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Evaluation and Selection of Battery Swap Operation Mode of New Energy Vehicles

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Abstract: *With the advantages of "vehicle-electricity separation", effectively shortening the replenishment time, relieving users' mileage anxiety, and facilitating the perfection of power battery recycling system, new energy vehicle battery swap has become an important research direction to respond to the government's "low carbon" policy and promote the development of new energy vehicle industry. In this paper, we analyze the differences in the supply chain structure of the three battery swap models led by car manufacturers, battery manufacturers and battery swap operators, and build models of battery swap operation under three different power structures based on the actual market situation. Using the combination of Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE), we use the questionnaires and expert evaluation methods to evaluate and analyze the input and output of the battery swap enterprises, supply chain risk resilience and competitiveness of new energy vehicles under the three different supply chain structures. We compare and conclude that the battery swap model dominated by battery enterprises is generally better than the other two battery swap operation models, then we analyze and conclude the advantages of different operation modes in order to draw some management insights.*

Keywords: *New Energy Vehicle Battery Swap Supply Chain, AHP-FCE, Model Evaluation*

1. Introduction

With the carbon peak and carbon neutrality policies put forward, the development of green low-carbon industry has been widely concerned [1]. As an important part of traditional manufacturing industry and one of the main contributors of carbon emissions, the low-carbon development of automobile industry has also been put on the agenda. Under the joint action of international climate factors, national carbon emission pressure, crude oil prices and other factors, the scale of new energy automobile industry is also growing[2], but there are also many problems in its rapid development. As one of the energy supplement methods of new energy vehicles, the new energy vehicle battery-swap mode has become an important development and research direction of new energy automobile industry, with its advantages of realizing ' vehicle-electricity separation ', effectively shortening the energy supplement time, alleviating user mileage anxiety, and improving the power battery recovery system[3].

At present, there are many representative new energy automobile enterprises and battery swap operation enterprises in the Chinese market. As leading enterprises, they form different battery swap operation business models. Correspondingly, different battery swap models also produce different supply chain structures. Domestic and foreign scholars have abundant research results on battery swap of new energy vehicles. The existing research shows that the centralized battery-swap mode has a stronger scale advantage than the vehicle battery-charging mode[4]. Considering the factors of customer arrival, power grid price change, power grid connection limit, battery wear and so on, the optimal charging, discharging and battery-swap can be obtained[5]. The new energy vehicle battery swap model is applied to the electric taxi industry, and the real-time pricing model of battery-swap taxi is established to obtain the pricing strategy with the most energy and economic benefits[6]. However, the above research has not been extended to the selection of supply chain evaluation with structural differences.

Therefore, based on China ' s national conditions, this paper takes NIO, CATL and Aulton New Energy as examples to analyze the supply chain structure differences of the three battery-swap modes dominated by car companies, battery enterprises and Battery-swap operators, and constructs three different battery swap operation models according to the actual market situation. Then, the analytic

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hierarchy process (ahp) is used to determine the index hierarchy structure and the weight of the primary and secondary indicators. Combined with fuzzy comprehensive evaluation method (fce), using the methods of questionnaire survey and expert evaluation, this paper evaluates and analyzes the input-output, supply chain risk resilience, new energy vehicle product competitiveness and other indicators under the three different supply chain structures, compares and obtains the better battery-swap operation mode, and analyzes the respective advantages of different operation modes. Thus, some management implications are obtained, which can provide policy support for relevant departments and decision-making reference for the production and operation management of battery-swap market participants. This paper seeks to make up for the theoretical gap and further expand the research field of new energy vehicle power conversion through practical research, objective analysis and in-depth exploration. It has important theoretical and practical significance.

2. Analysis of Battery Swap Mode of New Energy Vehicles

2.1 Battery-swap Operation Mode Dominated by Car Companies

As the leader in this kind of battery exchange model in China, NIO has the industry's leading battery-swap robot technology, which can shorten the automatic battery-swap time to less than 3 minutes. Since 2020, the company has successively launched a number of models that support battery swap, and jointly proposed the battery rental service named Baas to establish a relatively complete personal battery swap business model. By December 18, 2021, NIO has built 733 power changing stations called NIO Power, providing power changing services for 97 new cities, and the accumulative power changing times of users have reached 5.5 million times. Baic BJEV, SAIC, Geely-Automobile, GAC-Group and other domestic mainstream new energy vehicle brands also have battery exchange layout.

As the figure1 shows, In this car enterprise-led battery-swap operation mode, the upstream of the industrial chain includes a series of spare parts enterprises related to electric vehicle production and battery-swap station construction service enterprises. In the middle reaches of the industrial chain, the construction of battery-swap stations and the demand design of batteries are mainly in car companies and their subsidiaries. Oems order batteries from battery companies and assemble vehicles with other auto parts. Automobile enterprises simultaneously assume the responsibilities of battery swap operators, build battery swap stations only for their own brands, and form the corresponding battery-swap service network to serve consumers. The downstream of the supply chain can choose to rent or buy batteries after purchasing cars from automobile companies, and automobile companies take the initiative to provide consumers with very cheap or even free battery-swap service to stimulate the sales of battery exchange EV. Consumers can also choose different sizes of batteries to meet long-distance or short-distance needs. But waste batteries need to be recycled by changing stations, car companies and then battery companies in turn.

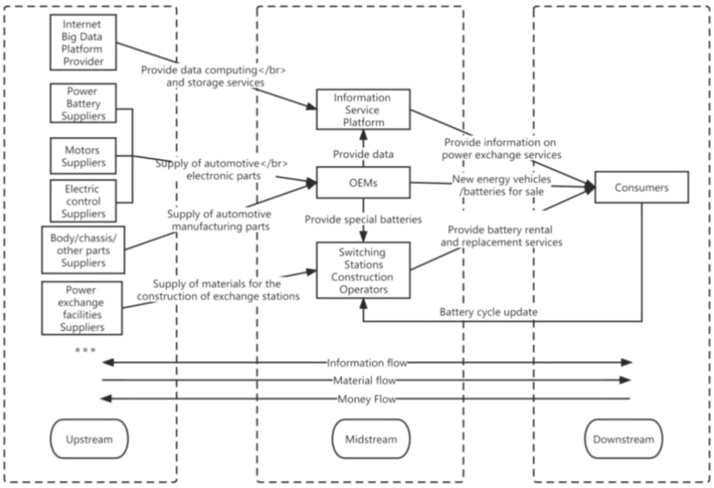

Figure 1: Battery-swap operation mode diagram dominated by automobile enterprises

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2.2 Battery-swap operation mode dominated by battery enterprises

CATL is typical representative of this kind of mode, as the lithium battery research and development manufacturing enterprise, CATL after the incoming new energy car in electricity market, not only for car companies to provide its designated power battery products, began to layout can be a new type of power in rechargeable battery pack, and puts forward the concept of chocolate battery, using wireless BMS technologies, the flexibility of battery combination can be greatly improved, and the battery can be rented according to the needs of mileage. The chocolate battery can be adapted to 80% of the world's listed models and pure level platform development models to be launched in the next three years. CATL also launched its own battery exchange brand EVOGO, which has formed its own battery swap plan with three aspects: battery swap block, quick exchange station and APP, and took the lead in launching the first batch of EVOGO battery swap station services in 10 cities.

As the figure2 shows, By summarizing and analyzing the battery swap supply structure under the battery enterprise-led mode from the perspective of logistics, capital flow and information flow, the battery enterprise-led battery swap operation model is obtained. Under this model, the upstream of the industrial chain includes two major parts, one is the battery raw material production enterprises, and the other is the supplying enterprises of battery exchange facilities and supporting services. As a leading enterprise, battery manufacturers are located in the middle of the industry chain. In addition to developing and producing batteries that can be adapted to most models in the market, they also build battery swap stations, build information service platforms, assume the responsibilities of battery swap operator and battery swap information service provider by establishing subsidiaries and sub-brands. The batteries it produces are not only provided to new energy car companies, but also deployed in their own battery swap stations. New energy vehicle enterprises undertake batteries provided by battery manufacturers, can reduce the cost of independent research and development of power batteries and focus on power, chassis, body and other traditional automotive enterprises required technology researches. It lowered the threshold for vehicle manufacturing companies to enter the new energy sector. In the downstream of the industrial chain, consumers purchase electric car from new energy vehicle enterprises and synchronously complete the battery rental from battery enterprises. In the process of car purchase, the separation of vehicle and electricity is mandatory, which can effectively reduce the initial purchase cost of consumers. When changing electricity, users can independently choose the battery combination of large and small to meet long-distance or short-distance needs. At the same time, the waste batteries of new energy vehicles can be uniformly recycled to the battery enterprises for the recycling of raw materials through the changing stations of the battery enterprises, which is accurate and efficient.

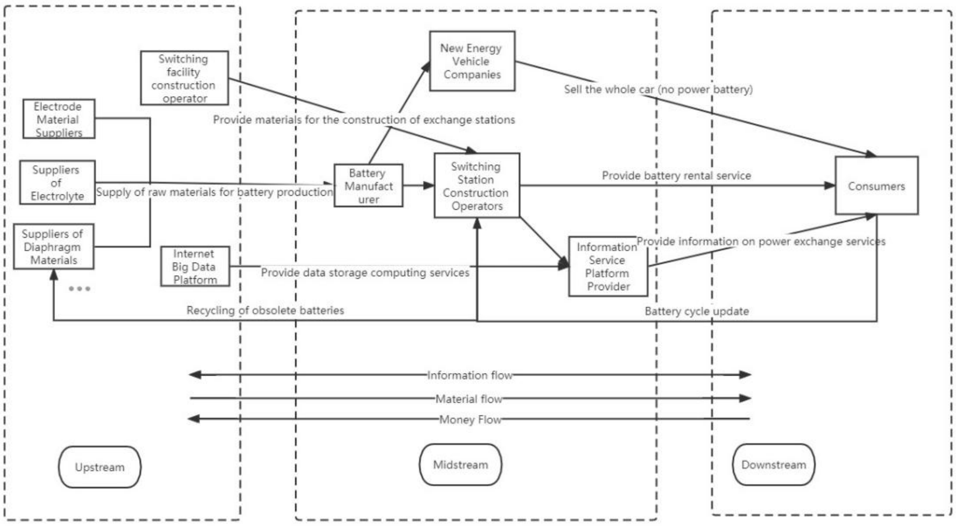

Figure 2: Battery-swap operation mode led by battery enterprises

2.3 Battery-swap operation mode dominated by Battery-swap operator

As the earliest battery-swap operator to participate in the battery-swap industry, Aulton New Energy has built more than 600 battery swap stations nationwide and established battery-swap service network

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in 26 cities. The accumulative number of electric car changing service is more than 50,000, and the mileage of single battery-swap is more than 1.3 million kilometers. It has gradually developed from the original ToB mode to ToC mode. Providing technical support for battery swap to more private car users. It is expected that 5,000 battery swap stations will be built nationwide by 2025.

As the figure3 shows, Upstream of the industrial chain are the manufacturers of battery swap station facilities and materials, providing midstream operators with equipment for battery swap stations, power batteries and related services. The middle reaches are dominated by battery-swap operators, who need to establish close cooperation with automobile and battery companies. Battery companies provide a large number of power batteries for battery-swap operators. After different car companies design their own battery exchange vehicle models, they can propose battery swap service requirements to operators. Battery exchange operators provide construction services for battery exchange stations and related battery exchange facilities, while charging the corresponding fees. Consumers are forced to separate the vehicle and rent the battery, after purchasing new energy vehicles. They can go to the battery-swap station operated by the operator to change their battery. In this mode, operators can provide battery-swap services of different brands and models of new energy vehicles at one site at the same time. Therefore, the battery-swap station covers a large area and has diversified functions. Besides providing battery-swap services for domestic vehicles, it can also provide battery-swap services for commercial vehicles and passenger vehicles.

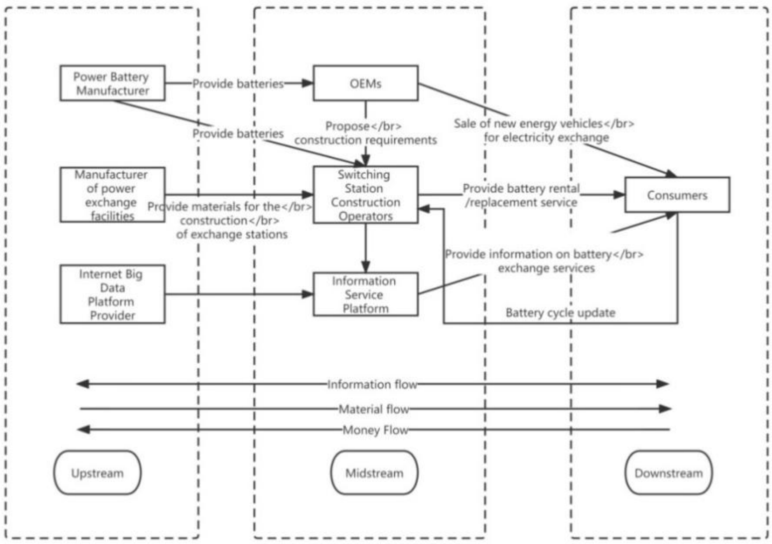

Figure 3: Battery-swap operation mode led by Battery-swap operators

3. Using AHP-Fuzzy Comprehensive Evaluation Method to Operate Model Evaluation

3.1 Analytic Hierarchy Process

3.1.1 Determining the Metric Hierarchy

The evaluation index system of battery-swap electric vehicle operation mode is composed of a large number of indicator factors. According to their mutual subordination, each factor is categorized in layers, with the upper layer having a dominant effect on the lower layer indicators and the indicators in the same layer being independent of each other. The evaluation index system is generally divided into three levels, namely, the target level, the criterion level and the indicator level.

Following the risk evaluation index system of the battery exchange project constructed by expert Yong Liang [7]; the evaluation indexes of construction capital investment, indirect costs, profitability of charging stations, and contribution to society considered by Xingguo Sun[8]; the evaluation indexes of electric vehicle charging and battery-swap service capacity, focusing on the evaluation of charging capacity, battery exchange capacity, and operation capacity, while considering the development needs of electric vehicles themselves and the socioeconomic environment adaptation needs established by Chang Liu et al.[9]; an economic evaluation model for charging and battery-swap stations based on the cost-benefit model, and analyzed financial indicators in three aspects: net present value, benefit-cost

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ratio and internal rate of return established by Yang Ruipeng[10]. Combined with the suggestions of senior experts in the industry invited by the team, a summary analysis was conducted to obtain the hierarchical structure of evaluation indexes for the new energy vehicle battery exchange operation model as the figure4 shows.

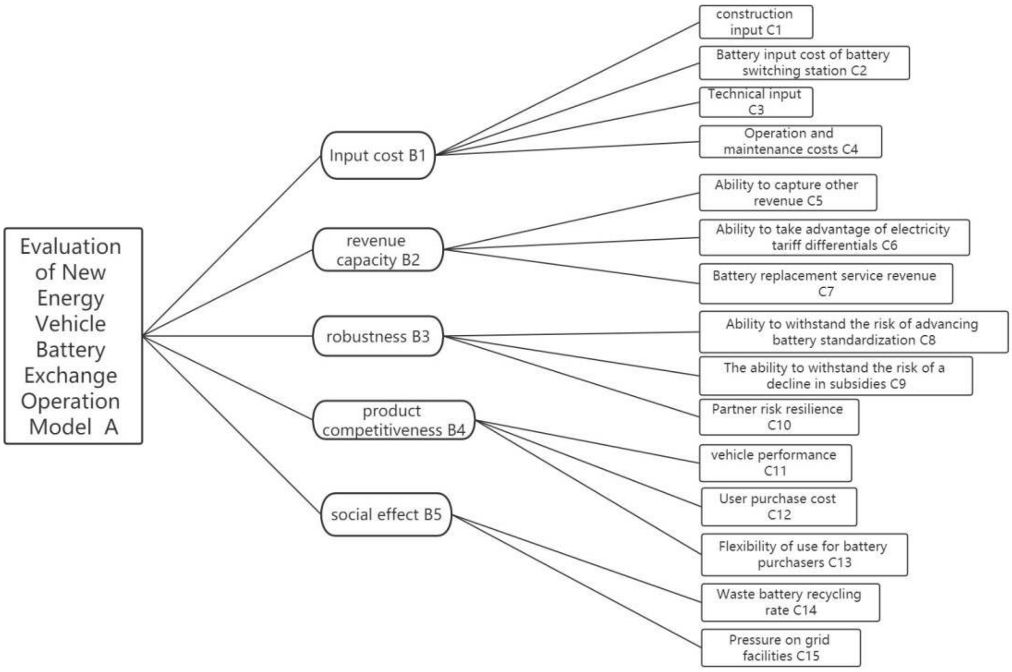

Figure 4: New Energy Vehicle Battery-swap Operation Mode Evaluation Index System

Target layer: Evaluation of New Energy Vehicle Battery Exchange Operation Model A

Level 1 indicator layer: input cost B1, revenue capacity B2, robustness B3, product competitiveness B4, social effect B5.

Secondary index layer: construction input C1, Battery input cost of battery-swap station C2,Technical input C3, Operation and maintenance costs C4, Ability to capture other revenue C5, Ability to take advantage of electricity tariff differentials C6, Battery swap service revenue C7, Ability to withstand the risk of advancing battery standardization C8, The ability to withstand the risk of a decline in subsidies C9, Partner risk resilience C10, vehicle performance C11, User purchase cost C12, Flexibility of use for battery purchasers C13, Waste battery recycling rate C14, Pressure on grid facilities C15

3.1.2 Construction of judgment matrix and calculation of index weights

Through the information provided by the project department, field research and consultation with senior experts and professional consultants to compare the factors of the index system, the relative weights of the indicators are obtained, and the relative importance of each factor obtained is quantified by using the 1-9 scale method, and the significance of the numerical values is shown in Table 1:

Table 1: Judgment matrix scale and its meaning

Scale	Meaning
1	The importance of the two factors is the same
3	The influencing factors of the former are slightly greater than those of the latter
5	The influencing factors of the former are greater than those of the latter
7	The influencing factors of the former are obviously greater than those of the latter
9	The influencing factors of the former are significantly greater than those of the latter
2,4,6,8	The important factors between the two are between the importance of the above
1/2,1/3,1/4,1/5,1/7,1/9	The importance of the two is the opposite

Construct the judgment matrix. Determine the relative importance of the criterion-level factors and indicator-level factors, respectively shown in Table 2:

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Table2: a-b Judgement matrix

a	b1	b2	b3	b4 …… bn
b1	b11	b12	b13	b14 …… b1n
b2	b21	b22	b23	b24 …… b2n
b3	b31	b32	b33	b34 …… b3n
b4	b41	b42	b43	b44 …… b4n
			……	
bn	bn1	bn2	bn3	bn4 …… bn

Calculate the weight after standardization

$$\overline{b_{ij}} = \frac{b_{ij}}{\sum_{i=1}^{n} b_{ij}} \quad (1)$$

Add the rows to get the sum, and normalize to get the weight coefficient.

$$\overline{w_i} = \sum_{i=1}^{n} \overline{b_{ij}} \quad (2)$$

$$W_i' = \frac{\overline{w_i}}{\sum_{i=1}^{n} \overline{w_i}} \quad (3)$$

Total sorting weight:

$$W_i(c) = W_i'(B) \cdot W_i'(c) \quad (4)$$

Calculate the maximum eigenvalue of the judgment matrix

$$\lambda_{max} = \sum_{i=1}^{n} \frac{[AW]_i}{nW_i} \quad (5)$$

Consistency check

$$C.I. = \frac{\lambda_{max} - n}{n-1} \quad (6)$$

Consistency ratio

$$C.R. = \frac{C.I.}{R.I.} \quad (7)$$

When C.R. < 0.1, consistency requirements are met.

(1) First-order judgment matrix and weight calculation

The results of a-B judgment matrix obtained are shown in Table 3:

Table 3: First-level judgment matrix and its weight

Evaluation of electric conversion operation mode A	Input cost B1	Revenue capacity B2	Robustness b3	Product competitiveness B4	Social effects B5	W
Input cost B1	1	4	3	3	4	0.4444
Revenue capacity B2	1/4	1	2	2	2	0.1944
Robustness b3	1/3	1/2	1	2	2	0.1581
Product competitiveness B4	1/3	1/2	1/2	1	2	0.1203
Social effects B5	1/4	1/2	1/2	1/2	1	0.0827

According to the formula (1) ~ (4), the weights of input cost B1, revenue capacity B2, robustness B3, product competitiveness B4 and social effect B5 are {0.4444, 0.1944, 0.1581, 0.1203, 0.0827} respectively.

According to the formula (5) ~ (7), it can be concluded that $\lambda_{max} = 5.2106$ and C.I.= 0.0470<0.10, which has passed consistency verification.

(2) Secondary judgment matrix and weight results

Similarly, we can obtain the second-level judgment matrix and weight results, as shown in Table 4,

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5, 6, 7, 8:

Table 4: Comparison of importance of input cost indicators

Input cost B1	Construction input C1	Battery input cost of battery-swap station C2	Technical input C3	Operation and maintenance costs C4	W1	Consistency test
Construction input C1	1	2	5	2	0.4420	C.R.=0.0243 < 0.10
Battery input cost of changing station C2	1/2	1	3	2	0.2783	
Technical input C3	1/5	1/3	1	1/3	0.0809	
Operation and maintenance costs C4	1/2	1/2	3	1	0.1988	

Table 5: Importance comparison of revenue capability indicators

Revenue capacity B2	Ability to capture other revenue c5	Ability to take advantage of electricity tariff differentials c6	Battery swap service revenue C7	W2	Consistency test
Ability to capture other revenue c5	1	1/2	1/3	0.1593	C.R.=0.0518 < 0.10
Ability to take advantage of electricity tariff differentials c6	2	1	1/3	0.2519	
Battery swap service revenue C7	3	3	1	0.5889	

Table 6: Comparison of importance of robustness indicators

Robustness B3	Ability to withstand the risk of advancing battery standardization C8	Ability to withstand the risk of a decline in subsidies C9	Partner risk resilience C10	W3	Consistency test
Ability to withstand the risk of advancing battery standardization C8	1	1/2	1	0.2409	C.R.=0.0176 < 0.10
Ability to withstand the risk of a decline in subsidies C9	2	1	3	0.5485	
Partner risk resilience C10	1	1/3	1	0.2106	

Table 7: Comparison of importance of product competitiveness indicators

Product competitiveness B4	Vehicle performance C11	User purchase cost C12	Flexibility of use for battery purchasers C13	W4	Consistency test
Vehicle performance C11	1	1/5	1/2	0.1222	C.R.=0.0036 < 0.10
User purchase cost c12	5	1	3	0.6479	
Flexibility of use for battery purchasers C13	2	1/3	1	0.2299	

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Table 8: Comparison of importance of social effect indicators

Social effects B5	Waste battery recycling rate C14	Pressure on grid facilities C15	Wi	Consistency test
Waste battery recycling rate C14	1	4	0.8000	C.R.=0.0000 < 0.10
Pressure on grid facilities C15	1/4	1	0.2000	

We can obtain the comprehensive weight results of the primary and secondary evaluation indicators by summarizing the above tables, as shown in Table 9.

Table 9: Comprehensive weight results of the primary and secondary evaluation indicators

The target layer	Rule layer	Wi	Time rule layer	At the same weight	Global weight
Evaluation of electric conversion operation mode	Input cost B1	0.4444	Construction input C1	0.4420	0.1964
			Battery input cost of battery-swap station C2	0.2783	0.1237
			Technical input C3	0.0809	0.0360
			Operation and maintenance costs C4	0.1988	0.0884
	Revenue capacity B2	0.1944	Ability to capture other revenue C5	0.1593	0.0310
			Ability to take advantage of electricity tariff differentials C6	0.2519	0.0490
			Battery swap service revenue C7	0.5889	0.1145
	Robustness b3	0.1581	Ability to withstand the risk of advancing battery standardization C8	0.2409	0.0381
			The ability to withstand the risk of a decline in subsidies C9	0.5485	0.0867
			Partner risk resilience C10	0.2106	0.0333
	Product competitiveness B4	0.1203	Vehicle performance C11	0.1222	0.0147
			User purchase cost C12	0.6479	0.0780
			Flexibility of use for battery purchasers C13	0.2299	0.0277
	Social effects B5	0.0827	Waste battery recycling rate C14	0.8000	0.0662
			Pressure on grid facilities C15	0.2000	0.0165

3.2 Fuzzy comprehensive evaluation model

The team invited 12 senior experts for statistical scoring, including senior engineers in intelligent driving, project managers in the construction department of operators, and university researchers in the field of new energy vehicles and new energy sources.There are 15 secondary evaluation indicators for each of the three programs, and the evaluation set V={5,4,3,2,1} is established to represent the five evaluation levels of "excellent, good, moderate, fair, and poor", and the statistical results of the evaluation are combined with the weight distribution results.

Table 10 shows the expert evaluation results of battery swap operation mode dominated by car companies:

Table 10: Expert evaluation results of Battery swap operation mode dominated by car companies

The evaluation factors			The evaluation index		Evaluation grade proportion statistics				
The serial number	Rule layer	Wi	Second rule layer	The same weight	Excellent	good	medium	general	poor
1	Input cost B1	0.4444	Construction input C1	0.4420	0	0.5	0.25	0.25	0
			Battery input cost of battery-swap station C2	0.2783	0.25	0	0.75	0	0
			Technical input C3	0.0809	0	0.5	0.25	0.25	0
			Operation and maintenance costs C4	0.1988	0.25	0.75	0	0	0
2	Revenue capacity B2	0.1944	Ability to capture other revenuec5	0.1593	0	0.25	0.25	0.5	0
			Ability to take advantage of electricity tariff differentials C6	0.2519	0	0.25	0.75	0	0
			Battery swap service revenue C7	0.5889	0	0	0.25	0.5	0.25
3	Robustness b3	0.1581	Ability to withstand the risk of advancing battery standardization C8	0.2409	0.25	0.5	0.25	0	0
			The ability to withstand the risk of a decline in subsidies C9	0.5485	0.25	0.25	0.25	0	0.25
			Partner risk resilience C10	0.2106	0	0.75	0.25	0	0
4	Product competitiveness B4	0.1203	Vehicle performance C11	0.1222	0.75	0.25	0	0	0
			User purchase cost c12	0.6479	0	0	0.25	0.5	0.25
			Flexibility of use for battery purchasers C13	0.2299	0.25	0.5	0.25	0	0
5	Social effects B5	0.0827	Waste battery recycling rate C14	0.8000	0	0	0.75	0	0.25
			Pressure on grid facilities C15	0.2000	0	0	0.5	0.25	0.25

1) Construct a first-level fuzzy comprehensive evaluation matrix. The fuzzy comprehensive evaluation matrix of input cost B1 and its index layer can be obtained as:

$$R_{b1}=\begin{bmatrix} 0 & 0.5 & 0.25 & 0.25 & 0 \\ 0.25 & 0 & 0.75 & 0 & 0 \\ 0 & 0.5 & 0.25 & 0.25 & 0 \\ 0.25 & 0.75 & 0 & 0 & 0 \end{bmatrix}$$

Similarly, the values can be obtained in sequence.$R_{b2}, R_{b3}, R_{b4}, R_{b5}$

2) Determine the weights of each factor. The values of the evaluation index weight set vector for each factor obtained by the Analytic Hierarchy Process are shown in the weight (Wi) column of the above table

3) One-level fuzzy transformation is performed. As aboveA_{b1}~A_{b5} describe the fuzzy relationship between each evaluation factor and its index set, and R_{b1}~R_{b5} describe the fuzzy relationship between the factor set and the evaluation level set, the evaluation results of each evaluation factor can be obtained by fuzzy transformation.

$$B_1=A_{b1}\cdot R_{b1}=(0.4420,\ 0.2783,\ 0.0809,\ 0.1988)\begin{bmatrix} 0 & 0.5 & 0.25 & 0.25 & 0 \\ 0.25 & 0 & 0.75 & 0 & 0 \\ 0 & 0.5 & 0.25 & 0.25 & 0 \\ 0.25 & 0.75 & 0 & 0 & 0 \end{bmatrix}=(0.119275,\ 0.41055,\ 0.33945,\ 0.130725,\ 0)$$

$$B_2=A_{b2}\cdot R_{b2}=(0.1593,\ 0.2519,\ 0.5889)\begin{bmatrix} 0 & 0.25 & 0.25 & 0.5 & 0 \\ 0 & 0.25 & 0.75 & 0 & 0 \\ 0 & 0 & 0.25 & 0.5 & 0.25 \end{bmatrix}=(0,\ 0.1028,\ 0.375975,\ 0.3741,\ 0.147225)$$

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$$B_3=A_{b3}\cdot R_{b3}=(0.2409,\ 0.5485,\ 0.2106)\begin{bmatrix}0.25 & 0.5 & 0.25 & 0 & 0\\ 0.25 & 0.25 & 0.25 & 0 & 0.25\\ 0 & 0.75 & 0.25 & 0 & 0\end{bmatrix}=(0.19735,\ 0.415525,\ 0.25,\ 0,\ 0.137125)$$

$$B_4=A_{b4}\cdot R_{b4}=(0.1222,\ 0.6479,\ 0.2299)\begin{bmatrix}0.75 & 0.25 & 0 & 0 & 0\\ 0 & 0 & 0.25 & 0.5 & 0.25\\ 0.25 & 0.5 & 0.25 & 0 & 0\end{bmatrix}=(0.149125,\ 0.1455,\ 0.21945,\ 0.32395,\ 0.161975)$$

$$B_5=A_{b5}\cdot R_{b5}=(0.8,\ 0.2)\begin{bmatrix}0 & 0 & 0.75 & 0 & 0.25\\ 0 & 0 & 0.5 & 0.25 & 0.25\end{bmatrix}=(0,\ 0,\ 0.7,\ 0.05,\ 0.25)$$

Thus, the fuzzy comprehensive evaluation matrix of factor layer is:

$$R=\begin{bmatrix}0.19275 & 0.41055 & 0.33945 & 0.130725 & 0\\ 0 & 0.1028 & 0.375975 & 0.3741 & 0.147225\\ 0.19735 & 0.415525 & 0.25 & 0 & 0.137125\\ 0.149125 & 0.1455 & 0.21945 & 0.32395 & 0.161975\\ 0 & 0 & 0.7 & 0.05 & 0.25\end{bmatrix}$$

$$A=(0.4444,\ 0.1944,\ 0.1581,\ 0.1203,\ 0.0827)$$

$$B=A\cdot R=(0.1022,\ 0.2857,\ 0.3478,\ 0.1739,\ 0.0905)$$

It can be concluded that the comprehensive evaluation score of the electric change operation mode led by automobile enterprises= 0.1022*5+0.2857*4+0.3478*3+0.1739*2+0.0905*1=3.1355

According to the principle of maximum degree of membership, the maximum comprehensive evaluation value of the battery-swap operation mode dominated by automobile enterprises is 0.3478. Compared with the standard level of membership degree, it belongs to the third level of evaluation grade, indicating that the overall evaluation level of the battery-swap operation mode dominated by automobile enterprises is "moderate".

Similarly, comprehensive evaluation results of battery enterprise-led battery-swap operation mode and battery-swap operator-led battery-swap operation mode can be obtained as shown in Table 11

Table 11: Comprehensive evaluation scores of the three battery-swap operation modes

Battery-swap operation mode	Evaluation vector B	Comprehensive evaluation score	Comprehensive rating
Battery-swap operation mode dominated by car companies	(0.1022, 0.2857, 0.3478, 0.1739, 0.0905)	3.1351	moderate
Battery-swap operation mode dominated by battery enterprises	(0.2342, 0.3342, 0.2960, 0.1356, 0.0000)	3.667	good
Battery-swap operation mode dominated by Battery-swap operator	(0.0286, 0.3235, 0.4160, 0.2008, 0.0311)	3.1178	moderate

Using AHP-fuzzy comprehensive evaluation to evaluate analysis, dominated by battery enterprises in battery-swap model of comprehensive evaluation score of 3.667, according to the principle of maximum membership degree of evaluation is "good", which shows that battery swap operation mode dominated by battery enterprises is better than by car companies or by battery-swap operator.

4. Results Analysis

According to the comprehensive evaluation scores of the three battery exchange operation modes and the principle of maximum affiliation, it can be obtained that battery swap operation mode dominated by battery enterprises is better than other two modes. At the same time, by summarizing the scoring results of experts, we can obtain the score details of the criterion level and sub-criterion level of the three modes as shown in Table12.

Table 12: Detailed scores of criteria layer and sub-criteria layer (full mark is 5)

The serial number	Rule layer	Battery-swap operation mode: Dominated by car companies	Battery-swap operation mode: Dominated by battery enterprises	Battery-swap operation mode: Dominated by battery-swap operator	Second rule layer	Battery-swap operation mode: Dominated by car companies	Battery-swap operation mode: Dominated by battery enterprises	Battery-swap operation mode: Dominated by battery-swap operator
1	Input cost B1	3.518	4.079	2.659	Construction input C1	3.25	4.25	2.5
					Battery input cost of changing station C2	3.5	4.25	3.25
					Technical input C3	3.25	2.75	2.5
					Operation and maintenance cost C4	4.25	4	2.25
2	Revenue capacity B2	2.434	2.79	4.023	Ability to capture other revenue c5	2.75	3	3.75
					Ability to take advantage of electricity tariff differentials C6	3.25	2.75	4.25
					Battery swap service revenue C7	2	2.75	4
3	Robustness b3	3.536	3.622	3.472	Ability to withstand the risk of advancing battery standardization C8	4	3	3.25
					The ability to withstand the risk of a decline in subsidies C9	3.25	3.75	3.75
					Partner risk resilience C10	3.75	4	3
4	Product competitiveness B4	2.796	3.496	3	Vehicle performance C11	4.75	3	3
					The user purchase cost C12	2	3.5	3
					Flexibility of use for battery purchasers C13	4	3.75	3
5	Social effects B5	2.45	3.85	2.95	Waste battery recycling rate C14	2.5	4	2.75
					Pressure on grid facilities C15	2.25	3.25	3.75

(1) According to the detailed score table, the battery-led battery-swap operation mode is better than the other two battery-swap operation modes in terms of input cost, robustness, product competitiveness and social effects, while in terms of revenue capacity, the battery-led battery-swap operation mode has a lower score of 2.79 points, which is lower than the 4.023 points of the battery swap operator-led mode. This is mainly due to the fact that the battery company-led model has a smaller footprint, weaker independent power generation capacity, and the number of stored power batteries is significantly less than that of the battery operator-led model, and the scale benefit of centralized battery charging is weaker, and the ability to utilize the difference in electricity tariff is weaker. At the same time, it is easier to form a complete database of different brands of home cars, commercial vehicles and passenger cars under the switch operator-led model, and the ability to obtain revenue from the switch service and other revenues is also stronger under the switch operator-led model.

(2) Among the initial investment costs of the three modes, the operator-led mode scores lower than the other two modes in terms of construction investment, technology investment, battery investment and operation and maintenance investment, and is at a significant disadvantage. This is mainly due to the fact that the operator-led mode serves many models, the battery specifications of the models are scattered, and it is difficult to scale up the battery investment, and it is necessary to develop and build different battery-swap methods and equipment for different models, so the individual station

construction cost is high. In the process of construction and operation, especially in the early stage of construction investment, the battery-swap mode is very dependent on the national switch policy support and financial subsidies.

(3) In terms of robustness, the three modes of battery swap operation have different degrees of dependence on the process of battery standardization, with the highest score of 4 for the vehicle-led mode. The existing subsidies for the new energy vehicle industry mainly include vehicle purchase subsidies, double points for vehicle enterprises, and subsidies for the construction of charging and battery-swap stations, etc. If the national subsidies for the new energy vehicle industry as a whole are weakened, the impact on the vehicle-led model will be more significant; the risk-resistance score of the partners is 3.25. It can be seen that the battery-led model has the highest score of 4, because the battery companies have strong dominant power and voice in the new energy vehicle industry and the power exchange industry, and are more resilient to partner risks, while the power exchange operators rely more on frequent business cooperation with other vehicle manufacturers and battery manufacturers in the power exchange business, and are in a weaker position in the supply chain.

(4) In terms of product competitiveness, the vehicle performance score of the vehicle-led model is 4.75, which has a significant advantage, mainly due to the fact that in the vehicle-led model, the battery, spare parts and assembly business of the vehicle manufacturer are more complete, and the vehicle drive performance is stronger. Management, the cost of the vehicle is relatively high, and the user purchase cost is also higher, scoring 2 points, at a disadvantage. The other two models are more conducive to the scale effect, which is conducive to reducing the cost of the vehicle and the user's purchase cost; the vehicle-led model and the battery-led model perform better in terms of the flexibility of the buyer's battery use, with scores of 4 and 3.75 respectively. It is difficult to equip with unified power batteries, and it is difficult to take into account the user's right to choose.

(5) In terms of social effects, the battery company-led model has a score of 4 in the recycling of used batteries, which has obvious advantages. This is mainly due to the fact that used batteries can be recycled to battery enterprises for recycling of raw materials through the exchange stations of battery enterprises, which can reduce environmental pollution and at the same time recycle precious metals in power batteries in time, with economic benefits.

5. Conclusion

Using the analytic hierarchy process (ahp) and fuzzy comprehensive evaluation method (fce), this project evaluates and analyzes the input-output, supply chain risk resilience, new energy vehicle product competitiveness and other indicators under the three different supply chain structures, compares and obtains the Battery-Swap Operation Mode Dominated by Battery Enterprises is the best operation mode, and analyzes the respective advantages of the three operation modes. Thus, some management implications are obtained, which can provide policy support for relevant departments and decision-making reference for the production and operation management of battery-swap market participants. This paper seeks to make up for the theoretical gap and further expand the research field of new energy vehicle power conversion through practical research, objective analysis and in-depth exploration. It has important theoretical and practical significance. The major limitation of this study is the subjective intention of the experts interviewed and more researches using different indicators is needed in this battery-swap mode area.

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