Research on Maximal Covering Problem Based on Cost and Customer Satisfaction Degree

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***Abstract*—According to cost and customer satisfaction degree, we build a bi-objective maximal covering problem in order to study the influence of central station siting by cost and customer satisfaction degree. During solving this bi-objective maximal covering problem, we use the normalized normal constraint method owing to cost and customer satisfaction degree having different dimensions. Finally, taking Shandong waste electronics recycling as an example, we code and solve by CPLEX, and analyzed the results.**

Keywords-customer satisfaction; cost; maximal covering problem; service center; service center; the normalized normal constraint method

I. INTRODUCTION

In the fierce market competition, the quality of enterprise service has become a key factor to merits the success of enterprise logistics. "Close to customer" has appeared when enterprise development marketing strategies, thus the customer satisfaction has been unprecedented attention. Because the customer satisfaction not only plays a key role to development marketing strategies, but also improve the comprehensive competitiveness of enterprises (Angilella et al.,2014 ; Szymanski et al., 2001). Now, many companies adopt a variety of strategies to measure customer satisfaction in order to meet customer needs and analyzing the company's current marketing strategy is appropriate (Fornell et al., 2006). Ma(2005) presents that service facility siting and distribution route choice play a key role to maximize customer satisfaction. When enterprise introduces time satisfaction to location problem, it can help enterprise to lay the foundation to establish an effective mechanism and optimally limited resources, and then keeping the location goals and corporate Strategy consistency.

There are two streams of literature concerning this study. One stream is about customer satisfaction. Subramanian et al.(2014) study the Chinese electronics retail customer satisfaction and competition based on SEM model, and provide the basis for enterprises to develop marketing strategies to meet the growing customer needs and government regulation of electronic retailing. Chow et al.(2014) research customer satisfaction and quality service of Chinese aviation industry and analysis the main factors affecting customers satisfaction and how to improve the quality service of aviation industry. Terpstra et al. (2013) present that customer service costs and customer value pay a positive correlation to customer satisfaction based on the financial services sector experience data. Overall, the above study focused on customer satisfaction how to impact on business marketing strategies and provide decision-making to government to improve service, however, those study did not consider the cost of customer satisfaction.

The second stream is about maximal covering problem. Wang et al.(2006) established a logistics distribution center location model based on modifying alternative expenses and time and solving this model by heuristic algorithm. Ma et al. (2006) defined the time satisfaction and presented the time-satisfaction-based maximal covering location problem, and provided a heuristic algorithm based on Lagrangian relaxation to solve this problem. Yang et al(2013), Mahdi et al.(2013) and Sim et al.(2009) established risk aversion P-hub model, fuzzy P-hub model to solve minimize transport time and r-allocation P-hub model. However, the study above only reached the cost and ignored the customer satisfaction.

In summary, this paper established P-hub model considering cost and customer satisfaction, and token recycling waste engine in Shangdong a case. The normalized normal constraint method was used to solve the P-hub problem considering the different dimensions.

II. MODEL INTRODUCTION

A. Notes

j : alternative recycling center, $j \in \{1, 2, \cdots, M\}$;

i : the i-th recycling center, $i \in \{1, 2, \cdots, N\}$;

G : the alternative recycling center is needed to select from the number of recycling centers, the G is 3 in this paper;

k_j : the disposal costs per unit of product of alternative recycling center j (such as storage costs) ;

f_j : establishment costs of alternative recycling center j ;

c_{ij} : recycling fee per unit of product from alternative recycling center j to recycle bin i ;

c_{mj} : recycling fee per unit of product from alternative recycling center j to recycling center;

r_i : the recovery amount of recycle bin i ;

r_{mj} : the recovery amount from alternative recycling center j to recycling center;

t_{sj} : the operation time of alternative recycling center j ;

t_{ij} : the recovery time per unit used product from alternative recycling center j to recycle bin i ;

t_{mj} : the recovery time per unit used product from alternative recycling center j to recycling center;

f : the customer time satisfaction function ;

U_i : customer could receive the minimum waiting time about recycling bin i when he feels very dissatisfied;

$$x_{ij} = \begin{cases} 1 & \text{the recycle bin } i \text{ chooses alternative recycling center } j; \\ 0 & \text{otherwise.} \end{cases}$$

$$y_j = \begin{cases} 1 & \text{alternative recycling center is choosed as center}; \\ 0 & \text{otherwise.} \end{cases}$$

According to (Karasakal et al.,2004), the customer time satisfaction function is as follows:

$$S_{ij} = \begin{cases} 1 & \text{if } t_{ij} \le U_i; \\ f(t_{ij}) & \text{if } U_i \le t_{ij}. \end{cases}$$

In this paper, we use sigmoid function to measure customer satisfaction function:

$$f(t_{ij}) = \begin{cases} 1 & \text{if } t_{ij} \le U_i; \\ \dfrac{2e^{-\beta(t_{ij}-U_i)}}{1+e^{-\beta(t_{ij}-U_i)}} & \text{if } U_i < t_{ij}; \end{cases}$$

Where β is positive time-sensitive factor.

B. Model

$$\min_{x_{ij},y_j} \sum_{i=1}^{N}\sum_{j=1}^{M} c_{ij}x_{ij}r_i + \sum_{j=1}^{M} c_{mj}y_j r_{mj} + \sum_{j=1}^{M} k_j y_j r_{mj} + \sum_{j=1}^{M} f_j y_j \quad (1)$$

$$\max_{x_{ij},y_j} \sum_{i=1}^{N}\sum_{j=1}^{M} f(t_{ij})x_{ij} + \sum_{j=1}^{N} f(t_{sj})y_j + \sum_{j=1}^{N} f(t_{mj})y_j \quad (2)$$

Constraints:

$$x_{ij} \le x_{jj} \quad \forall j \in M, \forall i \in N \quad (3)$$

$$\sum_{j=1}^{M} x_{ij} = 1 \quad \forall i \in N \quad (4)$$

$$y_j r_{mj} = \sum_{i=1}^{M} x_{ij} r_i \quad \forall j \in M, \forall i \in N \quad (5)$$

$$r_i^t \ge 0 \quad \forall i \in N, \forall t \in T \quad (6)$$

$$\sum_{j=1}^{N} x_{jj} = G \quad (7)$$

$$x_{ij} \in \{0,1\} \quad \forall j \in M, \forall i \in N \quad (8)$$

$$y_j \in \{0,1\} \quad \forall j \in M, \forall i \in N \quad (9)$$

The objective functions (1) and (2) respectively represent the minimum cost and maximize customer satisfaction time. Constraints from (3) to (7) respectively represent the recycling center could recycle the waste products when alternative recycling centers is selected as a recycling center, one recycle bin only belonging to one recycling centers, the amount of recycling center should be equal to the sum of the number of trash recycling of waste products, amount of recovery is greater than zero, the number of recycling centers need to select.

To facilitate solving, the objective functions (2) can be changed to (2a).

$$\min_{x_{ij},y_j} \sum_{i=1}^{N}\sum_{j=1}^{M} -f(t_{ij})x_{ij} - \sum_{j=1}^{N} f(t_{sj})y_j - \sum_{j=1}^{N} f(t_{mj})y_j \quad (2a)$$

III. THE NORMALIZED NORMAL CONSTRAINT METHOD

The normalized constraint method is divided into seven steps:

Setp-1: Anchor. The optimal solution μ^{1*} and μ^{2*} by solving the problems (1) and (2) , and connecting these two points, then the utopia line is got, see it in Fig1.

Setp-2: Normal. In order to avoid different scales and solving optimization problems, the space should be normed. The specific process is as follows:

Let

$$\mu^u = [\mu_1(x^{1*}), \mu_2(x^{2*})]^T$$

$$l_1 = \mu_1(x^{2*}) - \mu_1(x^{1*})$$

$$l_2 = \mu_2(x^{1*}) - \mu_2(x^{2*})$$

Then, the normal space is as follow(see it in Fig2):

$$\bar{\mu} = \{\frac{\mu_1(x) - \mu_1(x^{1*})}{l_1}, \frac{\mu_2(x) - \mu_2(x^{2*})}{l_2}\}$$

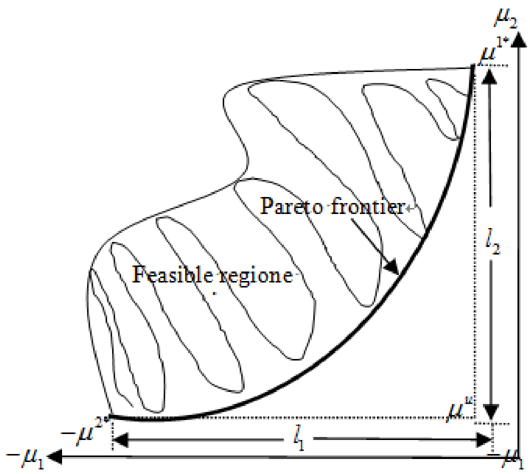

FIGURE I. GENERAL DESIGN METRIC SPACE

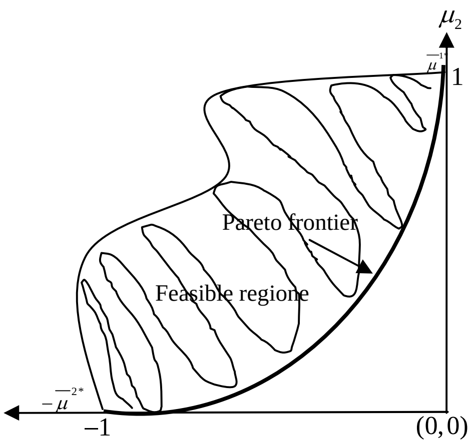

FIGURE II. NORMALIZED DESIGN METRIC SPACE

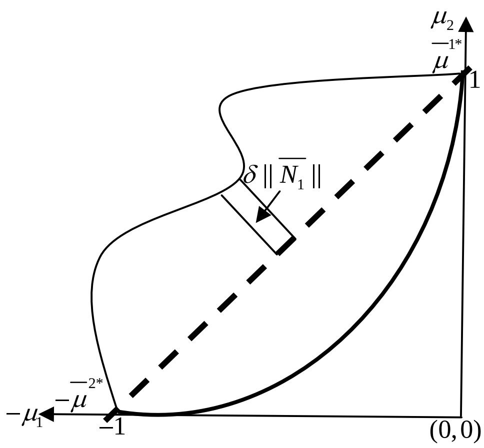

FIGURE III. FIG.3 A SET POINTS ON THE UTOPIA LINE FOR $\bar{\mu}_2$

Setp-3:direction select. $\overline{N_1}$ is the direction from $\bar{\mu}^{1*}$ to $\bar{\mu}^{2*}$, i.e. $\overline{N_1} = \bar{\mu}^{2*} - \bar{\mu}^{1*} = [1,-1]$.

Setp-4:points select. Get incremental δ_1 in standard space and the incremental direction is $\overline{N_1}$, generally, $\delta_1 = \frac{1}{m_1 - 1}$ (m_1 is integer). see it in Fig3.

Setp-5:Generate more anchors according to the direction and increment. The method is as follows:

$$\overline{X_{pj}} = \alpha_{1j}\bar{\mu}^{1*} + \alpha_{2j}\bar{\mu}^{2*}$$

where $0 \le \alpha_{1j} \le 1, \sum_{k=1}^{2}\alpha_{kj} = 1, j \in \{1,2,\cdots,m_1\}$

generally, α_{kj} is δ_1.

Setp-6:Generate Pareto points. The Pareto points can get through the following optimization problems:

$$\min_x \bar{\mu}_2$$

s.t.

$$g_j(x) \le 0 \quad (1 \le j \le r)$$
$$h_k(x) = 0 \quad (1 \le k \le s)$$
$$x_{li} \le x_i \le x_{ui} \quad (1 \le i \le n_x)$$
$$\overline{N}_1(\bar{\mu} - \overline{X}_{pj})^T \le 0$$
$$\bar{\mu} = \{\bar{\mu}_1(x), \bar{\mu}_2(x)\}$$

Setp-7:Solving optimal value in non-standardized space. The optimal value can be got through the following relation:

$$\mu = [\bar{\mu}_1 l_1 + \mu_1(x^{1*}) \quad \bar{\mu}_2 l_2 + \mu_2(x^{2*})]$$

IV. CASE STUDY

A. *Data Preparation*

This paper takes used engine as an example in Shangdong. The used engine is handle in Jinan, and there are 15 recycle bins in Shandong(see Table 1). The 6 recycling bins among the 15 regards as potential service center(see Table 2), and 3 recycling bins are choosed as recycling centry.

TABLE I. THE NAME OF RECYCLE BIN IN SHANDONG PROVINCE

1. recycle bin of Longkou	2. recycle bin of yantai	3. recycle bin of Weifang
4. recycle bin of rizhao	5. recycle bin of dongying	6. recycle bin of jining
7. recycle bin of boxing	8. recycle bin of zibo	9. recycle bin of zaozhuang
10. recycle bin of heze	11. recycle bin of yanzhou	12. recycle bin of laiyang
13. recycle bin of liaocheng	14. recycle bin of qingzhou	15. recycle bin of wendeng

TABLE II. POTENTIAL SERVICE CENTER BEING CHOOSED

1. recycle bin of yantai	2. recycle bin of jining	3. recycle bin of boxing
4. recycle bin of yanzhou	5. recycle bin of laiyang	6. recycle bin of qingzhou

TABLE III. THE DISTANCE FROM POTENTIAL SERVICE CENTER TO RECYCLE BIN (KILOMETER)

No.	1	2	3	4	5	6
1	100	280	130	270	70	120
2	0	300	180	290	100	160
3	120	200	100	190	100	50
4	170	140	155	130	110	120
5	170	210	50	200	125	50
6	300	0	170	40	250	170
7	180	170	0	160	135	50
8	180	150	60	130	126	28
9	300	70	190	60	250	180
10	350	60	200	70	300	170
11	290	40	160	0	240	150
12	100	250	135	240	0	110
13	300	85	130	110	240	130
14	160	170	50	150	110	0
15	60	300	200	300	100	180

TABLE IV. THE TIME FROM POTENTIAL SERVICE CENTER TO RECYCLE BIN (HOUR)

No.	1	2	3	4	5	6
1	4.5	10	7	10	5	6
2	0	11	8	11	5	7
3	6	8	5	8	5	4.5
4	7.5	7	7.5	7	6	6.5
5	7.5	8.5	5	8	9	6.5
6	11	0	7.5	4	10	7.5
7	8	7.5	0	7.5	7	5
8	7.5	7	4	6.5	6.5	4
9	11	5	8	5	9.5	7.5
10	12	5	8	5	10.5	8
11	11	4	7.5	0	9.5	7.5
12	5	10	7	9.5	0	7.5
13	10	6	7	6	9	7
14	7	7.5	5	7.5	7.5	0
15	5	11.5	9	11	11	8

TABLE V. THE UNIT COST OF HANDLING IN THE POTENTIAL SERVICE CENTER(YUAN)

No.	1	2	3	4	5	6
fee	120	90	55	70	100	70

TABLE VI. THE UNIT COST OF TRANSPORTATION FROM ALTERNATIVE RECYCLING CENTER TO RECYCLING CENTER(YUAN)

No.	1	2	3	4	5	6
fee	75	80	75	120	110	90

TABLE VII. THE SETUP COST OF POTENTIAL SERVICE CENTER(YUAN)

No.	1	2	3	4	5	6
fee	11000	12000	15000	13000	11500	10000

TABLE VIII. THE OPERATION TIME OF POTENTIAL SERVICE CENTER(HOUR)

No.	1	2	3	4	5	6
fee	2	3	5	5	4	4

TABLE IX. THE TRANSPORTATION TIME FROM ALTERNATIVE RECYCLING CENTER TO RECYCLING CENTER (HOUR)

No.	1	2	3	4	5	6
time	9	6	5	5.5	5.5	5

B. Solving

This paper solved this problem by matlab(R2012a,64 -bit). The optimal is as follows:

TABLE X. OPTIMAL VALUES OF DIFFERENT PARAMETERS

A	29α	the optimal location	the optimal values of $\mu_1(x)$	the optimal values of $\mu_2(x)$	the optimal values of $\overline{\mu_2}(x)$
0.1	1	Fig.4	44347	-18.5094	0.999998
	2-4	Fig.5	46970	-18.5141	0.944727
	5-11	Fig.6	46106	-18.5221	0.852335
	12-13	Fig.7	48521	-18.5435	0.604159
	14-16	Fig.8	46354	-18.5499	0.530672
	17-28	Fig.9	45458	-18.5599	0.414053
0.3	1-9	Fig.4	44347	-14.2916	1.000001
	10-28	Fig.10	45415	-14.2999	0.671382
0.5	1-2	Fig.10	45415	-14.4632	0.98419
	3-5	Fig.11	44551	-14.4732	0.90155
	6-7	Fig.9	45458	-14.4823	0.82634
	8-28	Fig.6	45490	-14.4922	0.74371
	1	Fig.4	44347	-9.18438	0.999996
	2-4	Fig.10	45415	-9.18942	0.952022

0.7	5-8	Fig.11	44551	-9.20032	0.848129
	9	Fig.15	45787	-9.21571	0.701458
	10-15	Fig.12	46022	-9.21779	0.681657
	16-17	Fig.13	45527	-9.24209	0.449985
	18-28	Fig.14	46595	-9.24713	0.402011

notes: $\mu_1(x)$ is the objective functions(1) , $\mu_2(x)$ is the objective functions(2a)

C. *Result analysis*

(1)The optimal solution of iterative point of 2-16 is inadvisable comparing with iterative point of 2-16 17-28 when β is 0.1 , because the optimal value of iterative point of 2-16 is more than the optimal value of iterative point of 2-16 17-28. The optimal value of $\mu_1(x)$ has great volatility when β is 0.5 or 0.7. However, the optimal value of $\mu_2(x)$ and is becoming smaller when No. is becoming bigger.

(2)Overall, there are 4 conditions to choose the recycling Center, the first one is :Yantai, Qingzhou, Jining; the second one is : Yantai, Qingzhou, Yanzhou; the third one is Yantai, Boxing, Jining; the last one is Yantai, Boxing, Yanzhou. (3)Volatility of Rizhao and Liaocheng is relatively large than other recycling Bin.

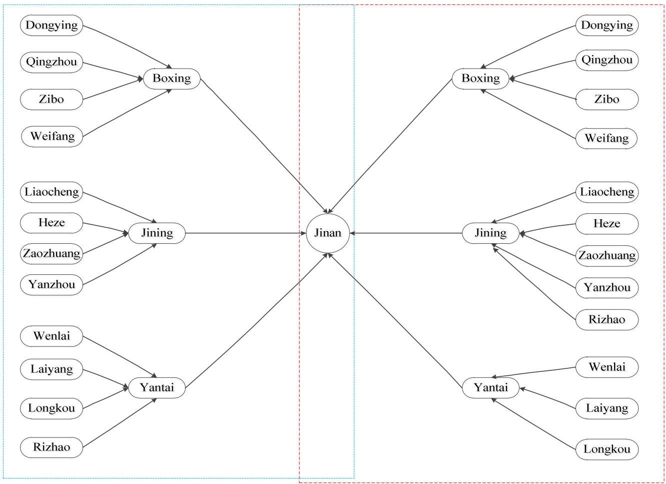

Fig.4 Fig.5

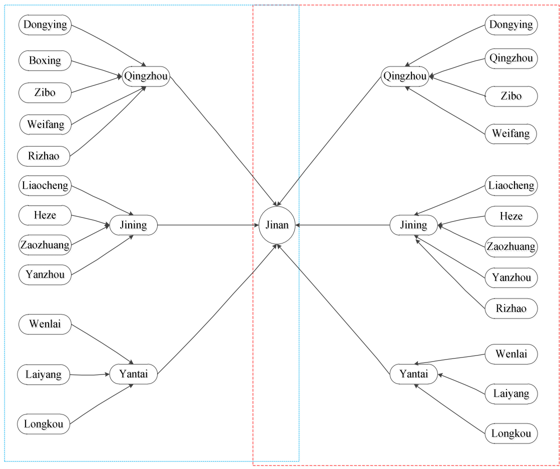

Fig.6 Fig.7

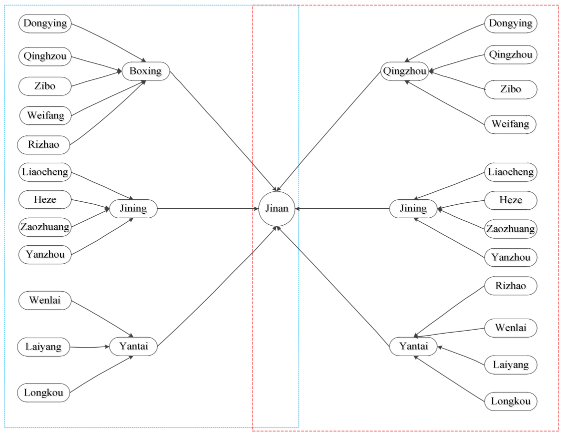

Fig.8 Fig.9

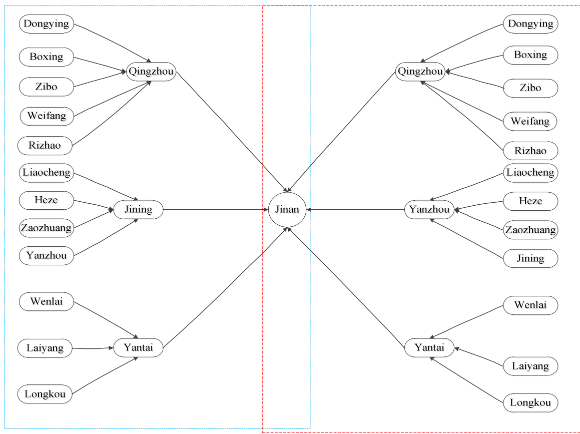

Fig.10 Fig.11

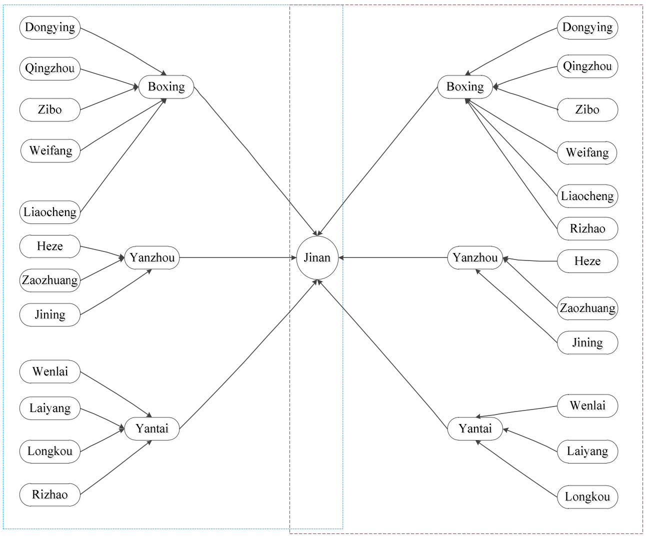

Fig.14 Fig.15

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