Establishment of Residual Value Assessment Model for Electric Vehicle Based on AHP

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Abstract. With the rapid increase of sales of new energy vehicles in China, electric vehicles begin to enter the homes of ordinary people. Like traditional diesel locomotives, electric vehicles will also face the problems of residual value assessment and recycling in the life cycle of products. Based on the traditional evaluation of used vehicles of internal combustion engines, combined with the unique factors of electric vehicles, this paper analyzed the substantial devaluation, functional devaluation and economic devaluation of electric vehicles, systematically sorted out the influencing factors of residual value of electric vehicles, and constructed the calculation model of residual value of electric vehicles by reset cost method and AHP analytic hierarchy process. At present, the scale of electric vehicle has not been formed in our country, the state has not yet promulgated the relevant evaluation criteria for second-hand electric vehicle, and the second-hand electric vehicle has not formed a market. Therefore, the calculation model deduced in this paper can not be verified by the market for the time being, but it has certain reference significance for the evaluation of second-hand electric vehicle.

1. Introduction

In 2018, the production and sales of new energy vehicles in China were 1.27 million and 1.256 million, respectively, up 59.9% and 61.7% year-on-year. The new energy automobile industry is one of the seven strategic emerging industries in China. It has ranked first in the world for sales for four consecutive years from 2015 to 2018[1]. However, the circulation of new energy vehicles in the secondary market is difficult[2]. According to the report of the China Automobile Dealers Association, as the growth of new energy vehicles has occurred mainly in the past year, the age of used cars is generally shorter[3]. Among them, the new energy vehicles with the age of one year accounted for the most, at 44.8%, the second-year vehicles with new energy vehicles took the second place, accounting for 36.2%, the three-year vehicle age was 14.7%, and the minimum age of four years and above[4], accounting for only 4.3%. At the same time, the 1-year-old new energy vehicle maintenance rate is 74.8%, the 2-year vehicle age is 60.1%, and the 3-year vehicle age is only 47.5%. The performance of new energy vehicles over 3 years is very backward and basically no longer has circulation value. Based on AHP and replacement cost method, this paper constructs the residual value evaluation model of pure electric vehicle based on the cycle life calculation of electric vehicle battery under different conditions[5].
2. New energy used car comprehensive rate calculation

2.1. Battery depreciation

Depreciation of the battery is the amount of depreciation that is taken at a certain depreciation rate to compensate for the loss of the battery after it has been used for a certain period of time[6]. The depreciation of the battery is due to the loss of the battery, which is reflected in the battery can not store 100% of the power, so the capacity retention rate (SOC) of the battery can be used to reflect the depreciation, that is, the ratio of the battery capacity to the rated capacity after a period of charging and discharging[7].

2.1.1. Battery cycle life times.

At present, there are two main types of batteries for electric vehicles in China: acid batteries and alkaline batteries. Among them, the acid battery is mainly a lead-acid battery. Lead-acid batteries are inexpensive, but have short cycle life and low energy density and power density. Alkaline batteries, including nickel-cadmium, nickel-metal hydride, and lithium-ion batteries, have higher specific energy and specific power than lead-acid batteries[8].

The theory of battery life prediction proposed by the US Renewable Energy Laboratory (NREL) when researching wind power supply systems is of great significance for the theory of battery life of electric vehicles. The theory explores the factors affecting battery life, pointing out that the depth of charge and discharge and the rate of charge and discharge will have the greatest impact on the life of the battery. There is relevant evidence that charging the battery at a high-speed charging rate in a medium-low state of charge will not cause damage to the battery life. Zhe Lid et al. of Tsinghua University also proposed that battery life is more sensitive to the discharge rate than the charging rate. Therefore, the state of charge can be neglected in the research calculation, and the state of the battery is considered.

The predictive model of battery life is based on the assumptions made by symons, where the first is the charge life \( \Gamma \) if the life of each battery cell is measured as the effective ampere of the entire battery life. If the cumulative loss effective ampere is equal to the rated charge life, the battery unit life is terminated[9]. Therefore, the rated charge life of the battery unit is:

\[
\Gamma_R = L_R D_R C_R
\]

(1)

The relevant terms in the formula are as follows:

- \( C_R \) - Rated capacity: The energy that the battery can output when the discharge is terminated by \( I_R \) (A) current under the condition of \((20 \pm 5) ^\circ C\), the unit is Ah. According to GB/Z 18333.1-2001 "Lithium Ion Battery for Electric Road Vehicles", the rated capacity of lithium ion batteries is represented by \( C_3 \).

- \( I_R \) - rated discharge rate: also known as R hour rate discharge current, R represents the hourly rate of discharge, the unit is A. \( I_3 = C_3 / 3 \).

- \( D_R \) - Rated discharge depth: The ratio of the discharge capacity to the rated capacity at the rated cycle life, generally set to 100%.

- \( L_R \) - Indicates the rated ampere-hour capacity at the rated discharge depth \( D_R \) and the rated discharge current \( I_R \).

As the depth of discharge increases, the cycle life of the battery decreases with the increase of the depth of discharge. Regarding the influence of the depth of discharge on the cycle life of the battery, the best fit is obtained by using the function relationship, which is the relationship between cycle life and depth of discharge.

\[
L = a_2 \left( \frac{D_R}{D_a} \right)^{a_0} e^{a_1 \left( \frac{D_R}{D_a} \right)}
\]

(2)
Where $L$ represents the actual cycle life.

According to the relationship data between the discharge depth and the cycle life provided by the manufacturer, $a_0$, $a_1$, $a_2$ can be obtained by nonlinear fitting, and the effective discharge amount ($d_e$) of a specific discharge time can be obtained by substituting $L_R = a_2$ and $d_e / d_a = L_R / L$.

Where $L_R$ is the cycle life at the rated discharge depth $D_R$ and the rated discharge current $I_R$.

$$d_e = \left( \frac{D_A}{D_R} \right)^{a_0} e^{a_1 \left( \frac{D_R}{D_e} \right)^{a_2}} d_a$$

(3)

Where $d_e$ represents the effective discharge amount for a specific discharge time, and $d_a$ represents the actual discharge amount.

The second assumption: when discharging at a higher than rated rate, the charge life of the battery unit will decrease. The higher the discharge rate, the greater the conduction loss between the active particles in the precursor of the battery material. By this physical relationship analysis, the relationship between the effective discharge amount and the discharge rate can be obtained. Due to the power battery, the battery capacity does not change much with the discharge current, so the following expression:

$$d_e = \left( \frac{I_A}{I_R} \right)^{a_0} d_a$$

(4)

Multiplying the discharge rate by the relationship between the depth of discharge and the cycle life can obtain the combined effect of discharge rate and depth on cycle life.

$$d_e = \left( \frac{D_A}{D_R} \right)^{a_0} e^{a_1 \left( \frac{D_R}{D_e} \right)^{a_2}} \left( \frac{I_R}{I_A} \right) d_a$$

(5)

From $D_e = \frac{d_e}{c_R}$ and $D_A = \frac{d_a}{c_R}$, you can get

$$D_e = D_A^{(a_0+1)} e^{a_1(D_A^{-1})}$$

(6)

Where $D_R$ is set to 100%, the SOC (long term) lost in a single discharge event is expressed as an effect on battery life.

According to S. Drouilhet's paper "A Battery Life Prediction Method for batteries for electric vehicles on short and longer term", the life formula of the battery can be established:

$$L_T = \frac{L_R D_R}{\sum_{i=1}^{n} D_e}$$

(7)

among them:

$$D_e = D_A^{(a_0+1)} e^{a_1(D_A^{-1})} \left( \frac{I_A}{I_R} \right)$$

(8)

Through simulation calculation, the depreciation rate can be calculated as:

$$K_B = \frac{t}{L_T}$$

(9)

t is the battery usage time in years.

2.2. Factors affecting the residual value of electric vehicles

2.2.1. Basic parameters of the rate of new rate. Time parameter, The influence of the time parameter on the residual value is mainly reflected in the influence of the use time on the residual value of the electric vehicle, and the depreciation rate affected by it is theoretically equal to the ratio of the service
life to the specified service life of the vehicle. This is a linear relationship, but Hu Ning and others at Shanghai University of Engineering and Technology believe that vehicle transactions have many market factors in addition to their own life. Therefore, the new rate of $\alpha$ is proposed, in which $P_A$ and service life are One-to-one correspondence.

$$\alpha = \frac{P_A}{P} \times 100\%$$  \hspace{1cm} (10)

In the formula, $\alpha$ represents the new year rate, and $P_A$ represents the base price of the vehicle under the average social mileage.

This is a new rate of market-based price from the market point of view, which includes the market's acceptance of the brand. Through a large number of research statistics, Hu Ning et al. proposed four types of vehicles based on the impact of different years of use on the new rate, namely: strong anti-fall type, anti-fall type, normal type and non-resilient type [15]. Because electric vehicles have not yet formed scale, the main purpose of purchasing electric vehicles is to travel. Therefore, electric vehicles are not resistant to falling, and the relationship between their new rate and service life is based on the formula calculated by Hu Ning et al.

$$\beta = 1 - (0.0001X_2^2 + 0.0331X_2 + 0.009)$$  \hspace{1cm} (13)

Where $X_2$ is the cumulative mileage.

2.3. New rate correction parameters

Physical devaluation, By reviewing Wang Qin's "Analysis and Selection of the Correction Coefficient of Second-hand Vehicles", Chongqing University-Long Yan, "China's Used Car Market Price Strategy and Market Development Research", Chang'an University - Yan Limin, "Old Motor Vehicle Appraisal Valuation Method and Information System" Research, Nanjing University of Science and Technology - Peng Jianglei "Research on the current market price of used car evaluation" and other people's literature, can comprehensively determine several types of parameters as a correction parameter. It mainly includes comprehensive performance parameters (output power loss, fuel economy, emission performance, tire factors), vehicle condition factors, accident conditions and environmental impact factors. Among them, fuel economy and emission performance are not considered in the scope of electric vehicles. Electric vehicles are generally used for short-distance driving, and there are fewer accidents, so the accident condition can be ignored.

2.3.1. Comprehensive performance parameters. The power of the power motor includes the rated power and the maximum power. When the power of the motor exceeds the rated power, the motor is overloaded and the life is reduced. Assume that in the example, the electric vehicle has no overload phenomenon, and the power consumption of the electric vehicle can be determined according to the maximum vehicle speed, the climbing degree and the acceleration performance. At this stage, the main use scenarios of electric vehicles are concentrated in urban roads, and the roads are flat. In addition, the acceleration performance of electric vehicles is difficult to determine, so the maximum vehicle
speed is used in the evaluation to determine the driving power consumption.

$$\sum U_{\text{max}}P = \frac{Mgf}{3600}u_m + \frac{C_D A}{76140} u_m^3$$  \hspace{1cm} (14)$$

Where $M$ is the mass of the vehicle and $f$ is the coefficient of rolling resistance. For cars, the following formula is generally used:

$$f = 0.0165 + 0.0001(u_m - 50)$$  \hspace{1cm} (15)$$

Where $C_D$ represents the windward resistance coefficient, the average car takes 0.4-0.6, $A$ represents the windward area, the calculation formula of the windward area adopts: $A \approx 0.78BH$, where $B$ is the total height of the car, $H$ is the total width of the car, and $u_m$ is the highest speed.

The calculation formula for the maximum transmission speed of the electric vehicle is:

$$\theta_t = \frac{\sum U_{\text{max}}P}{P_2} \times 100\%$$  \hspace{1cm} (16)$$

Where $P_2$ represents the motor output power.

According to Xu Ting, "Analysis of energy efficiency of electric vehicles and path research to improve energy economy", Luo Wei "Efficiency Analysis of Electric Vehicle Transmission System" and other literatures, the efficiency of electric vehicle transmission system is about 70%-95%.

According to GB/T 18276-2000 "Automobile Power Bench Test Method and Evaluation Index", the output efficiency loss of the engine must be less than 25% of the original value. Therefore, based on the basis of these two aspects, the efficiency coefficient value of the electric drive mechanical transmission system can be obtained:

| Driveline efficiency level | Efficiency loss range | Coefficient value |
|----------------------------|-----------------------|------------------|
| High transmission system efficiency | $\leq 5\%$ | 1.0 |
| Transmission system efficiency | 5.1%-15% | 0.8 |
| Drive system efficiency is poor | 15.1%-25% | 0.6 |

Vehicle condition

Vehicle condition refers to the physical loss of the parts of the vehicle and is a major component of the physical devaluation. Tianhong Chengxin used car will be compared by combining 32 test forms of Tianhong Chengxin used cars, detection of electric vehicles by Gaozhan New Energy Sales Co., and “Evaluation Table and Evaluation Standards for Electric Vehicles” of Tongji University Newsletter. Based on the evaluation of the grading criteria, the following coefficient assignment results are obtained:

| Overall condition level | Evaluation score interval | Coefficient value |
|-------------------------|---------------------------|------------------|
| Excellent overall condition | 0.833-1.000 | 1.0 |
| Overall good condition | 0.625-0.832 | 0.8 |
| Overall condition | 0.417-0.624 | 0.6 |
| Overall poor condition | 0.208-0.416 | 0.2 |

Maintenance situation

The maintenance situation can reflect the maintenance and maintenance level of a car, and the project will also have a certain impact on the valuation of electric vehicles. Maintenance can be assessed based on the maintenance records of the 4S shop.
Table 3. Car maintenance condition coefficient value.

| Car maintenance status       | Maintenance situation                        | Coefficient value |
|-----------------------------|---------------------------------------------|-------------------|
| Excellent maintenance       | Scheduled maintenance / 4S shop maintenance  | 1.0               |
| Good maintenance            | Between good and bad maintenance            | 0.8               |
| Poor maintenance            | Never scheduled maintenance / 4S shop        | 0.6               |

- **Working environment**
  
The environment in which the car is used can have a different impact on the condition of the car. Because of the battery life, electric vehicles are more sensitive to the working environment of automobiles.

Table 4. Vehicle working environment coefficient values.

| Work environment assessment | Nature of the work                  | Coefficient value |
|-----------------------------|-------------------------------------|-------------------|
| Excellent working environment | From home / private / private car | 1.0               |
| Good working environment     | Official car/unit car               | 0.8               |
| Working environment          | Rental car / shared car             | 0.6               |
| Bad working environment      | Taxi / long drip car               | 0.4               |

- **Battery depreciation**
  
Through the data research conducted by the Tongji University newsletter, through the battery depreciation cashback service provided by BYD, it can be known that the battery used for more than one year has a depreciation rate of about 5% and two years of more than 15%.

Table 5. Battery Depreciation Coefficient Value.

| Battery depreciation level       | Depreciation rate | Coefficient value |
|----------------------------------|-------------------|-------------------|
| Low depreciation rate            | 0-10              | 1.0               |
| Depreciation rate                | 10.1-30           | 0.8               |
| High depreciation rate           | ≥ 30.1            | 0.6               |

2.3.2. **Functional devaluation.** The functional devaluation is mainly reflected in the price stability and model upgrade of new cars of the same or close to the model.

- **New car price stability**
  
Changes in the price of new cars will have an impact on the pricing of used cars, and the decline in the price of new cars will drive down the price of used cars. The replacement cost method is used when referring to the price of a new car under the same conditions.

Table 6. Stability of new car prices.

| New car price changes | Coefficient value |
|-----------------------|-------------------|
| Floating up           | 1.0               |
| Stable                | 0.8               |
| Fall                  | 0.6               |

- **Model upgrade**
  
The technology of automotive products is becoming more and more mature, and the speed of updating is getting faster and faster. New technologies continue to replace old technologies, which inevitably lead to the depreciation of cars that use backward technology.

Table 7. Model replacement factor values.

| Model change          | Coefficient value |
|-----------------------|-------------------|
| big change            | 0.7               |
| Mid-term change       | 0.9               |
| Minor changes         | 1.0               |

2.3.3. **Economic devaluation.** The economic devaluation mainly includes three aspects, namely: auto brand preservation rate, after-sales service and national policy subsidies.
Car brand preservation rate
In the used car market, car brands have an extraordinary significance for the pricing of used cars. Different car brands have different effects on the residual rate. Even if the configuration is the same and the technical conditions are the same, the residual values of the two cars with different brands are different. Therefore, for the brand of the car, it is necessary to focus on measuring its weight coefficient.

| Brand rating | Specific brand | Coefficient value |
|--------------|----------------|-------------------|
| good         | Volkswagen / Nissan / General Line | 1.0               |
| medium       | SAIC/BYD and other second lines     | 0.8               |
| general      | Jianghuai / Chery / Zotye and other three lines | 0.6               |

Service level
After-sales service not only represents the image of a brand, but also solves the worries of consumers after buying a car. Generally speaking, the general after-sales service of the car enterprises with good brand benefits is also in place, and there is a good reputation among consumers. In the used car market, this type of car has a relatively good selling price.

| Specific service | Coefficient value |
|------------------|-------------------|
| Able to provide complete service | 1.0               |
| Able to provide more services      | 0.8               |
| Can only complete basic services   | 0.6               |

Policy subsidies
In the initial stage of entering the market, electric vehicles have been able to quickly open up the market, occupy market share, and raise people's awareness of green travel. The state and policies have introduced many preferential policies. The main measures of these policies are realized through taxation and subsidies. In different cities, the subsidies for different brands of electric vehicles are different. The preferential policies that electric vehicles have when buying cars will also have an impact on the residual value of used electric vehicles.

| Specific description | Coefficient value |
|----------------------|-------------------|
| Subsidy + license free fee | 1.0               |
| Free license fee       | 0.8               |
| No subsidy            | 0.6               |

2.4. Establishment of residual value evaluation model for electric used vehicles

2.4.1. Weight Analysis of Influencing Factors of Residual Values (AHP Analysis)
Through the above, it is possible to basically determine the factors affecting the valuation of electric used cars, and the structural model that constitutes the influencing factors of the residual value of electric vehicles is shown in the following figure.
By listing the above elements, the weights of each element are scored by the professional, and after obtaining the corresponding scores, the largest eigenvalue and the corresponding eigenvector can be calculated. In the specific operation, we can use the Matlab program for calculation.

The A judgment matrix is as follows:

![Figure 1. New rate correction parameter structure diagram](image)

**Table 11. A judgment matrix.**

|     | B1   | B2   | B3   |
|-----|------|------|------|
| B1  | 1    | 3    | 5    |
| B2  | 1/3  | 1    | 4    |
| B3  | 1/5  | 1/4  | 1    |

Input the above judgment matrix into Matlab, you can get:
The maximum eigenvalue is: \( \lambda_{1A} = 3.0858 \)
The normalized is: \( P_A = [0.6267, 0.2797, 0.0936] \)
therefore \( P_A = [0.6267, 0.2797, 0.0936] \)
Consistency indicator \( CI = \frac{(\lambda_1 - n)}{(n - 1)} = 0.0429 \)
Calculate random consistency ratio \( CR = \frac{CI}{RI} = 0.0825 < 0.1 \)
Since \( CR < 0.1 \), the consistency check passes, and \( P_A \) can be used as the weight of the \( B_n \) factor for \( A \).

- **B1 judgment matrix**

![B1 Judgment Matrix](image)

**Table 12. B1 Judgment Matrix.**

|     | C1   | C2   | C3   | C4   | C5   |
|-----|------|------|------|------|------|
| C1  | 1    | 1/3  | 3    | 1/3  | 1/4  |
| C2  | 2    | 1    | 2    | 2    | 1/3  |
| C3  | 1/3  | 1/2  | 1    | 1/3  | 1/5  |
| C4  | 3    | 1/2  | 3    | 1    | 1/4  |
| C5  | 4    | 3    | 5    | 4    | 1    |

Input the above judgment matrix into Matlab, you can get:
The maximum eigenvalue is: \( \lambda_{1B} = 5.2642 \)
The normalized is: \( P_{B1} = [0.1023, 0.1946, 0.0660, 0.1687, 0.4684] \)
Consistency indicator \( CI = \frac{(\lambda_1 - n)}{(n - 1)} = 0.0660 \)
Calculate random consistency ratio \( CR = \frac{CI}{RI} = 0.0590 < 0.1 \)
Since CR < 0.1, the consistency check passes, and $\overline{P}_{B1}$ can be used as the weight of the $C_n$ factor for $B_1$.

- **B2 judgment matrix**

  Table 13. B2 Judgment Matrix.

| B2 | C6 | C7 |
|----|----|----|
| C6 | 1  | 1/2|
| C7 | 2  | 1  |

Input the above judgment matrix into Matlab, you can get:

The maximum eigenvalue is: $\lambda_{1B} = 2$

The normalized is: $\overline{P}_{B2} = [0.3333 \quad 0.6667]$

Consistency indicator $CI = \frac{(\lambda_1 - n)}{(n - 1)} = 0$

Calculate random consistency ratio $CR = \frac{CI}{RI} = 0 < 0.1$

Since CR < 0.1, the consistency check passes, and $\overline{P}_{B2}$ can be used as the weight of the $C_n$ factor for $B_2$.

- **B3 judgment matrix**

  Table 14. B3 Judgment Matrix.

| B3 | C8 | C9 | C10 |
|----|----|----|-----|
| C8 | 1  | 4  | 3   |
| C9 | 1/4| 1  | 1/3 |
| C10| 1/3| 3  | 1   |

Input the above judgment matrix into Matlab, you can get:

The maximum eigenvalue is: $\lambda_{1B} = 3.0735$

The normalized is: $\overline{P}_{B3} = [0.6144 \quad 0.1172 \quad 0.2684]$

Consistency indicator $CI = \frac{(\lambda_1 - n)}{(n - 1)} = 0.0368$

Calculate random consistency ratio $CR = \frac{CI}{RI} = 0.0707 < 0.1$

Since CR < 0.1, the consistency check passes, and $\overline{P}_{B3}$ can be used as the weight of the $C_n$ factor for $B_3$.

### 2.4.2 Model construction

All the above matrices pass the consistency test, so the normalized feature vector obtained by it can be used as the weight value of each factor for the upper layer factor, and the weight value of $C_n$ is $P_n$.

| B to A weight | 0.6267 | 0.2797 | 0.0936 | $P_n$ |
|--------------|--------|--------|--------|-------|
| C to B weight |        |        |        |       |
| Entity devaluation B1 | 0.1023 | -      | -      | 0.0641 |
| Functional devaluation B2 | 0.1946 | -      | -      | 0.1220 |
| Economic devaluation B3 | 0.0660 | -      | -      | 0.0414 |
| C4           | 0.1687 | -      | -      | 0.1057 |
Therefore, the following model can be derived:

\[
P = P_0 \times C' = P_0 \times C \times k(P_e, P_f, P_s)
\]

Therefore, the residual value model of the electric used car is

\[
P = P_0 \times \frac{\alpha + \beta}{2} \times \sum_{n=1}^{10} P_n K_n
\]

\[
= P_0 \times \frac{\alpha + \beta}{2} \times (P_1 \theta_1 + P_2 K_2 + \ldots + P_5 K_B + \ldots + P_{10} K_{10})
\]

In the formula, the scoring dynamic parameters of \( P_1, \theta_1 \), and the score of the battery parameter \( K_B \) of \( P_5 \) are calculated, and the rest of the items are evaluated by professionals.

3. Conclusion

This paper starts with the identification and evaluation method of the used engine of the traditional internal combustion engine, and systematically sorts out the different structural characteristics, different evaluation criteria and different residual value calculation methods of the electric vehicle. However, because electric vehicles have not yet formed a scale, some quantitative methods are completely customized according to the characteristics of electric vehicles. Whether they meet the final price evaluation requirements, further research is needed. In terms of method, this paper mainly uses the replacement cost method and AHP analytic method to calculate the residual value of electric vehicles. This method is a new pricing model. It is believed that this method will have certain effects on new consumption patterns in the near future.

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