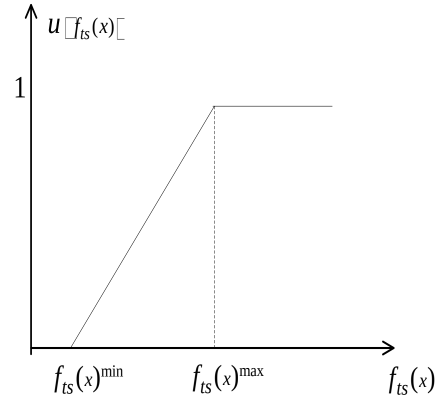

Fig 4: membership function of service satisfaction

Calculate the maximum and minimum values of each single objective, that is determining the value of $f_{tc}(x)^{max}$、$f_{tc}(x)^{min}$, $f_{ts}(x)^{max}$, $f_{ts}(x)^{min}$.

Construct the membership function of the total cost and total distribution service satisfaction, as shown in Eq. (13) and Eq. (14) .

$$u(f_{tc}(x)) = \begin{cases} 0 & f_{tc}(x) > f_{tc}(x)^{max} \\ \dfrac{f_{tc}(x)^{max} - f_{tc}(x)}{f_{tc}(x)^{max} - f_{tc}(x)^{min}} & f_{tc}(x)^{min} \le f_{tc}(x) \le f_{tc}(x)^{max} \\ 1 & f_{tc}(x) < f_{tc}(x)^{min} \end{cases} \quad (13)$$

$$u(f_{ts}(x)) = \begin{cases} 0 & f_{ts}(x) < f_{ts}(x)^{min} \\ \dfrac{f_{ts}(x) - f_{ts}(x)^{min}}{f_{ts}(x)^{max} - f_{ts}(x)^{min}} & f_{ts}(x)^{min} \le f_{ts}(x) \le f_{ts}(x)^{max} \\ 1 & f_{ts}(x) > f_{ts}(x)^{max} \end{cases} \quad (14)$$

Let the weight of the total cost and the total distribution service satisfactionis w_1, w_2 ($w_1 + w_2 = 1$) respectively, according to the principle of multi-objective fuzzy programming, a single objective optimization model is established as follows:

$$\max (w_1 \times l_1 + w_2 \times l_2) \quad (15)$$

Subject to

$$l_1 \le u(f_{tc}(x)) \quad (16)$$

$$l_2 \le u(f_{ts}(x)) \quad (17)$$

Solve the above single objective optimization model, then a compromise solution of multi-objective optimization will be obtained. If it can be accepted by decision maker, the optimization has been finished, otherwise, go to next step.

Modify the value of w_1, w_2, or adjust the value range of each target function.

IV. RESULTS AND DISCUSSION

There is a third party recyclers that undertake the recycling and distribution business of waste products for two remanufacturing factories, four recycling stations has been established to recycle two kinds of waste products in the center of the consumer area, and there are three

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alternative locations for determining the recovery center. Now supposing that the four recycling stations(i=1,2,3,4) are located in Mizhi County, Xianyang City, Weinan City and Hanzhong City, three alternative recycling centers (j=1,2,3) are set up in Yanan City, Xi'an city and Ankang city, and two remanufacturing factories (k=1,2) are located in Yulin city and Shangluo City in Shaanxi Province. The distance, average speed and the unit transportation cost between the recycle bin and recycling center are shown in TABLE III. The distance, average speed and the unit transportation cost between the recycling center and remanufacturing factory are shown in TABLE IV.The fixed investment cost, unit variable cost of disposal and maximum processing capacity of recycling center are shown in TABLE V. The recovery quantity of waste products from recycle bin are shown in TABLE VI.The demand for waste products and production capacity of remanufacturing plant are shown in TABLE VII and TABLE VIII.The shortest delivery time when time satisfaction equals 1 and the longest delivery time when time satisfaction equals 0 are shown in TABLE IX.

TABLE III. Distance, average speed and unit transportation cost between recycle bin and recycling center

Recycle bin and Recycling centre	d_{ij}^{sc} (km)	t_{ij}^{sc} (h)	v_{ij}^{sc} (km/h)	Total transportation cost (RMB/t)	e_{ij}^{sc} (RMB/km.t)
i=1, j=1	304.1	4.55	66.84	101.5	0.51
i=1, j=2	605.8	9.18	65.99	256.7	0.42
i=1, j=3	836.6	12.57	66.56	430.7	0.48
i=2, j=1	319.2	5.03	63.46	162.8	0.50
i=2, j=2	28.4	0.57	49.87	13.7	0.49
i=2, j=3	248.4	3.83	64.86	153.6	0.62
i=3, j=1	356.9	5.47	65.25	180.1	0.50
i=3, j=2	69.0	1.03	66.99	32.1	0.50
i=3, j=3	277.9	4.18	66.48	139.8	0.61
i=4, j=1	574.7	8.77	65.53	296	0.50
i=4, j=2	273.1	4.18	65.33	185.2	0.68
i=4, j=3	216.3	3.30	65.55	113.8	0.59

TABLE IV. Distance, average speed and unit transportation cost between recycling center and remanufacturing plant

Recycling center, remanufacturing plant	d_{jk}^{cm} (km)	t_{jk}^{cm} (h)	v_{jk}^{cm} (km/h)	Total transportation cost (RMB/t)	e_{jk}^{cm} (RMB/km.t)
j=1, k=1	267.0	3.93	67.94	136.7	0.51
j=1, k=2	416.0	6.38	65.20	213.8	0.50
j=2, k=1	568.2	8.53	66.61	292.4	0.51
j=2, k=2	127.1	1.95	65.18	63.2	0.52
j=3, k=1	805.5	11.95	67.41	433.3	0.54
j=3, k=2	336.1	5.07	66.29	167.9	0.59

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TABLE V. Fixed investment cost, unit variable cost of disposal and maximum processing capacity

Recycling center and Waste products	w_j (million RMB)	u_{jl} (RMB/t)	p_{jl}^c (t)
j=1, l=1	150	1000	20000
j=1, l=2		800	8000
j=2, l=1	300	950	10000
j=2, l=2		850	5000
j=3, l=1	100	900	15000
j=3, l=2		800	6000

TABLE VI. Recovery quantity of waste products

Recycle bin	q_{il} (t)	
	l=1	l=2
i=1	6000	2000
i=2	4000	3000
i=3	3000	1000
i=4	7000	2000

TABLE VII. Demand for waste products of remanufacturing plant

Remanufacturing plant	n_{kl} (t)	
	l=1	l=2
k=1	8000	5000
k=2	12000	3000

TABLE VIII. Production capacity of remanufacturing plant

Remanufacturing plant	p_{kl}^m (t)	
	l=1	l=2
k=1	10000	6000
k=2	15000	5000

TABLE IX. Shortest delivery time and longest delivery time

Remanufacturing plant	Delivery time(h)	
	Time satisfaction equals 1	Time satisfaction equals 0
k=1	5	15
k=2	1	10

By programming, the model has been optimized in the term of simple objective optimization, the result can be got that $f_{tc}(x)^{\min}=36618070$, $z_1=1$, $z_2=0$, $z_3=1$, $f_{tc}(x)^{\max}=47476340$, $z_1=1$, $z_2=1$, $z_3=1$, $f_{ts}(x)^{\max}=25723.32$, $z_1=1$, $z_2=1$, $z_3=1$, $f_{ts}(x)^{\min}=9998.67$, $z_1=1$, $z_2=0$, $z_3=1$.

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The conclusion can be drawn from the above optimization results that the objective of total cost and total service satisfaction conflict with each other, therefore, it is necessary to solve the problem by means of multi objective fuzzy optimization method.

Based on the results of single objective optimization, Eq. (13) and Eq. (14) can be changed to Eq. (18) and Eq. (19), as follows:

$$u\left(f_{tc}(x)\right)=\begin{cases}0 & f_{tc}(x)>47476340\\ \dfrac{47476340-f_{tc}(x)}{10858270} & 36618070\le f_{tc}(x)\le 47476340\\ 1 & f_{tc}(x)<36618070\end{cases}\qquad(18)$$

$$u\left(f_{ts}(x)\right)=\begin{cases}0 & f_{ts}(x)<9998.67\\ \dfrac{f_{ts}(x)-9998.67}{15724.65} & 9998.67\le f_{ts}(x)\le 25723.32\\ 1 & f_{ts}(x)>25723.32\end{cases}\qquad(19)$$

According to Eq. (15) to Eq. (17) and giving different weights to the objective of total cost and total service satisfaction, such as $w_1=0.9/w_2=0.1$, $w_1=0.1/w_2=0.9$, or $w_1=w_2=0.5$, and the solution of the multi-objective optimization mode can be acquired, the results are shown in TABLE X to TABLE XIX.

TABLE X. Optimal value of the objective and the location result($w_1=0.9, w_2=0.1$)

w_1	w_2	$f_{tc}(x)$	$f_{ts}(x)$	$u\left(f_{tc}(x)\right)$	$u\left(f_{ts}(x)\right)$	$w_1\times u\left(f_{tc}(x)\right)+w_2\times u\left(f_{ts}(x)\right)$	z_1	z_2	z_3
0.9	0.1	36618070	21216.42	1	0.7134	0.9713	1	0	1

TABLE XI. Optimal value of the objective and the location result ($w_1=0.1, w_2=0.9$)

w_1	w_2	$f_{tc}(x)$	$f_{ts}(x)$	$u\left(f_{tc}(x)\right)$	$u\left(f_{ts}(x)\right)$	$w_1\times u\left(f_{tc}(x)\right)+w_2\times u\left(f_{ts}(x)\right)$	z_1	z_2	z_3
0.1	0.9	37807850	25723.32	0.8904	1	0.9890	1	1	1

TABLE XII Optimal value of the objective and the location result ($w_1=w_2=0.5$)

w_1	w_2	$f_{tc}(x)$	$f_{ts}(x)$	$u\left(f_{tc}(x)\right)$	$u\left(f_{ts}(x)\right)$	$w_1\times u\left(f_{tc}(x)\right)+w_2\times u\left(f_{ts}(x)\right)$	z_1	z_2	z_3
0.5	0.5	37346720	25432.16	0.9329	0.9815	0.9572	1	1	0

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TABLE XIII. Optimal traffic volume between recycle bin and recycling center ($w_1 = 0.9, w_2 = 0.1$)

i	j	l	x_{ijl} (t)
1	1	1	6000
1	1	2	2000
2	1	1	2000
2	1	2	3000
2	3	1	2000
3	3	1	3000
3	3	2	1000
4	3	1	7000
4	3	2	2000

TABLE XIV. Optimal traffic volume between recycle bin and recycling center ($w_1 = 0.1, w_2 = 0.9$)

i	j	l	x_{ijl} (t)
1	1	1	6000
1	1	2	2000
2	2	1	4000
2	2	2	3000
3	1	2	1000
3	2	1	3000
4	1	1	2000
4	1	2	2000
4	2	1	3000
4	3	1	2000

TABLE XV. Optimal traffic volume between recycle bin and recycling center ($w_1 = w_2 = 0.5$)

i	j	l	x_{ijl}
1	1	1	6000
1	1	2	2000
2	2	1	4000
2	2	2	3000
3	1	2	1000
3	2	1	3000
4	1	1	4000
4	1	2	2000
4	2	1	3000

TABLE XVI. Optimal traffic volume between recycling center and remanufacturing plant ($w_1 = 0.9, w_2 = 0.1$)

j	k	l	y_{jkl} (t)
1	1	1	8000
1	1	2	5000
3	2	1	12000
3	2	2	3000

TABLE XVII. Optimal traffic volume between recycling center and remanufacturing plant ($w_1 = 0.1, w_2 = 0.9$)

j	k	l	y_{jkl}
1	1	1	8000
1	1	2	5000
2	2	1	10000
2	2	2	3000
3	2	1	2000

TABLE XVIII. Optimal traffic volume between recycling center and remanufacturing plant ($w_1 = w_2 = 0.5$)

j	k	l	y_{jkl}
1	1	1	8000
1	1	2	5000
1	2	1	2000
2	2	1	10000
2	2	2	3000

Comparing the result with different weight, as shown in Table 19.

TABLE XIX. Comparison of the results with different weights

w_1	w_2	$f_{tc}(x)$	$f_{ts}(x)$	$u(f_{tc}(x))$	$u(f_{ts}(x))$	$w_1' u(f_{tc}(x)) + w_2' u(f_{ts}(x))$	z_1	z_2	z_3
0.9	0.1	36618070	21216.42	1	0.7134	0.9713	1	0	1
0.1	0.9	37807850	25723.32	0.8904	1	0.9890	1	1	1
0.5	0.5	37346720	25432.16	0.9329	0.9815	0.9572	1	1	0

In Table 19, the optimization results are different because of the difference in target weight for each optimization. When $w_1 = 0.9$ and $w_2 = 0.1$, the first and third recycling centre is selected, the optimized total cost is 36618070 RMB, the decision-makers satisfaction with the total cost is 1, but the total distribution service is only 0.7134. That is because the total cost target weight value is larger, the total service satisfaction is small, so the model reduces the decision-makers satisfaction with the distribution service to improve the total cost target value. When $w_1 = 0.1$ and $w_2 = 0.9$, the three recycling centre are all selected, the optimized total cost is 37807850

RMB, the decision-makers satisfaction with the total cost is 0.8904, and the total distribution service is enhanced to 1. Because the weight value of the total service goal is far greater than the total cost, compared with the previous results, the decision-makers satisfaction with the total distribution service target is significantly improved, but the satisfaction with the total cost target is reduced. When $w_1 = w_2 = 0.5$, the first and second recycling centre is selected, the optimized total cost is 37346720 RMB, the decision-makers satisfaction with the total cost is 0.9329, and the total distribution service is 0.9815. The goal of the model has been compromised in the optimization process, therefore, the decision-makers satisfaction with the total cost target and the total delivery service satisfaction target are between the above two situations.

V. CONCLUSION

This paper studies a location and network optimization problem of waste products recycling centers simultaneously considering total cost and service satisfaction, and a multi-objective mixed integer programming model for site selection is developed. By establishing the membership function of each objective and using the multi-objective fuzzy optimization method, the multi-objective model is converted into a single target optimization model. Finally, a synthetic example in Shaanxi Province is given, and the model is solved by computer. Digital simulation analyses show that the location and network optimization results of waste products recycling centres are different under the different target weights, which reflects the influence of different decision preferences on the decision results. This paper should be able to provide some suggestions to Third party Recyclers when planning the recycling centre under independent decision.

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