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Optimization of Power Batteries in Reverse Logistics Network

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A multi-level reverse logistics network for power batteries is constructed. Considering the uncertainty of recycling quantity, direct utilization rate and recycling utilization rate, a multi-objective programming model is established from the economic and environmental perspectives. The multi-objective is transformed into a single objective by using epsilon-constraint method. Genetic algorithm is chosen to solve the problem. The effect of direct utilization rate on location selection and network cost is analyzed. The results show that: direct utilization rate has little effect on location selection. When the network is in short supply, with the increase of the direct utilization rate the network cost will decrease in the current period. when there is storage of network, with the increase of the direct utilization rate the network cost will increase in the current period.

Keywords: Multi-objective optimization, Power battery, Reverse logistic, Uncertainty, Epsilon-constraint method.

1. Introduction

It's estimated that the total scrap batteries from new energy power vehicles will reach about 134.49GWh in 2025. In the face of such high volume of scrapping batteries, if they cannot be treated and recycled reasonably, it will not only affect the resource recycling, but also will bring pollution to the environment. Therefore, it is of great practical significance to study the recycling of power batteries.

There are many researches carried out on reverse logistics network, in terms of optimization objectives, Xiao et al. (2019) constructed reverse logistics network and developed a mixed-integer programming model with the goal of minimizing the cost. Ayvaz et al. (2015) designed a multi-echelon reverse logistics network and a mixed-integer programming model for maximizing the profit was developed. EI-Sayed et al. (2010) constructed a mixed-integer programming model aiming at profit maximization. This literature mainly focused on the single objective of economic, and gives little consideration to the environmental perspectives. The optimization of economic goals is always at the expense of environment and there's no optimization for both at the same time. In order to maximize the overall profits, the balance between the two goals is essential. In the area of uncertainty, Soleimani and Govindan (2014) proposed two-stage stochastic programming model, considering the uncertainty of return quantity. Sasikumar et al. (2010) considered the uncertainty of demand and prices of return products, and a model with stochastic demand and prices of return products was presented. Ding et al. (2014) stated the uncertainty of demand and built a stochastic programming model. This literature uses scenario analysis and stochastic programming, while fuzzy programming is rarely mentioned. Stochastic programming needs the distribution model of uncertain parameters.

Based on those above, this paper builds a multi-period, multi-objective and multi-level reverse logistics network. Considering the uncertainties of recycling quantity, direct utilization rate and recycling rate, a multi-objective model is established. The uncertain parameters of the model are processed by fuzzy programming method, and the multi-objective is transformed into single objective by epsilon-constraint method. By solving the model, location selection, quantity of shortage and flow between facilities are obtained, and the influence of direct utilization rate on total network cost and facility location is analyzed.

2. Model Construction

2.1.*Problem description*

As it is shown in Fig. 1., the recycle points of the network are responsible for collecting waste power batteries, and the transit stations will check the quality of the waste power batteries after receiving them from the recycle points. Based on the quality inspection results, the recyclable parts of the power batteries will be sent to the maintenance centers or the recycling centers. The rest is wound up to waste disposal stations. The serviceable power batteries are renewed in the maintenance centers and sent to the warehouse centers, then shipped to the second-hand markets for sale. A multi-objective mixed-integer programming model is established.

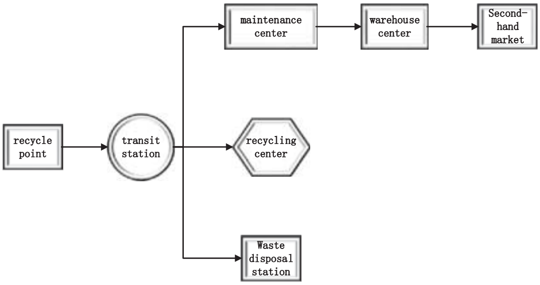

Fig. 1.A reverse logistics network.

2.2.*Model assumption*

(1) In addition to the warehouse center, other sites ignore the storage costs, select a warehouse center from multiple alternative storage centers;
(2) It is necessary to bear the corresponding punishment costs when the demand of second - hand markets can't be meet;
(3) The waste treatment station should be selected near the transfer station. The transportation cost from the transit stations to the waste treatment station and the fixed cost of the waste treatment station should be ignored.

2.3.*Parameter definition*

2.3.1. *Indexes*

L : Set of recycle points $l \in L$.
I : Set of transit stations $i \in I$.
J : Set of second-hand markets $j \in J$.
N : Set of warehouse centers $n \in N$.
M : Set of recycling centers $m \in M$.
R : Set of maintenance centers $r \in R$.
T : Period $t \in T$.

2.3.2. *Decision variable*

x_i : if establishing transit station i ,1; otherwise,0.
x_m : if establishing recycling center m ,1; otherwise,0.
x_n : if establishing warehouse center n ,1; otherwise,0.
x_r : if establishing maintenance center r ,1; otherwise,0.
q_{lit} : Number of transferred from recycle point l to transit station i in period t .
q_{irt} : Number of transferred from transit station i to maintenance center r in period t .
q_{imt} : Number of transferred from transit station i to recycling center m in period t .
q_{rnt} : Number of transferred from maintenance center r to warehouse center n in period t .
q_{njt} : Number of transferred from warehouse center n to second-hand market j in period t .
o_{nt} : Number of detained in the warehouse center n in period t .
k_{jt} : Shortage number of second-hand market j in period t .

q_{it} : Number of waste power batteries from the transit station i to the waste treatment station in period t.

y_t : If the demand of second-hand markets is not met j in period t, 1; otherwise, 0.

2.3.3. *Parameters*

f_i : the fixed opening cost for transit station i.

f_r : the fixed opening cost for maintenance center r.

f_m : the fixed opening cost for recycling center m.

f_n : the fixed opening cost for warehouse center n.

d_{li} : distance between recycle point l and transit station i.

d_{ir} : distance between transit station i and maintenance center r.

d_{im} : distance between transit station i and recycling center m.

d_{rn} : distance between maintenance center r and warehouse center n.

d_{nj} : distance between warehouse center n and second-hand market j.

t_{li} : unit cost of transportation between recycle point l and transit station i.

t_{ir} : unit cost of transportation between transit station i and maintenance center r.

t_{im} : unit cost of transportation between transit station i and recycling center m.

t_{rn} : unit cost of transportation between maintenance center r and warehouse center n.

t_{nj} : unit cost of transportation between warehouse center n and second-hand market j.

b_i : unit cost of disposal at transit station i.

b_r : unit cost of disposal at maintenance center r.

b_m : unit cost of disposal at recycling center m.

q_{jt} : demand quantity of the second-hand market j in period t.

$\tilde{g}_{lt}$: fuzzy recycling quantity of recycle point l in period t.

s_l : unit recycling price at recycle point l.

c_{nt} : unit storage cost of detained in the warehouse center n.

c_{jt} : unit penalty cost of shortage in the second-hand market j.

c_{it} : unit cost of disposal of waste power batteries from the transit station i to the waste treatment station in period t.

e_i : fixed CO2 emissions of establishing transit station i.

e_r : fixed CO2 emissions of establishing maintenance center r.

e_m : fixed CO2 emissions of establishing recycling center m.

e_n : fixed CO2 emissions of establishing warehouse center n.

e_{it} : unit CO2 emission of disposal of waste power batteries from the transit station i to the waste treatment station in period t.

w : CO 2 emission in moving one unit of product in one unit of distance.

g_i : unit CO2 emission of disposal at transit station i.

g_r : unit CO2 emission of disposal at maintenance center r.

g_m : unit CO2 emission of disposal at recycling center m.

$\tilde{a}_1$: direct utilization rate (fuzzy number).

$\tilde{a}_2$: recycling rate (fuzzy number).

H_i : Maximum capacity of transit station i.

H_m : Maximum capacity of recycling center m.

2.4. *Model formulation*

According to the problem description and the parameter definition, the objective function is described as follows.

Eq. (1) is the objective function which is minimized total costs. The total costs F_1 includes the fixed costs of CF in Eq. (2), disposal costs CP in Eq. (3), storage costs and penalty costs CS in Eq. (4), transportation costs CT in Eq. (5) and recycling cost CL in Eq. (6).

$$\min F_1 = CF + CP + CS + CT + CL \tag{1}$$

$$CF = \sum_{i\in I} x_i f_i + \sum_{r\in R} x_r f_r + \sum_{m\in M} x_m f_m + \sum_{n\in N} x_n f_n \tag{2}$$

$$\begin{aligned} CP = &\sum_{l\in L}\sum_{i\in I}\sum_{t\in T} q_{lit} b_i + \sum_{i\in I}\sum_{r\in R}\sum_{t\in T} q_{irt} b_r \\ &+ \sum_{i\in I}\sum_{m\in M}\sum_{t\in T} q_{imt} b_m + \sum_{i\in I}\sum_{t\in T} q_{it} c_{it} \end{aligned} \tag{3}$$

$$CS = \sum_{j\in J}\sum_{t\in T} k_{jt} c_{jt} y_t + \sum_{n\in N}\sum_{t\in T} o_{nt} c_{nt} (1 - y_t) \tag{4}$$

$$\begin{aligned} CT = &\sum_{i\in I}\sum_{l\in L}\sum_{t\in T} q_{lit} d_{li} t_{li} + \sum_{r\in R}\sum_{i\in I}\sum_{t\in T} q_{irt} d_{ir} t_{ir} \\ &+ \sum_{i\in I}\sum_{m\in M}\sum_{t\in T} q_{imt} d_{im} t_{im} + \sum_{r\in R}\sum_{n\in N}\sum_{t\in T} q_{rnt} d_{rn} t_{rn} \\ &+ \sum_{n\in N}\sum_{j\in J}\sum_{t\in T} q_{njt} d_{nj} t_{nj} \end{aligned} \tag{5}$$

$$CL = \sum_{l\in L}\sum_{t\in T} \tilde{g}_{lt}\, s_l \tag{6}$$

The carbon emissions are minimized in Eq. (7). The carbon emissions F_2 includes the fixed carbon emissions *EF* in Eq. (8), transportation carbon emissions *ET* in Eq. (9) and disposal carbon emissions *EP* in Eq. (10).

$$\min F_2 = EF + ET + EP \tag{7}$$

$$EF = \sum_{i\in I} e_i x_i + \sum_{r\in R} e_r x_r + \sum_{m\in M} e_m x_m + \sum_{n\in N} e_n x_n \tag{8}$$

$$\begin{aligned} ET = (&\sum_{l\in L}\sum_{i\in I}\sum_{t\in T} q_{lit} d_{li} + \sum_{i\in I}\sum_{r\in R}\sum_{t\in T} q_{irt} d_{ir} \\ &+ \sum_{i\in I}\sum_{m\in M}\sum_{t\in T} q_{imt} d_{im} + \sum_{r\in R}\sum_{n\in N}\sum_{t\in T} q_{rnt} d_{rn} \\ &+ \sum_{n\in N}\sum_{j\in J}\sum_{t\in T} q_{njt} d_{nj}) w \end{aligned} \tag{9}$$

$$\begin{aligned} EP = &\sum_{l\in L}\sum_{i\in I}\sum_{t\in T} q_{lit} g_i + \sum_{i\in I}\sum_{r\in R}\sum_{t\in T} q_{irt} g_r \\ &+ \sum_{i\in I}\sum_{m\in M}\sum_{t\in T} q_{imt} g_m + \sum_{i\in I}\sum_{t\in T} q_{it} e_{it} \end{aligned} \tag{10}$$

Subject to

$$\sum_{i\in I} q_{lit} = \tilde{g}_{lt} \quad \forall l \in L, \forall t \in T \tag{11}$$

$$\sum_{l\in L} q_{lit} = \sum_{r\in R} q_{irt} + \sum_{m\in M} q_{imt} + q_{it} \ \forall i \in I, \forall t \in T \tag{12}$$

$$\tilde{a}_1 \sum_{l\in L} q_{lit} = \sum_{m\in M} q_{imt} \ , \forall i \in I, \forall t \in T \tag{13}$$

$$\tilde{a}_2 \sum_{l\in L} q_{lit} = \sum_{r\in R} q_{irt} \quad \forall i \in I, \forall t \in T \tag{14}$$

$$\sum_{i\in I} q_{imt} \le H_m x_m \, , \forall m \in M, \forall t \in T \tag{15}$$

$$\sum_{i\in I} q_{irt} \le H_r x_r , \forall r \in R, \forall t \in T \tag{16}$$

$$\sum_{l\in L} q_{lit} \le H_i x_i , \forall i \in I, \forall t \in T \tag{17}$$

$$\sum_{n\in N} q_{rnt} = \sum_{i\in I} q_{irt} , \forall r \in R, \forall t \in T \tag{18}$$

$$\begin{aligned} &\sum_{r\in R}\sum_{n\in N} q_{rnt} + \sum_{n\in N} o_{n(t-1)} = \sum_{j\in J} q_{jt} - \sum_{j\in J} k_{jt} y_t \\ &+ \sum_{n\in N} o_{nt} (1 - y_t) \forall t \in T, \ \ y_t \in \{0,1\} \end{aligned} \tag{19}$$

$$\sum_{n\in N} x_n = 1 \tag{20}$$

Eq. (11) indicates the recycled batteries can be transported to the transit stations; Eq. (12) represents the equilibrium of flows to the transit stations; Eq. (13) and Eq. (14) indicate that the waste batteries meet the quality requirements, respectively; Eq. (15), Eq. (16) and Eq. (17) are the capacity constraints; Eq. (18) represents the equilibrium of flows to maintenance centers; Eq. (19) represents the equation relationship between the storage number and the shortage number; Eq. (20) represents the number of warehouse center that be established.

2.5. *Model transformation*

The $\tilde{g}_{lt}$, $\tilde{a}_1$ and $\tilde{a}_2$ are triangular fuzzy numbers, which are respectively recorded as $\tilde{g}_{lt} = (g_{lt1}, g_{lt2}, g_{lt3})$, $\tilde{a}_1 = (a_{11}, a_{12}, a_{13})$, $\tilde{a}_2 = (a_{21}, a_{22}, a_{23})$. The fuzzy constraints are processed by triangular distribution, and the chance-constrained programming model is obtained:

$$Pos\{\sum_{i\in I} q_{lit} = \tilde{g}_{lt}\} \ge b_1 \tag{21}$$

$$Pos\{\tilde{a}_1\sum_{l\in L}q_{lit}=\sum_{m\in M}q_{imt}\}\geq b_2 \tag{22}$$

$$pos\{\tilde{a}_2\sum_{l\in L}q_{lit}=\sum_{r\in R}q_{irt}\}\geq b_3 \tag{23}$$

Eqs. (21)~(23) reflect that the probability of satisfying the constraints should not be less than the given confidence level b_1, b_2, b_3. Theorem 1. is quoted from Liu and Guo (2021) as follows:

Theorem1. Suppose the triangular fuzzy number $\tilde{\varepsilon}=\{\varepsilon_1,\varepsilon_2,\varepsilon_3\}$, then for any given confidence level $\alpha(0\leq\alpha\leq 1)$ when $(1\text{-}\alpha)\varepsilon_1+\alpha\varepsilon_2\leq z,(1-\alpha)\varepsilon_3+\alpha\varepsilon_2\geq z,$

$Pos\{\tilde{\varepsilon}=z\}\geq\alpha$, is true.

According to the expected value of triangular fuzzy numbers and Theorem 1., Eq. (1), Eq. (11), Eq. (13) and Eq. (14) can be converted into the following formulas:

$$\begin{aligned}\min E[F_1]=&\sum_{\mathrm{i}\in\mathrm{I}}x_i f_i+\sum_{r\in R}x_r f_r+\sum_{m\in M}x_m f_m+\sum_{k\in K}x_k f_k\\&+\sum_{n\in N}x_n f_n+\sum_{l\in L}\sum_{i\in I}\sum_{t\in T}q_{lit}b_i+\sum_{n\in N}\sum_{t\in T}o_{nt}c_{nt}(1-y_t)\\&+\sum_{i\in I}\sum_{t\in T}q_{it}c_{it}+\sum_{i\in I}\sum_{r\in R}\sum_{t\in T}q_{irt}b_r+\sum_{i\in I}\sum_{m\in M}\sum_{t\in T}q_{imt}b_m\\&+\sum_{t\in T}\sum_{i\in I}\sum_{r\in R}q_{irt}d_{ir}t_{ir}+\sum_{i\in I}\sum_{m\in M}\sum_{t\in T}q_{imt}d_{im}t_{im}\\&+\sum_{j\in J}\sum_{t\in T}k_{jt}c_{jt}y_t+\sum_{n\in N}\sum_{j\in J}\sum_{t\in T}q_{njt}d_{nj}t_{nj}+\sum_{i\in I}\sum_{l\in L}\sum_{t\in T}q_{lit}d_{li}t_{li}\\&+\sum_{n\in N}\sum_{j\in J}\sum_{t\in T}q_{njt}d_{nj}t_{nj}+\sum_{r\in R}\sum_{n\in N}\sum_{t\in T}q_{rnt}d_{rn}t_{rn}\\&+\sum_{l\in L}\sum_{t\in T}s_l(g_{lt1}+2g_{lt3}+g_{lt2})/4\end{aligned} \tag{24}$$

$$\sum_{i\in I}q_{lit}\geq(1-b_1)g_{lt1}+b_1g_{lt2} \tag{25}$$

$$\sum_{i\in I}q_{lit}\leq(1-b_1)g_{lt3}+b_1g_{lt2} \tag{26}$$

$$\sum_{m\in M}q_{imt}\geq[(1-b_2)\alpha_{11}+b_2\alpha_{12}]\sum_{l\in L}q_{lit} \tag{27}$$

$$\sum_{m\in M}q_{imt}\leq[(1-b_2)\alpha_{13}+b_2\alpha_{12}]\sum_{l\in L}q_{lit} \tag{28}$$

$$\sum_{r\in R}q_{irt}\geq[(1-b_3)\alpha_{21}+b_3\alpha_{22}]\sum_{l\in L}q_{lit} \tag{29}$$

$$\sum_{r\in R}q_{irt}\leq[(1-b_3)\alpha_{23}+b_3\alpha_{22}]\sum_{l\in L}q_{lit} \tag{30}$$

3. Solution Method

3.1.*Epsilon-constraint method*

Epsilon-constraint method can be used to transform the multi-objective into a single objective problem, so Eq. (7) can be converted into Eq. (31).

$$\begin{aligned}&\sum_{i\in I}e_ix_i+\sum_{r\in R}e_rx_r+\sum_{m\in M}e_mx_m+\sum_{n\in N}e_nx_n++(\sum_{l\in L}\sum_{i\in I}q_{lit}d_{li}\\&+\sum_{r\in R}\sum_{n\in N}q_{rnt}d_{rn}+\sum_{i\in I}\sum_{r\in R}q_{irt}d_{ir}+\sum_{i\in I}\sum_{m\in M}q_{imt}d_{im}\\&+\sum_{n\in N}\sum_{j\in J}q_{njt}d_{nj})w+\sum_{i\in I}q_{it}c_{it}+\sum_{l\in L}\sum_{i\in I}q_{lit}g_i\\&+\sum_{i\in I}\sum_{r\in R}q_{irt}g_r+\sum_{i\in I}\sum_{m\in M}q_{imt}g_m\leq\varepsilon,\ \forall t\in T\end{aligned} \tag{31}$$

3.2.*Genetic algorithm*

Genetic Algorithm applied in machine learning and optimization problems. It has the advantages of operating simple and strong robustness. The initial population size is 1000, the maximum number of iterations is 200, the crossover rate is 0.8, and the mutation rate is 0.1.

3.2.1. *Coding*

Hybrid coding is used to enhance the search ability of the algorithm model. Binary coding is simple, but the chromosome length is long and has large search space. The variables related to traffic use real-number coding.

3.2.2. *Fitness function*

In order to make better individuals in the population inherit to the next generation, the only fitness function that can evaluate the selection opportunity of the population is established. In this paper, the objective function value is used as the fitness function value.

3.2.3. *Selection operator*

Roulette wheel selection is the most commonly used selection operator. The probability of chromosome selection is proportional to its fitness value.

3.2.4. *Crossover operator*

This paper selects single-point crossover of binary code and simple crossover of real-number. Simple crossover's process is similar to binary single-point crossover.

3.2.5. *Mutation operator*

According to the different coding methods, uniform mutation operator of real-number code is adopted.

4. A Case Study

4.1 *An optimization solution*

In order to achieve the recovery of power batteries, it is planned to design a reverse logistics network consisting of recycle points, transit stations, maintenance centers, recycling centers, warehouse centers and second-hand markets to achieve the required goals at a lower cost.

Considering three recycle points (L_1, L_2, L_3), two transit stations (I_1, I_2), three recycling centers (M_1, M_2, M_3), two maintenance centers (R_1, R_2), two storage centers (N_1, N_2), and three second-hand markets (J_1, J_2, J_3), and solving three periods; set the confidence level, b_1=0.8, b_2=b_3=0.9 other parameters are shown in Table 1.

Table 1. Model parameter value

Parameter	Value	Parameter	Value
f_i	1500000(CNY)	f_r	780000(CNY)
f_m	680000(CNY)	f_n	760000(CNY)
t_{rn}	U(0.025,0.045) (CNY)	t_{li}	U(0.015,0.025) (CNY)
t_{ir}	U(0.015,0.025) (CNY)	t_{im}	U(0.015,0.025) (CNY)
t_{nj}	U(0.025,0.045) (CNY)	b_i	U(1500,1900) (CNY)
b_r	U(1500,1900)(CNY)	b_m	U(1500,1900) (CNY)
w	0.023(kg)	s_l	U(2000,2500)(CNY)
e_i	U(20000,24000)(kg)	e_r	U(20000,24000)(kg)
e_m	U(20000,24000) (kg)	e_n	U(20000,24000) (kg)
g_i	U(170,230) (kg)	g_m	U(170,230) (kg)
g_r	U(170,230) (kg)	H_r	7000000(units)

Table 1. (continued)

Parameter	Value	Parameter	Value
H_i	1000000(units)	H_m	7000000(units)
$\tilde{a}_1$	(0.2,0.4,0.5)	$\tilde{a}_2$	(0.3,0.4,0.45)
$\tilde{g}_{l1}$	(180000,200000,290000) (units)	$\tilde{g}_{l2}$	(280000,350000,380000) (units)
$\tilde{g}_{l3}$	(680000,780000,800000) (units)	ε	10000000(kg)
d_{li}	U(7.2,12)(km)	d_{ir}	U(11.7,15) (km)
d_{im}	U(9.6,12.1) (km)	d_{rn}	U(4.5,9.1) (km)
d_{nj}	U(5.6,11.4) (km)	c_{nt}	U(80,100) (CNY)
c_{jt}	U(2500,3000) (CNY)	c_{it}	U(50,70) (CNY)
e_{it}	U(150,180)(kg)		

Table 2. The demand of the second-hand market in period(units)

q_{11}	90000	q_{21}	80000	q_{31}	100000
q_{12}	150000	q_{22}	140000	q_{32}	130000
q_{13}	190000	q_{23}	170000	q_{33}	140000

According to the parameter values in Table 1 and Table 2, F_1 is taken as the solution target, and F_2 is transformed into constraint. Considering $\tilde{g}_{lt}$, $\tilde{a}_1$ and $\tilde{a}_2$ are triangular fuzzy numbers, and the hybrid coding genetic algorithm is used to solve the model. As can be seen from the calculation results: the location strategy is I_2, r_2, m_2 and n_2 are selected. The optimal solution of the objective function in each period is obtained, as shown in Table 3. Meanwhile, the quantity of shortage and storage in the market in period are obtained, as shown in Table 4. It can be concluded that the second-hand markets are in short supply in the first period t; With the increase of recycling quantity, the second-hand markets demand in the last two periods are satisfied.

Table 3. Optimal solution in each period

	t=1	t=2	t=3
F_1(CNY)	2.75×10^{15}	2.81×10^{9}	5.76×10^{9}
F_2(kg)	2.36×10^{6}	3.72×10^{6}	7.09×10^{6}

Table 4. Quantity of shortage and inventory

	t=1	t=2	t=3
$\sum_{j\in J} k_{jt}$ (units)	21217		
$\sum_{n\in N} o_{nt}$ (units)		3356	376576

4.2.*Influence of direct utilization rate*

Direct utilization rate has an impact on the flow rate of the maintenance centers, which affects the flow rate between the warehouse centers and the second-hand markets. Direct utilization rate sets as high, medium and low (+10%, 0, -10%), and direct utilization rate=(0.2,0.4,0.5) when it is medium. and the other parameters don't change. The solution results are shown in Table 5, Table 6 and Table 7.

The following conclusions can be drawn: the change of direct utilization rate has little influence on location selection. In the first period, when the markets are in shortage the total network cost and quantity of shortage decreases with the increase of direct utilization rate, as shown in Fig. 2. In the second period, when utilization rate is medium and high the cost increases with the increase of direct utilization rate, as shown in Fig. 3. In the third period, the demand of the second-hand markets is satisfied, and there are enough inventories in the warehouse center. With the increase of direct utilization rate, the quantity of inventory increases, thus the network cost increases, as shown in Fig. 4. When the network is in short supply, with the increase of direct utilization rate the network cost will decrease in the current period. When there is inventory in the network, with the increase of direct utilization rate the network cost will rise in the current period.

Table 5. T=1 the influence of direct utilization rate

$\tilde{a}_1$	F_1(CNY)	$\sum_{j\in J} k_{jt}$ (units)	Location selection
-10%	2.81×10^{15}	49092	I_2,r_2,m_2,n_1
0	2.75×10^{15}	21217	I_2,r_2,m_2,n_2
+10%	2.71×10^{15}	5008	I_2,r_1,m_2,n_1

Table 6. T=2 the influence of direct utilization rate

$\tilde{a}_1$	F_1(CNY)	$\sum_{j\in J} k_{jt}$ (units)	$\sum_{n\in N} o_{nt}$ (units)
-10%	2.92×10^{9}	41943	
0	2.81×10^{9}		3358
+10%	3.03×10^{9}		25642

Table 7. T=3 the influence of direct utilization rate

$\tilde{a}_1$	F_1(CNY)	$\sum_{n\in N} o_{nt}$ (units)
-10%	5.72×10^{9}	350401
0	5.77×10^{9}	376576
+10%	6.0×10^{9}	503946

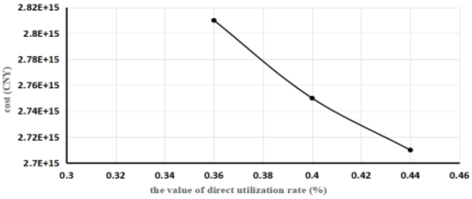

Fig. 2.T=1 The effect of direct utilization rate on cost.

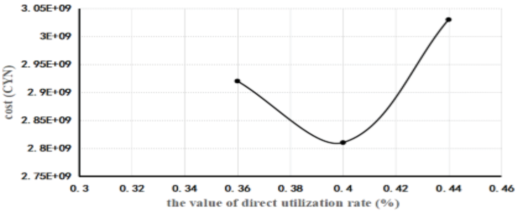

Fig. 3.T=2 The effect of direct utilization rate on cost.

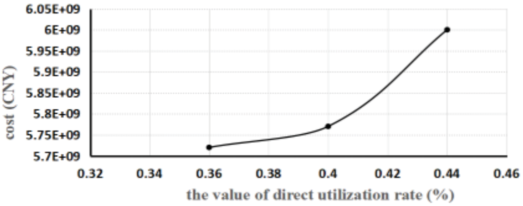

Fig. 4.T=3 The effect of direct utilization rate on cost.

5. Conclusion

This paper constructs a multi-period and multi-objective power battery reverse logistics network. Considering the uncertainties of recovery quantity, direct utilization rate and recycling rate, a mixed-integer programming model is established with the goal of minimizing cost and carbon emissions. The location and quantity of various facilities can be determined, as well as the quantity of shortage, and the influence of the change of direct utilization rate on the network cost and facility location is analyzed. The next research will comprehensively discuss dynamic location.

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