Research on Health Evaluation of New Energy Vehicle Brands Based on AHP-Fuzzy Mathematical Model

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Abstract. The health degree of new energy vehicle brands directly affects the health status and asset value of automotive companies. This article focuses on the health evaluation of ten representative new energy vehicle brands in China, providing a reference direction for the further value-added of Chinese new energy vehicle brands in the international market and achieving the internationalization and modernization development goals of domestic new energy vehicles. Using 754 data from valid questionnaires, and based on relatively complete evaluation criteria, two methods, item by item evaluation and AHP fuzzy mathematical model evaluation, were used to quantitatively and qualitatively evaluate the health status of the top ten new energy vehicle brands. We have constructed an evaluation system consisting of three factor layers of brand awareness, brand association, and brand loyalty, as well as six sub factor layers corresponding to our subordinates. Evaluation results are: Geely, NIO, Xiaopeng, Li Auto, Wuling, Tesla, and BYD belong to the "very healthy" level and are classified as first-class brands; Chery and Changan belong to the "general health" level and are classified as second level brands; Aion belongs to the "unhealthy" level and is classified as a third level brand.

Keywords: Brand health AHP-Fuzzy, Mathematical Model, New energy vehicle

1 Introduction

The new energy vehicle industry is a core area for promoting the carbon peaking and carbon neutrality goals and realizing green development. In June 2023, the Chinese government network in the "high-quality development of new energy automobile industry again welcome policy support" put forward: to create a world-class brand. Continuing to carry out the "Chinese auto brand upward development" special action, support the advantageous enterprises to strengthen quality management, optimize production capacity layout, market-oriented, rule of law to promote the backward vehicle enterprises and production capacity to exit, promote the development of the group on a large scale, accelerate the cultivation of Chinese brands with international competitiveness. Strengthening brand building, focus on brand health has become a major new energy vehicle enterprise into the next stage of the policy layout of the key.

Since brand health and its asset value objectively reflect brand competitiveness, it is crucial to study the brand health of new energy vehicle manufacturers, which is of great significance for understanding the competitive situation of the new energy vehicle market and consumer

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satisfaction with each brand. There is a large gap between the sales volume of new energy vehicle brands, as shown in Figure 1. Enhancing brand construction and focusing on brand health have become key to major new energy vehicle enterprises as they engage in the next phase of policy deployment. This article selects ten representative new energy vehicle brands, including NIO, Chery, Aion, BYD, Li Auto, Wuling, Geely Auto, Tesla, Changan, and Xiaopeng Motors, and uses the AHP-fuzzy mathematical model to systematically analyze the health status of the top ten new energy vehicle brands. The evaluation results of the health degree of each brand are derived, which have effective reference value for the healthy development of domestic new energy vehicles [1][2].

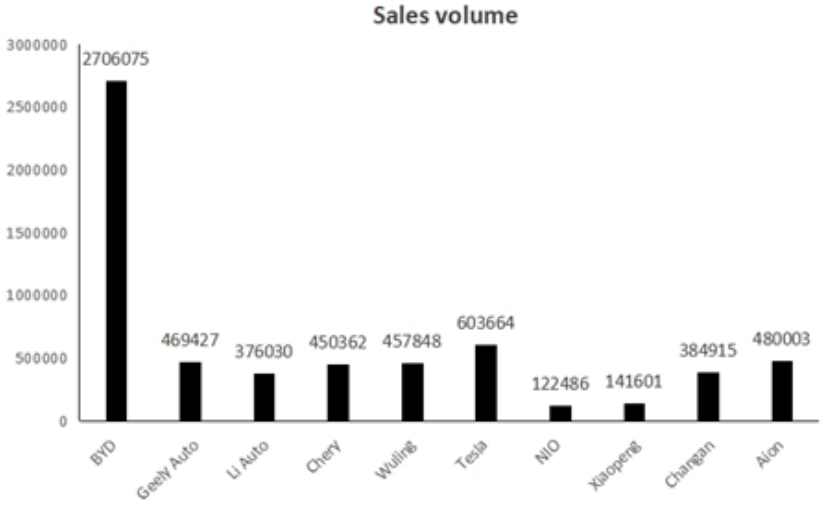

Figure 1. 2023 Sales of new energy vehicles by brand.

2 Data Sources and Methods

2.1 Data Sources

The data of this study were obtained through questionnaires, and 784 questionnaires were collected, of which 754 were valid questionnaires. According to A David's five-star model of brand equity and the theory related to brand health, the health level of the top ten new energy automobile brands is examined from multiple angles and levels through brand awareness, brand association and brand loyalty [3].

2.2 Itemized evaluation method

2.2.1 Constructing health evaluation indexes.

Combining the theory of brand health and the actual situation of the new energy automobile market[4], this paper selects the representative and differentiated independent indexes, and constructs an evaluation index system with three factor layers of brand awareness[5], brand association[6] and brand loyalty, as well as six sub-factor layers, as shown in Figure 2. The

brand awareness layer includes pre-tip awareness and post-tip awareness; the brand association layer includes brand image and perceived quality; The brand loyalty layer includes brand net recommendation value and user satisfaction [7].

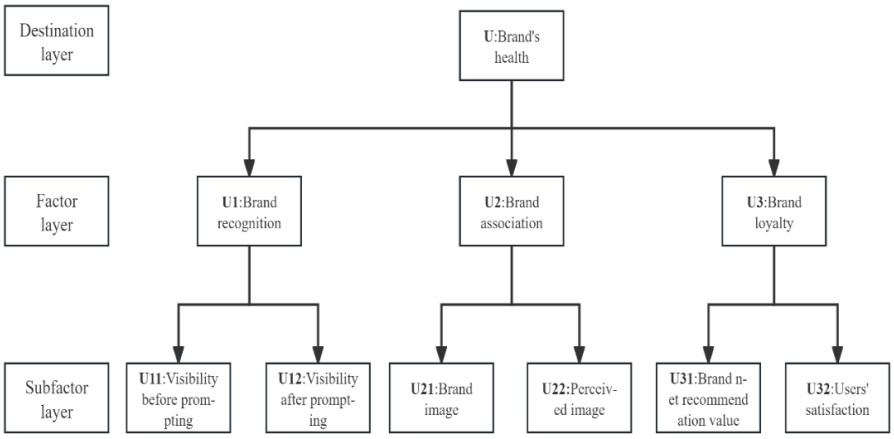

Figure 2. Schematic diagram of the integrated evaluation system model.

2.2.2 Classification of brand health evaluation.

The health evaluation of the top ten new energy vehicle brands is categorized into three categories, which are Level 1 brands (very healthy), Level 2 brands (generally healthy) and Level 3 brands (unhealthy).

2.3 AHP-Fuzzy Mathematical Modeling

In the health evaluation of the top ten new energy vehicle brands, AHP and fuzzy comprehensive evaluation method are combined to construct AHP fuzzy mathematical model [8]. The model firstly constructs the evaluation system and judgment matrix through AHP, calculates the weights of sub-factors, and then applies the fuzzy comprehensive evaluation method and the principle of maximum affiliation in fuzzy mathematics to determine the high and low status of the brand health evaluation and then analyses the results.

3 Evaluation processes and results

3.1 Determine the factor set

The factor set is the set of each of the above indicators, i.e. $U=\{U_1,U_2,U_3\}$, where $U_1 = \{U_{11}, U_{12}\}$, $U_2=\{U_{21},U_{22}\}$, $U_3=\{U_{31},U_{32}\}$.

3.2 Determine the weight set

Let the weights of the factor layer on the target layer be:

$$A=\{a_1,a_2,a_3\} \quad (1)$$

Then let the weights of the sub-factor layers on the corresponding main factor layers be respectively:

$$a_1=\{a_{11},a_{12}\},$$

$$a_2=\{a_{21},a_{22}\},$$

$$a_3=\{a_{31},a_{32}\}.$$

The weights in this paper are based on the steps and methods of determining the weights by X Zang in the Research on Brand Asset Evaluation Based on AHP Method, and the specific operation steps are as follows: Experts participating in the evaluation of brand health are required to use the two-by-two comparison method to evaluate the importance of the indicators in the factor layer according to their importance between the values of 1 and 5, and the scoring criteria are shown in Table 1, which results in the judgment matrix X and the eigenvectors W are calculated as the corresponding weights. The eigenvector W of X is calculated as the corresponding weights, and it should be noted that the eigenvectors W need to be normalized to obtain the maximum root eigenvalue (CI), which can be used for the consistency test in the next step [9][10].

Table 1. A table with AHP scoring criteria and their meanings.

Scale	Implication
1	Indicates that two factors are equally important when compared
3	Indicates that one factor is important than the other
5	Indicates that one factor is more important than the other
2，4	The median of the above two adjacent near judgements
Reciprocal	The comparison between factor i and j determines aij, then the comparison between factor j and i determines $a_{ji}=1/a_{ij}$

3.3 Consistency test

In the construction of the judgment matrix before the need for consistency testing, this paper uses the CR value of consistency testing, CR value of the formula for the $CR=CI/RI$, CI value has been obtained in the search for eigenvectors, RI value is directly from the table.If the CR value is less than 1, that is, the data through the consistency test, and vice versa, the data did not pass the consistency test, at this time you need to check whether there are logical problems, etc., re-entry judgment matrix for analysis.

$$CR=CI/RI \quad (2)$$

$$CI=\frac{\lambda\text{-}n}{n\text{-}1} \quad (3)$$

3.4 Establishing evaluation sets

Evaluation set is a collection of various results that evaluators may make on the evaluation object, usually denoted by V. The evaluation set is a collection of results that evaluators may make on the evaluation object. The brand health evaluation set established in this paper is

$V=(V_1,V_2,V_3)$, where: V_1 means high, V_2 means average, and V_3 means low, which means that the brand is very healthy, generally healthy, and unhealthy respectively.

3.5 Establishment of fuzzy affiliation matrix

Comprehensive evaluation is carried out for each U_i separately. Since some indicators such as brand image Uij are fuzzy and cannot be directly quantified, it is necessary to construct a single-factor evaluation matrix R_i for the factor layer U_i by the Delphi method. If the evaluation vector of the ith factor layer of U is B_i, then $B_i=a_i\text{-}R_i$, and thus obtain the fuzzy evaluation matrix of each evaluation indicator of the factor layer as $B=(B_1, B_2, B_3)^T$, and then according to the weight indicators of the three factors in the factor layer A, and then based on the weight indicators of the three factors in the factor layer A, thus obtaining the comprehensive evaluation results of the target layer.

4 Evaluation results and analysis

As mentioned above, the comprehensive evaluation system of brand health status has been determined, which can be obtained according to the comprehensive evaluation of the company's market status by industry experts, as shown in Table 2.

Table 2. A table with each brand expert score.

Brand	BYD	Geely Auto	Li Auto	Chery	Wuling
R1	(0.36,0.64)	(0.06,0.94)	(0.04,0.96)	(0.05,0.95)	(0.02,0.98)
	(0.97,0.03)	(0.54,0.46)	(0.33,0.67)	(0.35,0.65)	(0.50,0.50)
R2	(0.74,0.26)	(0.58,0.42)	(0.67,0.33)	(0.69,0.31)	(0.62,0.38)
	(0.75,0.25)	(0.63,0.37)	(0.69,0.31)	(0.69,0.31)	(0.67,0.33)
R3	(0.81,0.19)	(0.69,0.31)	(0.86,0.14)	(0.70,0.30)	(0.68,0.32)
	(0.76,0.24)	(0.71,0.29)	(0.68,0.32)	(0.71,0.29)	(0.58,0.42)
Brand	Tesla	NIO	Xiaopeng	Changan	Aion
R1	(0.25,0.75)	(0.07,0.93)	(0.05,0.95)	(0.03,0.97)	(0,1)
	(0.85,0.15)	(0.44,0.56)	(0.47,0.53)	(0.45,0.55)	(0.26,0.74)
R2	(0.64,0.36)	(0.64,0.36)	(0.67,0.33)	(0.69,0.31)	(0.67,0.33)
	(0.69,0.31)	(0.76,0.24)	(0.73,0.27)	(0.71,0.29)	(0.73,0.27)
R3	(0.78,0.22)	(0.79,0.21)	(0.62,0.38)	(0.78,0.22)	(0.82,0.18)
	(0.72,0.28)	(0.78,0.22)	(0.79,0.21)	(0.67,0.33)	(0.88,0.12)

On this basis, the analytic hierarchy process is used to score each factor layer and sub-factor layer in Figure 2, and the weight of each factor layer is determined by sum-product method.[10] The weight matrix of each factor layer is calculated as follows (take BYD as an example here):

$$A=(0.532, 0.366, 0.102),$$
$$a_1=(0.833, 0.167),$$
$$a_2=(0.250, 0.750),$$
$$a_3=(0.750, 0.250).$$

Among them, A is the weight index of each of the three factors in the factor layer, a_i corresponds to the weight index of each sub-factor layer, and the above weight indexes have been normalized.

Industry experts vote on the performance of each factor in the sub-factor layer in the industry according to the evaluation set, and the fuzzy matrix of the sub-factor layer is obtained after normalization of the voting results:

$$R_1=\begin{bmatrix}0.36 & 0.64\\ 0.97 & 0.03\end{bmatrix}$$
$$R_2=\begin{bmatrix}0.74 & 0.26\\ 0.75 & 0.25\end{bmatrix}$$
$$R_3=\begin{bmatrix}0.81 & 0.19\\ 0.76 & 0.24\end{bmatrix}$$

First, brand awareness was assessed:

From the fuzzy matrix

$$R1=\begin{bmatrix}0.36 & 0.64\\ 0.97 & 0.03\end{bmatrix}$$

The final evaluation result is:

$$B_1=a_1 \cdot R_1 \tag{4}$$

Similarly, the assessment results of each other factor layer indicators B_2 and B_3 are derived, where B_1, B_2 and B_3 are the assessment results of the three elements of the factor layer, and the values in the parentheses correspond to the weights assigned to the three evaluation degrees in the evaluation set, and therefore, the fuzzy matrix of the factor layer can be derived as:

$$B=(B_1, B_2, B_3)^T \tag{5}$$

The final result of BYD's brand health rating was calculated as:

$$C=A \cdot B=(0.5073 \;\; 0.4525 \;\; 0.4429) \tag{6}$$

where each value in C corresponds to the weight of the three degrees in the evaluation set.

Repeat the above steps to obtain the brand health evaluation results for the remaining nine brands respectively:

Geely Auto: C = (0.5691 0.4774 0.4626),
Li Auto: C = (0.5790 0.4645 0.4395),
Chery: C = (0.4568 0.5863 0.4611),
Wuling: C = (0.5768 0.4698 0.4702),
Tesla: C = (0.5288 0.4659 0.4491),
NIO: C = (0.5707 0.4558 0.4448),
Xiaopeng: C = (0.5729 0.4587 0.4688),
Changan: C = (0.4468 0.5906 0.4515),
Aion: C = (0.4877 0.4587 0.5357).

Geely, NIO, Li Auto, Xiaopeng, Wuling, Tesla and BYD all have the highest proportion of V1, indicating that the brand is in good health and very healthy; Chery and Changan have the highest proportion of V2, which is average brand health and medium in the industry; and Aion has the highest proportion of V3, indicating that the brand is unhealthy and its brand equity value is relatively low in the industry.

5 Conclusion

According to the results of the study, Geely, NIO, Xiaopeng, Li Auto, Wuling, Tesla, BYD are level 1 brands, which belong to the evaluation level of "very healthy", while Chery and Changan are level 2 brands, which belong to the evaluation level of "generally healthy"; Aion is a tertiary brand and belongs to the "unhealthy" level. In this study, the health status and asset value of 10 new energy vehicle brands were assessed using AHP-fuzzy mathematical modelling and sub-evaluation method, which provides reference value for further value-adding of Chinese new energy vehicle brands in the international market.

This study employs the Analytic Hierarchy Process (AHP) combined with a fuzzy mathematical model, coupled with an Itemized evaluation method, to quantitatively assess the health status and asset value of ten major new energy vehicle (NEV) brands. The research culminates in the derivation of a composite brand health index for these mainstream NEV brands in the Chinese domestic market.

The findings not only serve as a critical reference for the brand value assessment of other NEV brands and potential market entrants but also provide a scientifically grounded direction for the strategic upgrade and market positioning of Chinese NEV brands. This research aims to enhance the competitiveness of Chinese NEV brands in the global market and to foster the industry's sustained and healthy development.

References

[1] Hao, H, Tao, S. (2022) Research on the development of new energy automobile industry under the background of green low-carbon. China Business Journal, (05):145-147. DOI:10.19699/j.cnki.issn2096-0298.2022.05.145.

[2] Zhang, Z, Liu, Q, Wang G. (2023) Study on the health evaluation of Feng River based on AHP-fuzzy mathematical model and itemized evaluation method. People's Pearl River, 44(01): 123-131. DOI:10.3969/j.issn.1001-9235.2023.01.017.

[3] David A. (2006) Managing Brand Equity. Advertisement Herald, (6): 1.

[4] Bai M. (2021) "Direction and path to enhance the competitiveness of new energy automobile industry in the 14th Five-Year Plan period. Price Theory and Practice, (02): 18-24. DOI:10.19851/j.cnki.cn11-1010/f.2021.02.59.

[5] Wang J, Qin M. (2011) Impact of Brand Awareness and Brand Image on Consumers' Purchase Intention. Enterprise Research: Theory Edition, (2): 50-51. DOI:CNKI:SUN:QYYJ.0.2011-02-028.

[6] Xiao S. (2012) Brand health measurement model and its application. Communication Enterprise Management, (8): 2. DOI:CNKI:SUN:YDQG.0.2012-08-027.

[7] Ding J, Lu Y, Hong D. (2016) Testing loyalty. Twenty-first Century Business Review. , (10): 108-111.DOI:CNKI:SUN:ESYS.0.2016-10-042.

[8] Cheng Q. (1997) Attribute mathematical model and fuzzy mathematical model for quality evaluation. Mathematical Statistics and Management, 16(6): 6. DOI:10.1007/BF02943147.

[9] Zang X, Guan Z. (2007) Research on brand asset evaluation based on AHP method. Journal of Beijing Jiaotong University: Social Science Edition, 6(2): 23-27. DOI:10.3969/j.issn.1672-8106.2007.02.005.

[10] Hussain A, Elkelish W. (2023) Impact of excise tax on consumption, brand loyalty and health awareness: Evidence from the United Arab Emirates. Cogent Business Management, 10(1):2160579. DOI:10.1080/23311975.2022.2160579.