Research on the location of waste battery recycling center for new energy vehicles based on a heuristic algorithm of greedy take-off

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Abstract: The peak period for the decommissioning of new energy vehicle power batteries in China is approaching, and it is imminent to establish a complete and efficient waste battery recycling system. In order to improve the recovery efficiency of waste batteries in China, this paper constructs a new type of waste battery recovery system, and proposes a new method to solve the location problem of the waste battery recovery center by using a method of goal ranking and a heuristic algorithm of greedy take-off. The grey prediction method of amplitude compression is used to simulate and predict the total battery recycling amount of each recycling station in a city, and then establishing a dual-target location model with the goal of maximizing total revenue and optimizing brand serviceability. Finally, the model is solved by the heuristic algorithm of greedy take-off to obtain the optimal location scheme of recycling center, which proves the feasibility of the model.

1. Introduction

New energy vehicles were listed as one of the seven strategic industries in China in 2012, and then entered a high-speed development stage. Because the service life of new energy vehicle power batteries is 5 to 8 years, it is expected that in 2020, China's new energy vehicle power batteries will begin to enter a scale retirement period, with a retirement volume of 149,900 tons / year, and it will enter an explosion period in 2026, at that time, the retirement volume will reach 662,800 tons / year [1], in the face of an unstoppable amount of retirement, the establishment of a perfect power battery recycling system has become an inevitable trend in the development of the new energy vehicle recycling market. However, after seven years of development, China's existing new energy vehicle waste battery recycling system still has disadvantages such as narrow recycling channels, traditional recycling methods, and low recycling efficiency.

In order to improve this situation, this paper proposes a new concept of reverse logistics model for waste battery recycling. Based on this, the research on choosing the location of new energy vehicle waste battery recycling center is carried out. This paper builds an optimization model through the method of grey prediction that is based on amplitude compression and the method of target classification, and use the heuristic algorithm of greedy take-off and the method of target ranking to maximize total revenue and optimize brand serviceability.
2. Establishment of a new recycling system for waste batteries

The operation process of the new recycling system: consumers send used batteries to various recycling points, and the classification and testing equipment in the recycling points will detect and sort them. Each recycling point will then integrate the waste batteries that need further recycling and transport them to recycling center. The recycling center will undertake the tasks of uniform dismantling, recycling, and secondary sales of used batteries. As for the used batteries whose value is lower than the national recycling standard, they will be discarded on the spot, that is, destroyed.

This recycling system has built several recycling centers in the city, and equipped various sorting and testing equipment for used batteries at each recycling point, thereby moving the classification and testing process forward to the recycling point and realizing the functional areas under the old recycling system. The merger will integrate the three functions of dismantling, recycling, and secondary sales into the recycling center. As a result, unnecessary transportation costs of waste batteries are saved, the used batteries can be quickly processed scientifically and returned to the market, and the environmental pollution and social and economic losses caused by unscientific recycling and batch retention of used batteries can be reduced.

3. Location model of recycling center

3.1 Problem description and model hypothesis

There are m known recycling points of waste batteries \( K_i \), n recycling centers that meet the requirements of urban construction \( L_j \). According to the operation process of the new waste battery recycling system to simulate the waste battery recycling activities. Try to work out the best location scheme of the recycling center to maximize the total revenue of the whole recycling reverse logistics chain (the first goal) and the brand service (the second goal).

In order to protect the model from unnecessary and complicated factors, this paper will abstract and simplify some problems, and make the following assumptions:
(1)The number and location distribution of recovery points are known;
(2)The number and location of the recycling centers to be selected are known and meet the site selection requirements;
(3)Every recycling point has and has only one recycling center to meet its recycling needs;
(4)Every recycling center has unlimited recycling capacity;
(5)Every recycling point is initially planned in where the nearest recycling center is located and they are served by a recycling center corresponding to the area. According to this, the recycling system is divided to n initial partition modules;
(6)There is only one recycling center in each partition module;
(7)After testing at the recycling point, the waste batteries that are not supposed to be scrapped will be sent to the recycling center;
(8) The nature of waste batteries recovered from every recycling point are similar, and the cost of transportation, treatment and waste is the same;
(9) Waste batteries can always be transported to the sorting and processing center in the first time, without the storage cost of the recycling station;
(10) Ignore the fixed investment such as human resource cost and equipment cost.

3.2 Model establishment

The definitions of symbols in the model are shown in Table 1-2

Table 1. Symbols and their definitions.

| Symbol | Definition | Range of values |
|--------|------------|-----------------|
| $K_i$  | Waste battery recycling point | $i \in \{1,2,3...m\}$ |
| $L_j$  | Recycling center | $j \in \{1,2,3...n\}$ |
| $Y_{ij}$ | Whether to be served by $L_j$ | $Y_{ij} \in \{0,1\}$ |
| $X_j$  | Whether to build $L_j$ | $X_j \in \{0,1\}$ |

Table 2. Symbols and definitions of decision variables.

| Decision variables | Definition |
|--------------------|------------|
| $W_{ij}$ | Total amount of used batteries shipped from $K_i$ to $L_j$ each year |
| $x_{ij}$ | The distance of $K_i$ to $L_j$ |
| $y_i$ | Annual forecast recovery of $K_i$ |
| $c$ | Average test cost per ton of used battery |
| $d$ | Average scrap cost per ton of used battery |
| $f$ | Unit construction cost of recovery center |
| $f(i)$ | Average scrap rate of recovery point |
| $e$ | Service level value |
| $h$ | Average recycling revenue per ton of used battery |
| $a$ | Unit freight |

Based on the above problem descriptions, model hypothesis and symbol definitions, establish the following model functions:

(1) Based on the gray prediction method of amplitude compression, the prediction models of the total amount of waste battery recycling in each recycling station are as follows:

**Definition 1** Data series $X = (x(1), x(2), ..., x(n))$, if $\forall k = 2, 3, ..., n$; Then called $X$ as a random oscillation sequence; Set $M = \max \{x(k) | k = 1, 2, ..., n\}$, $m = \min \{x(k) | k = 1, 2, ..., n\}$, called $T = M - m$ as the amplitude of $X$.

**Definition 2** Set random oscillation sequence $X^{(0)} = \{x^{(0)}(k)\}_{i=1}^{n}$, sequence $X^{(0)}D = (x^{(0)}(k)d)_{i=1}^{n-1}$ among them $X^{(0)}(k)d = [(x^{(0)}(k) + T) + (x^{(0)}(k+1) + T)]^{1/2}$, $k = 1, 2, ..., n-1$, $T$ is the amplitude of $X^{(0)}$, then $D$ is
called the first order smoothness operator of the sequence \(X^{(0)}\). And \(X^{(0)}D\) is the first-order smoothed sequence of the random oscillation sequence \(X^{(0)}\).

According to Definitions 1 and 2, the following models of forecast recovery total volume can be derived:

\[
\hat{x}^{(0)}(t) = F\beta_{\text{t}^{-1}} + F\beta_{\text{t}^{-1}} - C - 2T \quad \text{(t is odd)} \quad (1)
\]

\[
\hat{x}^{(0)}(t) = F\beta_{\text{t}^{-1}} + F\beta_{\text{t}^{-1}} + C \quad \text{(t is even)} \quad (2)
\]

Where \(\hat{x}^{(0)}(t)\) refers to \(y_i\), \(T = M - m\) is the amplitude of the data sequence \(X = (x(1), x(2), ..., x(n))\), \(C\) is the initial value predicted by the random oscillation sequence. \((\beta_1 + \beta_2)^T = (B'B)^{-1}B'y\), the expressions of \(Y\) and \(B\) are

\[
Y = \begin{bmatrix}
y^{(0)}(1) \\
y^{(0)}(2) \\
\vdots \\
y^{(0)}(n)
\end{bmatrix}, \quad B = \begin{bmatrix}
1 \\
1 \\
\vdots \\
1
\end{bmatrix}, \quad F = \frac{4y^{(0)}(1)\beta_{\text{t}^{-1}} + \beta_{\text{t}^{-1}}}{1 + \beta_{\text{t}^{-1}}} = \text{const}
\]

(2) Objective function:

\[
\text{max } S = \sum_i \sum_j W_i X_j Y_i h - \sum_i \sum_j x_i W_i X_j Y_i a - \sum_i W_i df(i) - \sum_i W_i c - nf \quad \text{(First objective)} \quad (3)
\]

\[
\text{max } D = \sum_i \left( \sum_j Y_i \times \frac{m - e + 1}{m} \right) \quad \text{(Second objective)} \quad (4)
\]

\[
\begin{align*}
\sum_j Y_i &= 1 \quad i \in (1, 2, 3 ..., m) \\
Y_i &= \{0, 1\} \\
X_j &= \{0, 1\} \\
\text{max } S - \sum_i \sum_j W_i X_j Y_i h &\leq C \quad \text{(5)}
\end{align*}
\]

max \(S\) refers to the maximum total revenue under the reverse logistics mode of the new recycling system. max \(D\) represents the largest brand service under the reverse logistics mode of the new recycling system.

The above models have a wide range of applicability. Taking the real and effective data of each city as the input, we can use the gray prediction method based on amplitude compression to predict the total amount of recycled batteries at each recycling site in a single recycling site in that year, and calculate the total economic benefits and brand service of each recycling site, as a mathematical basis for the location of the waste battery recycling center of new energy vehicles.

4. Case study

4.1 Solving steps

Step 1 Assuming that all recycling centers are incomplete, that is, the number of construction \(k = n\). Calculate the total revenue and brand service in this case;

Step 2 If constraint (5) is satisfied, it shows that the assumption is true, the scheme is feasible and listed as the initial scheme;

Step 3 Remove the corresponding recycling center of the partition module with the smallest recycling amount. At this time, \(k = k-1\). The recycling point in the deleted module is planned to be the module closest to the rest of the recycling center.

Step 4 Calculate the total revenue and brand service under the condition of Step 3. If the total revenue is less than the initial revenue, the scheme under the condition of Step 3 will be listed as the initial scheme. If total revenue = initial revenue and brand service = initial brand service, the scheme under
the condition of Step 3 will be listed as the initial scheme. In other cases, the initial plan remains unchanged.

**Step 5** Repeat Step 3 and repeat iterations until the highest value of total revenue appears. At this time, the optimal location scheme is selected under this condition. If the total revenue of several site selection schemes is the same, the one with high brand service shall be selected.

### 4.2 Model application

Taking Wuhan as an example, suppose there were 10 recycling points and 4 recycling centers to be selected. The locations are in line with Wuhan's urban layout plan. According to the data from the recycling market in recent years. All of \( f(i) \) are 10%, and the non-scrap batteries are all returned to the sorting and processing center after simple treatment. The setting data are as follows, \( a \) take 9.8 yuan / ton * km, \( b \) take 7000 yuan / ton, \( d \) take 1100 yuan / ton, \( c \) take 500 yuan / ton, \( f \) take 800000 yuan and 25000000 yuan for C. Other fixed expenditure is 15000000 yuan. The distribution distance of simulation logistics points and the recycling amount of waste batteries at each recycling point are shown in **Figure 2** and **table 3** below. The data sourced from “Wuhan Natural Resources and Planning Bureau.”

**Table 3. Actual and predicted recovery volume of recovery point.**

| Recycling point | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|-----------------|----|----|----|----|----|----|----|----|----|----|
| Annual recovery | 800| 1000| 1100| 990| 500| 400| 1050| 400| 700| 300|
| Annual recovery forecast | 745| 808| 1043| 1002| 387| 601| 1000| 550| 880| 422|

**Figure 2. Distribution of recycling points and initial module partition.**

**Table 4. Solution results.**

| Iteration | Site selection | Total revenue | Brand service | Given cost C | Total cost |
|-----------|----------------|---------------|---------------|--------------|-----------|
| 1         | 1, 2, 3, 4     | 27707389.60   | 1.0000        | 25000000.00  | 22972610.40|
| 2         | 1, 2, 3       | 28469757.60   | 0.9563        | 25000000.00  | 22210242.40|
| 3         | 1, 3          | 29157155.60   | 0.8894        | 25000000.00  | 21522844.40|
| 4         | 3             | 29776051.60   | 0.8021        | 25000000.00  | 20903948.40|

The experiment shows that the total income of the fourth site selection scheme is the highest. But it has only 618896 yuan higher than that of the third site selection scheme, while the brand service degree is greatly reduced. In reality, when the income difference is not much different, in order to ensure good...
response ability and service ability, enterprises often choose the third site selection scheme. That is, the construction of No.1 and No.3 recycling center.

5. Conclusion

This article proposes a new model of new energy vehicle waste battery recycling system logistics model, which reduces the reverse logistics link, shortens the length of the logistics chain, improves the efficiency of reverse logistics transportation and reduces the cost, and solves the problem of untimely recycling, improper recycling and high recycling costs. The problem is to save logistics costs for enterprises and the country and achieve the goal of promoting sustainable development of the country. The method of grey prediction that is based on amplitude compression is introduced to complete the calculation of brand serviceability, which can have large differences in historical development of new energy vehicles in various cities and historical data. Under inadequate conditions and large market changes, the brand serviceability of each recycling site is more accurate and more accurate. The arithmetic value is good, and it has good fitting performance. The multi-level benefit analysis is performed from four levels. Integrate the cost of the reverse logistics chain from an angle, and construct a mathematical model in line with the actual situation to calculate the best total economic benefit of building a network-type recycling classification point. The heuristic algorithm of greedy take-off and the method of target ranking to solve the model solving problem of maximizing total revenue and optimizing brand serviceability, and it has been proved to have better executable and auxiliary decision-making significance.

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