Electric Vehicle Power Battery Reverse Logistics Model Research

Liangyu Pu, Tianyuan Guo, Dongqi Wu, Yicheng Cao, Haiming Wen, Chengran Zhang and Rui Feng
Shanghai Maritime University, China

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Abstract: The market situation and recycling mode of power batteries at home and abroad are introduced, and the current situation, relevant policies, and existing problems of China's power battery recycling mode are analyzed. Combined with market research, an AHP fuzzy comprehensive evaluation mathematical model is established to explore the most suitable battery reverse logistics model for domestic enterprises, and the results show that the power battery manufacturer recycling model is the most suitable for Chinese enterprises.

1 INTRODUCTION

Energy and environmental issues are becoming a global hot topic of research. Traditional fuel vehicles are facing the problems of fossil energy shortage and air pollution caused by exhaust emissions, and their dominance is being challenged by new clean energy vehicles.

However, the battery state of health (SOH) of power batteries will gradually decay with the increase of charge and discharge times, and when the SOH of power batteries drops below 80% of the original, the batteries will be forced out according to the existing national standards. With the rapid increase of electric vehicle ownership, power battery packs that do not meet the electric vehicle inspection standards will be eliminated in large numbers, and from 2018 to 2020, the first batch of domestic new energy models have faced retirement, of which the total amount of batteries to be recycled is about 25 GWh (about 200,000 tons); it is expected that by 2025, the scale of batteries to be recycled is estimated to grow to 1 million tons (about 110 GWh) (Feng, 2021). At the same time, with the gradual growth of domestic demand for power batteries, the supply of raw materials for batteries has exceeded the demand, and the prices of raw materials for power batteries, such as lithium carbonate and lithium hydroxide, have continued to rise (Jiang, 2013). Therefore, whether the power battery can be scientifically recycled is particularly critical, which will be directly related to the sustainable development of the domestic electric vehicle industry and the steady promotion of the "double carbon" policy.

Compared with the mature battery reverse logistics model in Japan, the United States, and Germany (Hou, 2015), the current reverse logistics system of power battery recycling in China has problems such as a lack of guarantee of recycling quality, an immature recycling system, and lack of a perfect regulatory mechanism for power battery recycling, so it is necessary to choose a suitable battery reverse logistics model to improve the battery recycling system in China.

This paper analyzes the current situation of domestic power battery recycling mode from the perspective of power battery reverse logistics, investigates many famous enterprises engaged in power battery production and recycling in China, and establishes the AHP fuzzy comprehensive evaluation mathematical model to study the feasibility and economy of different reverse logistics modes of power battery based on the survey results.

2 DOMESTIC POWER BATTERY RECYCLING REVERSE LOGISTICS MODEL

To improve China's battery reverse logistics system, it is necessary to establish a battery recycling program according to China's national conditions, set up a producer responsibility system, complete the functions of the relevant departments and stimulate the relevant enterprises engaged in battery recycling, and explore the most efficient power battery recycling mode, the following is the basic status of power battery recycling in China today.

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At present, there are many enterprises engaged in power battery recycling in China, including not only battery raw material suppliers, but also midstream battery manufacturers and third-party waste power battery recycling enterprises in the industry chain. Among them, there are four main recycling modes (Zhu, 2019).

2.1 Producer Recovery Model

In establishing the recycling chain, battery manufacturers can develop their own reverse logistics chain to achieve the purpose of recycling, or they can cooperate with sellers in the industry chain to convert their forward logistics mode into a reverse logistics chain. No matter which reverse logistics model is adopted, all of them are responsible for the recycling of power batteries through the manufacturers.

For example, Ningde Times, as the pillar of power battery production in China, has established a business model of "production-sales-recycling-production" by acquiring shares of Bump Group, a battery recycling company.

2.2 Industry Alliance Recycling Model

In this model, manufacturers and sellers in an industry form a consortium organization and are responsible for recycling used products, which is known as the industry consortium recycling model. In this model, a type of agreement is reached between battery manufacturers and consumers to ensure that consumers will deliver used batteries to the industry consortium for recycling through reverse logistics. The industry alliance is large and well-funded and can build more professional recycling centers. The battery manufacturers that join the industry alliance do not have to participate in product recycling, but instead, pay the industry alliance a commissioning fee.

In the case of BAIC New Energy, for example, the company is responsible for the recycling of the power batteries it sells. The "Optimus Project" of BAIC New Energy is dedicated to the secondary utilization of used batteries, promoting the organic combination of new energy vehicles, lithium-ion batteries, photovoltaic power storage, and other industries, and maximizing the residual value of retired power batteries (Liang, 2022).

2.3 Third-Party Recycling Model

The producer pays the third-party recycling enterprise according to the type and number of batteries sold and transfers the responsibility and risk of handling end-of-life products to the third-party enterprise. The relationship between the producer and the third party is a principal-agent relationship, and because there is inequality in information between the producer and the third party, this leads to the reverse selection behavior of the third party that can cause problems such as a low recycling rate of end-of-life products and environmental pollution. The third-party company creates its own reverse logistics network to recycle the waste products from the consignee and then transports them to its recycling center for dismantling to achieve large-scale processing.

2.4 Small Workshop Recycling Mode

Currently, most of the retired power batteries in China are sent to small workshops lacking relevant qualifications for dismantling. These small companies have rudimentary equipment and mostly dismantle by hand with low operating costs to increase the market recovery price and make profits from it, with high recovery price and low recovery cost being their biggest competitive advantage.

However, after the recycling of retired power batteries, only after simple repair and refurbishment, they will flow back into the market again, thus causing damage to the normal order of the power battery market. The end-of-life treatment of batteries requires money and time, and is more polluting to the environment, while its reuse has greater economic value. In addition, the recycling process of these small enterprises is simple, backward, and not standardized, and in the process of recycling, a large amount of solid and liquid waste will be generated, causing serious pollution to the environment.

3 AHP FUZZY COMPREHENSIVE EVALUATION OF WASTE POWER BATTERY RECYCLING MODEL EXPLORATION

3.1 Overview of AHP Fuzzy Comprehensive Evaluation Method

To explore the most suitable battery recycling reverse logistics model for domestic enterprises, we investigated several domestic new energy battery enterprises such as Aodotion (Shanghai) New Energy, Ningde Times, Greenmax, Guanghua

Technology, Fang Yuan Environmental Protection and Bump Cycle Technology, and established AHP fuzzy comprehensive evaluation model to calculate the most suitable battery recycling reverse logistics, model. Among them, AHP fuzzy comprehensive evaluation method is a class of comprehensive evaluation methods based on mathematical modeling, which transforms qualitative evaluation into quantitative evaluation according to the principle of maximum affiliation of fuzzy mathematics.

In the process of the fuzzy comprehensive evaluation, it is important to determine the evaluation matrix and weights; in practice, the purpose of the study can be achieved through hierarchical analysis, weighted average method, and crowd assessment method (Liu, 2019). Among them, hierarchical analysis is a subjective assignment method, but it is a more commonly used method for establishing the relative importance of indicators in general and does not violate basic common sense; it can make a comprehensive connection between multiple factors in a complex problem by comparing them two by two, making it more organized.

To this end, this section combines a battery manufacturer's characteristics and relevant theoretical research to identify four high-level indicators and several bottom-level indicators to create a screening rubric for the reverse logistics model of power batteries.

Due to the presence of heavy metal elements mainly Ni and Co in waste batteries and electrolytes that can cause environmental pollution, a comprehensive evaluation index model is created using the fuzzy comprehensive evaluation method based on the three existing domestic retired power battery reverse logistics models, and the reverse logistics of retired power batteries is evaluated qualitatively using quantitative forms to establish a reasonable composite retired power battery reverse logistics recycling model.

3.2 Build AHP Model

3.2.1 Constructing the Judgment Matrix.

According to the comprehensive evaluation system constructed above, and combined with the judgment comparison of senior experts in the industry, the relative importance of the two factors is evaluated by the scaling method, and the relative judgment matrices D, D1, D 2, D 3 and D 4 of the high-level and low-level indicators are obtained.

Table 1: Scale of 1~9.

Scale	**Meaning**
1	Ai and Aj have the same contribution to the goal
3	Ai is slightly more important to the goal than Aj
5	Ai is more important to the goal than Aj
7	Ai is significantly more important to the goal than Aj
9	Ai is very important to the target than Aj
2,4,6,8	Between two adjacent importance degrees
Countdown	Aij=1/Aij

3.2.2 Calculating the Judgment Matrix

Based on yaahp, MATLAB software, the maximum eigenvalue λ of each matrix and the eigenvector A were calculated, then the eigenvectors were normalized, and finally, the weight magnitude of each layer evaluation index was calculated.

Table 2: Table of weight values of indicators in each layer.

High-level indicators	Low-level indicators	Weights
Economic benefits (0.1811)	Profitability	0.0863
	Logistics Costs	0.2641
	Market share	0.5068
	Risk resistance	0.1428
Social benefits (0.4832)	Environmental protection	0.2066
	Service Quality	0.1481
	Policy Support	0.5341
	Social Responsibility	0.1113
Development strategy (0.0788)	Reverse Logistics Specialization	0.1602
	Core Competence	0.5697
	Industry Competitiveness	0.2702
Technological Advantages (0.2569)	Battery Recycling Process	0.4673
	Product Development Technology	0.1537
	Reverse logistics infrastructure system	0.3790

3.2.3 Performing Consistency Tests

To avoid contradictions in the two comparisons of each indicator, which would lead to obvious errors in the constructed matrix, we define the consistency indicator CI = λ-n / n - 1; it can be seen that the CI changes with n changes, and to measure the value of CI, the random consistency index RI is introduced.

Table 3: Values of random consistency index RI.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.89	1.12	1.24	1.36	1.41	1.45

Define CR = CI / RI, when CI < 0.1, it means that the matrix has a good consistency and can be accepted, otherwise the matrix needs to be readjusted.

Table 4: Calculation results of maximum eigenvalue and consistency ratio.

	D	D1	D2	D3	D4
λ	4.0813	4.0211	4.1028	3.0291	3.0385
CR	0.0304	0.0079	0.0385	0.0279	0.0370

3.3 Constructing the Fuzzy Evaluation Matrix

3.3.1 Determine the Fuzzy Set.

For example, in the independent recycling model, the general steps are to create a factor set and a rubric set. Set the subset of factors as Ui (i = 1,2,3,...,n) as the top-level factor set, where U ij = {U ij, U i2,..., U ij} as the bottom-level factor set, the alternative set T= {T 1, T 2, T 3} corresponding to the three recycling modes, and the set of comments V=(good, good, fair, poor).

Table 5: Evaluation Levels by Score.

Grade	V1	V2	V3	V4
Interval	(3-4]	(2-3]	(1-2]	(0-1]
Evaluation results	Excellent	Good	Fair	Poor

3.3.2 Establishing Fuzzy Matrix.

Using the questionnaire method and combining the evaluation results of 20 relevant company executives and professionals in the industry The evaluation matrix R i = {ri 1, ri 2, ri 3, ri 4} (i =1,2, ...,14) was obtained for every single factor. Thus, a linear transformation from U to V is induced by judging every single factor independently.

Table 6: Single-factor evaluation values.

High-level indicators	Low-level indicators	Survey Results			
		Excellent	Good	Fair	Poor
Economic benefits	Profitability	0.10	0.20	0.50	0.20
	Logistics Costs	0.40	0.45	0.15	0.00
	Market share	0.65	0.30	0.05	0.00
	Risk resistance	0.10	0.40	0.40	0.10
Social benefits	Environmental protection	0.50	0.40	0.10	0.00
	Service Quality	0.40	0.40	0.10	0.10
	Policy Support	0.60	0.30	0.10	0.00
	Social Responsibility	0.30	0.40	0.20	0.10
Development strategy	Reverse Logistics Specialization	0.10	0.20	0.50	0.20
	Core Competence	0.50	0.30	0.20	0.00
	Industry Competitiveness	0.20	0.20	0.40	0.20
Technological advantages	Battery Recycling Process	0.10	0.20	0.50	0.20
	Product Development Technology	0.50	0.40	0.10	0.00
	Reverse logistics infrastructure system	0.20	0.20	0.40	0.30

3.3.3 Calculating the Fuzzy Evaluation Matrix

The operator M (●, ⊕) is used to fuzzy evaluate the underlying factor set, and the resulting evaluation matrix R leads to a fuzzy transformation:

$$T_R: f(U) \xrightarrow{M} f(V); \quad B_i = W_i \cdot R_{Di}$$

This calculation gives the low-level fuzzy evaluation vector. Then, still using the operator M, the comprehensive evaluation matrix RD of the high-level fuzzy vector B can be obtained, and the calculation results are shown in Table 7.

Table 7: Fuzzy matrix calculation results.

Judgment matrix	Weight vector	Evaluation results
RD1	W1=(0.0863 0.2641 0.5068 0.1428)	B1=(0.45797 0.34527 0.16522 0.03154)
RD2	W2=(0.2066 0.1481 0.5341 0.1113)	B2=(0.51639 0.34653 0.11114 0.02594)
RD3	W3=(0.1602 0.5697 0.2702)	B3=(0.35491 0.25699 0.30212 0.08608)
RD4	W4=(0.4673 0.1537 0.3790)	B4=(0.12359 0.14067 0.40062 0.13132)
RD	W=(0.1811 0.4832 0.0788 0.2569)	B=(0.39220 0.28770 0.21040 0.05870)

Combined with the comprehensive evaluation result B, according to the principle of maximum subordination, the maximum value is taken as the final evaluation, then the company uses independent recycling of used power batteries mode evaluation result is "good"; The final score of this model is 3.068 by using the weighted average method. By the same token, we can obtain the final results of the other two recycling models.

Table 8: Final evaluation results of the three models.

	Evaluation results	Evaluation level	Total score
Independent mode	(0.3922 0.2877 0.2104 0.0587)	Excellent	3.068
Joint Model	(0.3684 0.3244 0.2358 0.0715)	Excellent	2.990
Outsourcing Model	(0.2977 0.3066 0.3048 0.0978)	Good	2.800

Using the maximum affiliation and weighted average for the fuzzy synthesis of the high-level indicators, it can be found that enterprises such as Shanghai Aodin New Energy Co., Ltd. have better results for the independent mode and joint mode of recycling retired batteries, and the total score of these three reverse logistics modes can be arranged in descending order as independent mode > joint mode > outsourcing mode.

So the same method can be used for the lower-level indicators to obtain the evaluation rank and total score contribution ability of the three reverse logistics recycling models to the higher-level indicators under different conditions. The affiliation degrees and total scores of the bottom-level indicators are shown in Table 9 shows.

Table 9:Bottom fuzzy comprehensive evaluation results.

Indicators	Independent mode		Joint Model		Outsourcing Model	
	Comments	Score	Comments	Score	Comments	Score
Economic benefits	Excellent	3.064	Excellent	3.249	Fair	2.742
Social benefits	Excellent	3.353	Excellent	3.228	Fair	2.699
Development Prospects	Excellent	2.881	Good	2.974	Good	2.963
Technological advantages	Fair	1.865	Fair	2,363	Good	2.972

As can be seen from the information in the table, in terms of economic and social benefits, both independent and joint models have a better degree of suitability, because these two reverse logistics models will more directly reflect those battery manufacturers will follow the extended consumer responsibility system than the third-party outsourcing model; in terms of technical advantages, the outsourcing model shows a greater advantage compared to the first two, because the waste power battery recycling market is gradually expanding, more and more companies are beginning to layout related business, and the ability to outsource companies to recycle has been in a better technical position, which better validates the rationality of the model built.

4 CONCLUSION

In this paper, for the three main domestic retired power battery recycling modes at present, a fuzzy comprehensive evaluation method based on AHP is established to indicate the degree to which the three reverse logistics modes belong to the fuzzy set V. The qualitative description is turned into a quantitative analysis, and the advantages and shortcomings of the three modes under the influence of several sub-factors are studied in depth. Therefore, in the field of decommissioned battery recycling, it is possible to consider building a type of composite backbone network that is given to its own company for self-management at the stage of decommissioned battery recycling collection and pre-processing and given to third-party battery recycling companies for processing at the stage of subsequent battery dismantling and raw material recycling. Under this approach, the company can not only bring into play its advantages in economic and social factors, but also promote the enthusiasm of third-party battery recycling enterprises, and the whole battery recycling chain can thus improve efficiency, reduce costs and effectively drive the benefit growth of upstream and downstream enterprises. This paper only investigates the reverse logistics mode of some enterprises engaged in power battery production and recycling, which still has a certain reference value for the optimization of reverse logistics of other waste battery-related main enterprises.

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