Universe Scientific Publishing

Optimization of Logistics Recycling Network for New Energy Vehicle Batteries in Uncertain Environments

Jue Lu

School of Management, Shanghai University, Shanghai 200444, China.

Abstract: The new energy vehicle industry is developing rapidly, and discarded new energy vehicle power batteries need to be recycled and reused. This study proposes a new comprehensive new energy battery recycling model, establishes a new energy vehicle power battery recycling network model considering uncertain conditions, and combines the advantages of taboo search algorithm and genetic algorithm to design a new hybrid algorithm for solving, verifying the effectiveness and correctness of the model.

Keywords: New Energy Vehicle Power Battery; Uncertainty; Optimization Design of Logistics Network; Tabu Search Genetic Hybrid Optimization Algorithm; Integrated Mode

1. Introduction

With the rapid development of the world economy, the new energy vehicle industry has become one of the fastest growing industries in the new energy industry. Although new energy vehicles have little impact on the environment during use, the discarded batteries, if not handled properly, can have an impact on the environment. At present, China's new energy vehicles are in a period of development, and the market share of new energy vehicles is increasing year by year. Power batteries have also entered a period of scrapping. With the increasing market share and retirement quantity of different types of power batteries, new energy vehicle power battery companies, especially listed companies with resource advantages, are laying out new energy vehicle power battery recycling and processing businesses. This requires companies to have a high level of recycling efficiency, hazardous material control, and environmental pollution treatment measures. Therefore, the academic and business communities need to establish a sound electric vehicle waste battery recycling system from the economic, environmental, and social perspectives.

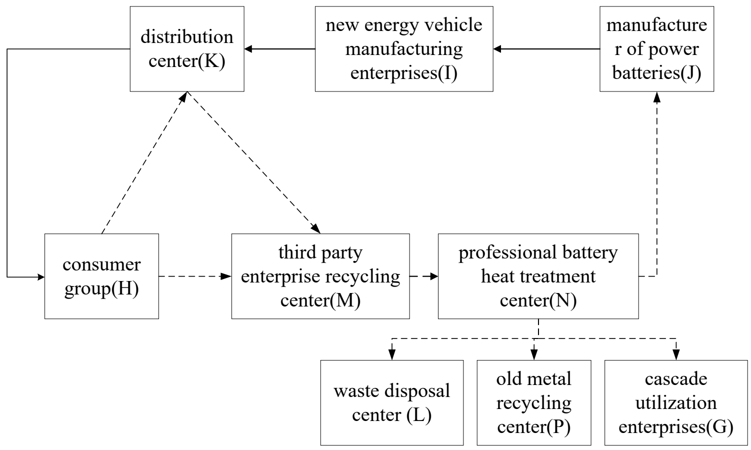
2. Related studies

At present, scholars have conducted research on various issues related to power battery recycling technology, recycling models and strategies, and recycling network design. Yun et al. [1] summarized the existing recycling technologies in mechanical programming and chemical recycling. Beaudet et al. [2] discussed the current economic and environmental factors related to power battery recycling, creating a favorable economic and regulatory environment for battery recycling. Kumar et al. [3] compiled a list of challenges related to the sustainability of electric vehicle battery logistics networks, including business, technological, economic, environmental, and social challenges. He et al. [4] proposed the design of a reverse logistics network for waste power batteries and two recycling models for the reverse logistics network for waste power batteries. Tang et al. [5] proposed and compared three scenarios: S1 no policy intervention, S2 subsidy mechanism, and S3 reward and punishment mechanism. Langarudi et al. [6] constructed a mixed integer linear programming model to minimize costs and carbon emissions, and conducted numerical examples for analysis. Tadaros et al. [7] constructed a mixed integer programming model and applied it to the Swedish market to optimize the future logistics network of discarded lithium-ion batteries. Lidan H et al. [8] optimized the reverse logistics network for power battery recycling to establish a complete green recycling network.

Himanshu et al. [9] proposed three reverse logistics models in the Indian industry. Islam et al. [10] proposed a mixed integer programming reverse logistics network model with the objective function of minimizing total cost. Reddy et al. [11] proposed a mixed integer linear programming (MILP) model to solve a multi-level, multi period green reverse logistics network. Wang et al. [12] constructed a reverse logistics network system for waste tires and analyzed the influencing factors of reverse logistics network location using the Analytic Hierarchy Process. Aqmar et al. [13] proposed a new multi cycle mathematical programming model for optimizing the restructuring of the network of household waste recycling centers.

3. Problem description and model formulation

This study considers uncertain factors such as carbon emission costs, consumer demand, and the quality of power battery recycling, and constructs a mixed integer stochastic programming model with the goal of minimizing total costs. The specific power battery network of new energy vehicles is shown in Figure 1, where the forward logistics supply network part is a solid line process, and the reverse logistics recycling network part is a dashed line process.



false

Figure 1 Design diagram of new energy vehicle power battery network

3.1 Notations

3.1.1 Indices and sets

J	power battery production plant J={1,2,…,j,….,J}
I	automobile manufacturing enterprises I={1,2,…,i,….,I}
K	automotive distributors, K={1,2,…,k,….,K}
H	consumer Group H={1,2,…,h,….,H}
M	power Battery Recycling Center M={1,2,…,m,….,M}
N	battery processing center N={1,2,…n,…,N}
L	waste disposal center L={1,2,…l,…L}
P	old metal recycling and processing center P={1,2,…p,…P}
G	power battery cascade utilization enterprise G={1,2,…g,…,G}
S	set of all scenarios S={1,2,…,s,…S}

3.1.2 Parameters

R_{hs}	the demand of consumer group h under scenario s
w_s	probability of scenario s
f_m	the construction cost of third-party recycling center
f_n	the construction cost of battery processing center
b_m	unit processing cost of third-party recycling centers

b_n	unit processing cost of battery processing center
b_l	unit processing cost of waste disposal center
c_b	unit transportation cost of batteries
c_a	unit transportation cost of raw materials
c_l	unit transportation cost of waste
O_m	the recycling capacity of third-party enterprise recycling centers
O_n	the processing capacity of professional battery processing centers
r	carbon Tax
E_m	unit CO2 emissions from third-party recycling centers
E_n	unit CO2 emissions of the processing center
E_l	unit CO2 emissions from waste disposal centers
E_d	unit CO2 emissions during transportation
c_s	unit storage cost of new energy batteries
d	distance between nodes
α	rate of recovery
β	recycling utilization rate

3.1.3 Decision variables

Q_{hks}	traffic volume from consumer group h to distribution center k under scenario s
Q_{kms}	traffic volume from distribution center k to third-party recycling center m under scenario s
Q_{mns}	traffic volume from third-party recycling center m to battery processing center n under scenario s
Q_{njs}	the transportation volume from battery processing center n to power battery manufacturer j under scenario s
Q_{nls}	the transportation volume from battery treatment center n to waste disposal center l under scenario s
Q_{nps}	the transportation volume from battery processing center n to old metal recycling p under scenario s
Q_{ngs}	the transportation volume from battery processing center n to cascading utilization enterprise g under scenario s
Y_{m}	binary variable equals '1' if third-party recycling center is established at point m, and '0' otherwise
Y_{n}	binary variable equals '1' if battery processing center is established at point n, and '0' otherwise

3.2 Mathematical model

According to the previous description, the optimization model is developed as follows:

$\text{Min}(TC1+TC2+TC3+TC4+TC5)$ (1)

transport cost:

$TC1=\sum_s w_s\, d\,(\sum_{hk} Q_{hks}\, C_b + \sum_{km} Q_{kms}\, C_b + \sum_{mn} Q_{mns}\, C_b + \sum_{(n\,l)} Q_{nls}\, C_l + \sum_{(n\,p)} Q_{nps}\, C_l + \sum_{(h\,g)} Q_{hgs}\, C_a + \sum_{(h\,j)} Q_{hjs}\, C_a)$

The construction cost of the network:

$TC2=\sum_m f_m\, Y_m + \sum_n f_n\, Y_n$

The cost of network recycling, processing, and storage:

$TC3 = \sum_s w_s(\sum_{km} Q_{kms}\, b_m + \sum_{mn} Q_{mns}\, b_n + \sum_{nl} Q_{nls} b_l + \sum_{hk} Q_{hks} c_s)$

Carbon emission cost: total transportation distance × Transport carbon emission conversion coefficient

$TC4 = \sum_s w_s E_d dr\, (\sum_{hk} Q_{hks} + \sum_{km} Q_{kms} + \sum_{mn} Q_{mns} + \sum_{nl} Q_{nls} + \sum_{np} Q_{nps} + \sum_{h\,g} Q_{hgs} + \sum_{hj} Q_{hjs})$

Carbon emission cost: total amount of treatment × Processing carbon emission conversion coefficient

$TC5 = \sum_s w_s r(\sum_{km} Q_{kms}\, E_m + \sum_{nm} Q_{mns}\, E_n + \sum_{nl} Q_{nls} E_l)$

Constraints:

$\sum_h Q_{hks} = \sum_m Q_{kms} \quad \forall k \in K, \forall s \in S$ (2)

$\sum_k Q_{kms} = \sum_n Q_{mns} \quad \forall m \in M, \forall s \in S$ (3)

$\sum_m Q_{mns} = \sum_l Q_{nls} + \sum_p Q_{nps} + \sum_g Q_{ngs} + \sum_j Q_{njs} \quad \forall n \in N, \forall s \in S$ (4)

$\sum_k Q_{kms} \leq O_m Y_m \quad \forall m \in M \quad \forall s \in S$ (5)

$\sum_m Q_{mns} \leq O_n Y_n \quad \forall n \in N \quad \forall s \in S$ (6)

$\alpha * \sum_m Q_{mns} \geq \sum_g Q_{ngs} \quad \forall n \in N \;\; \forall s \in S$ (7)

$\beta * \sum_m Q_{mns} \geq \sum_j Q_{njs} \quad \forall n \in N \quad \forall s \in S$ (8)

$Y_m, Y_n \in \{0,1\} \quad \forall\forall m \in M, \forall n \in N$ (9)

$Q_{hks}, Q_{kms}, Q_{mns}, Q_{nls}, Q_{nps}, Q_{ngs}, Q_{njs} \geq 0, \forall h \in H, \forall k \in K, \forall m \in M, \forall n \in N, \forall l \in L, \forall p \in P, \forall g \in G, \forall j \in J, \forall s \in S$ (10)

For the reverse logistics network of new energy vehicle power batteries, this paper establishes a mixed integer stochastic rule model with the objective function of minimizing total cost. The objective function (1) represents four components of the total cost, including transportation costs between network nodes, construction costs of network nodes, recycling and processing costs of network nodes, storage costs, and carbon emission costs. Constraint (2) ensures that all recyclable power batteries are collected by the recycling center M. Constraint (3) ensures that all power batteries transported to the recycling center M are transported to the battery processing center N. Constraint (4) ensures that the number of batteries transported to battery processing center N is equal to the number of batteries transported from N to battery manufacturer J, waste disposal center L, old metal recycling center P, and cascade utilization enterprise G. The constraints (5) and (6) are the processing capacity constraints of third-party enterprise recycling centers and processing centers, respectively. Constraint (7) indicates that the maximum number of power batteries from recycling center M to professional battery processing center N is α The ratio is transported to the cascade utilization enterprise G for utilization. Constraint (8) indicates that the maximum number of batteries recovered by battery processing center N is β The ratio is transported to battery manufacturer J for manufacturing. Constraints (9) and (10) define the range of variable values.

4. Solving Algorithm

When conducting in-depth research on the optimization design of the power battery recycling network for new energy vehicles, the model considers an increase in random scenarios, network hierarchy, and the number of nodes. As a result, the dimension and complexity of problem solving increase, and cplex is no longer able to solve and obtain results in a reasonable time. Therefore, complex heuristic algorithms should be used to solve the problem. This chapter designs a taboo genetic hybrid algorithm based on the characteristics of the model in this article to solve the optimization design problem of the power battery recycling network for new energy vehicles.

4.1 Hybrid algorithm design

This study adopted a combination of taboo search algorithm and genetic algorithm, and designed a taboo genetic hybrid algorithm to solve the optimization design problem of reverse logistics network for power battery recycling. Due to the unique processes and structures of taboo search algorithm and genetic algorithm, in the design and improvement process of hybrid algorithms, it is necessary to consider the characteristics of these two algorithms and the characteristics of the research problem to ensure the rationality of the algorithm and improve the efficiency and quality of the algorithm in solving the research problem.

5. Numerical experiments

This section takes random values for uncertain factors, approximates uncertainty, establishes numerical experiments of different scales, and uses the HGTS hybrid algorithm to solve the optimization design model of the new energy vehicle battery recycling logistics network, thereby verifying the effectiveness of the hybrid algorithm.

5.1 Setting of test data

Historical data from relevant literature on the optimization design of new energy battery recycling logistics network, including the construction of recycling and processing centers, unit processing costs, capacity limits, unit carbon emissions, consumer demand, carbon tax, recycling rate, and reuse rate, are shown in Table 1. On the basis of setting various parameters, randomly generate small-scale and large-scale experimental data, and conduct numerical experiments. The CPU for the numerical experiment is Intel Core i5 1.60GHz, and the example is solved using CPLEX 12.6.1. The code is implemented in C # of Visual Studio 2015.

Table 1 Experimental parameter settings

parameter description	Setting	unit
construction cost of recycling center	210,000	RMB
construction cost of processing center	240,000	RMB
unit processing cost of recycling center	373.8	RMB
processing center unit processing cost	123	RMB
unit processing cost of waste disposal center	0.48	RMB
unit transportation cost of batteries	0.00048	RMB
unit transportation cost of raw materials	0.03	RMB
unit transportation cost of waste	0.072	RMB
the upper limit of the recycling capacity of the recycling center	U(400,600)	piece
maximum processing capacity of the processing center	U(4000,6000)	piece
carbon tax	50	yuan/ton
unit CO2 emissions from recycling center	18.55	kg
the unit CO2 emissions of the processing center	21.03	kg
unit CO2 emissions from waste disposal center	0.35	kg
unit CO2 emissions during transportation	0.00249	kg
consumer group demand	N(200,20)	piece
distance between nodes	U(3,40)	km
recovery rate	N(0.7,0.04)	%
recycling utilization rate	N(0.8,0.03)	%

5.2 Numerical experiment

Firstly, numerical experiments were conducted on the constructed mixed integer stochastic programming model, with each set of examples randomly generating scenarios of different scales of 10, 30, and 50 for each experiment. The comparison results obtained through the hybrid algorithm of Cplex and HGTS are shown in Table 2.

Table 2 Comparison results of experiments

scale	number	CLPEX		HGTS		gap
k-i-j		cost 1(yuan)	time(s)	cost 2(yuan)	time (s)	
8-4-2	10	1402700.49	11.37	1404383.73	8.86	0.12%
	30	1402944.34	17.09	1404908.46	10.27	0.14%
	50	1403574.50	25.73	1404978.07	9.99	0.10%
10-6-2	10	1534681.43	12.88	1537443.86	9.63	0.18%
	30	1536690.44	29.04	1537612.46	10.19	0.06%
	50	1535180.21	69.41	1536868.91	12.04	0.11%

12-8-2	10	1876017.64	29.06	1877706.05	11.95	0.09%
	30	1879935.32	266.81	1883319.20	15.32	0.18%
	50	1875143.64	2428.89	1877393.81	19.02	0.12%
15-10-2	10	2286397.89	224.57	2291199.33	13.61	0.21%
	30	2289765.79	2907.48	2295261.23	20.18	0.24%
	50	2287395.45	6875.94	2292656.46	31.23	0.23%

Note: k-i-j represents the number of retail/distributor nodes - number of candidate recycling centers - number of candidate processing centers; Gap=(Cost 2-Cost 1)/Cost 1

From the results of the small-scale numerical experiments above, it can be seen that:

(1) The increase in the number of uncertain scenarios considered comprehensively increases the difficulty of solving the model and the time required for solving the examples.

(2) The experimental results show that the HGTS hybrid algorithm has good performance in solving the optimization design problem of the new energy vehicle battery recycling network studied in this paper, with fast solving speed and good solution time.

(3) The experiment shows that the HGTS hybrid algorithm has a solution result that is very close to the exact algorithm solution result for the model constructed in this article, which can achieve cost optimization to a certain extent. At the same time, it has a fast solution speed and can effectively achieve high solution quality and efficiency.

6. Conclusion

This article analyzes the uncertainty factors in the model through experiments, and provides management insights for power battery recycling related enterprises through the experimental results.

1) The demand and power battery recovery rate have a major impact on the network optimization design results.

2) With the increase of network size, the impact of uncertainty on network optimization design is gradually increasing. It is recommended that enterprises focus on changes in demand and battery recovery rate when designing power battery networks.

3) With the expansion of network models, the impact of carbon emission costs on the total network cost should not be ignored.

There are certain limitations to this study. In the face of the complexity of practical problems in new energy vehicle enterprises, future scholars can also optimize the design of multi-objective, multi cycle, and multi product logistics networks, so as to make the model more practical.

References

[1] Yun L, Linh D, Shui L, et al. Metallurgical and mechanical methods for recycling of lithium-ion battery pack for electric vehicles[J]. Resources, Conservation & Recycling, 2018, 136: 198-208.

[2] Beaudet A, Larouche F, Amouzegar K, et al. Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials[J]. Sustainability, 2020, 12(14) , 5837.

[3] Kumar P, Singh RK, Paul J, et al. Analyzing challenges for sustainable supply chain of electric vehicle batteries using a hybrid approach of Delphi and Best-Worst Method[J]. Resources Conservation and Recycling, 2021, 175(1): 105879.

[4] He L. Design of the Reverse Logistics Network of New Energy Vehicle Waste Power Batteries[C]//E3SWeb of Conferences. EDP Sciences, 2021, 275:02019.

[5] Tang Y, Zhang Q, Li Y, et al. Recycling Mechanisms and Policy Suggestions for Spent Electric Vehicles' Power Battery -A Case of Beijing[J]. Journal of Cleaner Production, 2018, 186:388-406.

[6] Langarudi RN, Sadrnia A, Sani PA. Recovering lead, plastic, and sulphuric acid from automobile used batteries by mathematical reverse logistics network modelling[J]. Progress in Industrial Ecology, An Int. J.,2019,13(1):63-83.

[7] Tadaros M, Migdalas A, Samuelsson B, et al. Location of facilities and network design for reverse logistics of lithium-ion batteries in Sweden[J]. Operational Research,2022,22(2):895-915.

[8] Lidan H, Xiaomeng W, Jun M. Research on Power Battery recovery Mode of New Energy Electric vehicles in China under Circular economy[J]. IOP Conference Series: Earth and Environmental Science,2021,651(4).

[9] Himanshu P, Ravi K, Ravi S. Selection of strategy for reverse logistics implementation[J]. Journal of Global Operations and Strategic Sourcing,2023,16 (1):1-23.

[10] Islam MT , Nizami MSH , Mahmoudi S, et al. Reverse logistics network design for waste solar photovoltaic panels: A case study of New South Wales councils in Australia:[J].Waste Management & Research, 2021, 39(2):386-395.

[11] Reddy NK, Kumar A, Sarkis J, et al. Effect of carbon tax on reverse Reverse Logistics Network Design for Product [J]. Computers & Industrial Engineering,2020,139,106184.

[12] Qiang W, Rong L, Li J, et al. Site Selection Optimization of Reverse Logistics Network for Waste Tires[J]. Wireless Communications and Mobile Computing,2022, 2022.

[13] Aqmar ZZ, Andrew B, Andrea G. A multi-period model for reorganising urban household waste recycling networks[J]. Socio-Economic Planning Sciences, 2022,84,101396.