Research on the Evaluation System of Battery Electric Vehicle Product Quality Satisfaction

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Abstract. The traditional fuel vehicle market has a relatively mature product quality evaluation system, which provides a scientific reference for consumer decision-making and enterprise’s research and design. However, the research on the product quality evaluation system of BEV (battery electric vehicle) on the market is still relatively preliminary. This paper first establishes a two-level BEV product quality satisfaction index system, then conducts a questionnaire survey of users in four typical scenarios: taxis, private vehicle, car-sharing and logistics vehicle, and finally uses SPSS and AMOS verifies the establishment of the satisfaction indicator in the four scenarios, and determines the weight in each scenario.

Keywords: Battery electric vehicle, quality satisfaction, structural equation model.

1. Introduction

A perfect and usable product quality evaluation system that keeps pace with the times is a major sign of the industry’s maturity. Therefore, it is of practical significance to study the quality satisfaction of BEV. On the one hand, it can provide consumers with professional guidance for car purchase decisions. On the other hand, it can help OEMs to accurately grasp product needs. The research focusing on the quality satisfaction model of BEV products started late, and the research of related scholars is also based on the private car scene. In 2016, Sun Yang [1] evaluated the product quality of BEV based on the subjective evaluation method scored by experts, established a two-level indicator system and determined the weights. Li Tianjiao used the analytic hierarchy process and structural equation model to hypothesize and verify the correlation between automotive product complaints, automotive product expectations and the objective performance of automotive products [2], and constructed a secondary indicator system for the objective performance of product quality. The determination is also determined by means of expert scoring.

In terms of methods, the structural equation model is a relatively mature. The professional structural equation modeling software AMOS can be used to verify the establishment of the indicators and determine the weights. The results can better reflect the real situation and avoid subjective errors. Wu Haidong of Chongqing University [3] established an index system after analyzing the influencing factors of library satisfaction, and verified the hypothetical relationship based on the structural equation model. Based on the path load fitted by the structural equation model, the various levels weights were calculated. Liang Feng of Jilin University[4] studied the satisfaction evaluation model of
urban rail transit safety operation based on structural equations, and determined the influence weights of all levels of indicators based on the path loads calculated by AMOS.

This paper establishes a BEV product quality satisfaction model under four typical scenarios: private cars, taxis, car-sharing and logistics vehicles. First, through literature research and expert interviews, a two-level indicator system consisting of 7 first-level indicators and 34 second-level indicators was initially established based on the characteristics of BEV. Then, a questionnaire survey was launched based on four scenarios, and a total of 1,500 questionnaires were distributed. Finally, SPSS is used to analyze the reliability and validity of the recovered data, and the AMOS structural equation modeling software is used to solve the pure electric vehicle product quality satisfaction model and index weights in four typical vehicle scenarios.

2. Satisfaction model establishment and data analysis

2.1. Index system establishment

Through research on previous related scholars, combined with the current market development, around the principle of customer-oriented, quantifiable and other quality system construction [5], it is preliminarily drawn that the BEV product quality evaluation system established in this paper will focus on 7 aspects of comfort performance, driving performance, design, charging performance, safety performance, information interaction and technological experience, which are 7 first-level indicators. In order to establish a sound and sufficient comprehensive level indicator system, this paper adopts the expert interview method to verify the effectiveness of the first-level indicators and expands them into richer second-level indicators. This paper invited a total of 7 experts from well-known car companies, logistics companies, a local taxi company in Shanghai, and universities to summarize and summarize the results of their interviews. The following indicator system was initially formed as Table 1, assuming that it is suitable for four car usage scenarios.
| First-level indicators       | Second-level indicators          |
|-----------------------------|---------------------------------|
| Comfort performance (CP)    | Driving comfort (CP1)           |
|                             | Voice comfort (CP2)              |
|                             | Space comfort (CP3)              |
|                             | Ventilation comfort (CP4)        |
|                             | Storage comfort (CP5)            |
| Driving performance (DP)    | Steering (DP1)                  |
|                             | Straight driving (DP2)           |
|                             | Curve driving (DP3)              |
|                             | Braking (DP4)                    |
|                             | Acceleration (DP5)               |
|                             | Starting (DP6)                   |
|                             | Shifting (DP7)                   |
| Design (DS)                 | Exterior design (DS1)            |
|                             | Exterior material (DS2)          |
|                             | Interior design (DS3)            |
|                             | Interior material (DS4)          |
| Charging performance (CE)   | Mileage (CE1)                   |
|                             | Electricity consumption (CE2)    |
|                             | Charging time (CE3)              |
|                             | Battery performance (CE4)        |
|                             | Charing pot (CE5)                |
|                             | On-board charger (CE6)           |
| Safety performance (SP)     | Vision lighting (SP1)            |
|                             | Active safety (SP2)              |
|                             | Passive safety (SP3)             |
|                             | Battery safety (SP4)             |
|                             | Grand (SP5)                      |
| Information interaction (IS)| Audio visual system (IS1)        |
|                             | Navigation system (IS2)          |
|                             | Display system (IS3)             |
| Technological experience (TE)| Central control screen (TE1)    |
|                             | ADAS (TE2)                       |
|                             | In-vehicle APP (TE3)             |
|                             | Network (TE4)                    |

According to the basic theory of the structural model and the background of the problem studied in this paper, the following hypotheses are established:

H1: "Comfort performance satisfaction" and "overall satisfaction" have a positive influence;
H2: "Driving performance satisfaction" and "overall satisfaction" have a positive influence;
H3: "Design satisfaction" and "overall satisfaction" have a positive influence;
H4: "Charging performance satisfaction" and "overall satisfaction" have a positive influence;
H5: "Safety performance satisfaction" and "overall satisfaction" have a positive influence;
H6: "Information interaction satisfaction" and "overall satisfaction" have a positive influence;
H7: "Technological experience satisfaction" and "Overall Satisfaction" have a positive influence.
2.2. Questionnaire preparation and distribution
The questionnaire issued mainly consists of two parts. The basic information part collects the respondents’ city, gender, car usage scene, income and car brand, etc. The main part measures the respondents’ overall quality of BEV products. And the satisfaction of the first-level index, a total of 8 variables are the latent variables in the structural equation model. The overall quality and first-level index satisfaction are measured by several quantifiable questions, which are the observed variables in the structural equation model and correspond to the second-level indicators in the satisfaction model. For these quantifiable questions, consumers need to subjectively score them according to Likert [6]'s seven-scale scoring method. A total of 1500 questionnaires were put into this project, and the response rate of questionnaires was 100%.

2.3. Reliability analysis and validity analysis
Reliability examines the unity, credibility and stability of the tested items and the recovery results. The Cronbach coefficient method is the most commonly used. If the value exceeds 0.7, the reliability is considered good and the relevant items can be retained. For four different car usage scenarios, SPSS is used to calculate the first-level index Cronbach α coefficients in each scenario to determine the reliability of the sample data. The calculation results show that the Cronbach α coefficients of the data variables of each scene sample are all greater than 0.7, which indicates good reliability. Validity examines the degree to which the measurement items in the preset questionnaire reflect the question or variable to be studied. This paper uses a combination of exploratory factor analysis and confirmatory factor analysis to analyze the validity. The former uses SPSS to analyze each Carry out principal component analysis on latent variable related items, calculate KMO and Barlett values, and observe whether the factor loading is qualified. The latter uses AMOS to judge whether the fitting results of the latent variable and the observation other shore are qualified. After the calculation results, the exploratory factor analysis and confirmatory factor analysis results in each scenario meet the requirements.

3. Satisfaction model verification and discussion
3.1. Satisfaction model verification
The sample data of each scenario is substituted into the AMOS software for calculation, and the path diagrams and fitting index values of 8 latent variables such as overall satisfaction, comfort performance, and driving performance are obtained. Taking the taxi scenario as an example, the path diagram of the empirical model is shown in Figure 1, and the fitted values are shown in Table 2.
In Figure 1, the blue path line represents the causal path of 7 latent variables such as comfort performance satisfaction and driving performance satisfaction to overall satisfaction. The number on the path represents the path load calculated by AMOS, which is the standardized path coefficient. In Table 2, some of the fitting indicators are not good, but they are very close to the ideal value. Learning from PM Bentler's research [7], in high complexity structural model, some poor fitting indicators are acceptable results. Analyze the hypothesis test results of the model. The P values of H1~H5 meet the requirements. The P values of H6 and H7 are too high and fail the test, the path relationship is cancelled, that is, the hypothesis is not valid. After fitting the remaining three scenarios, it can be found that the assumptions of H1~H7 for the private car and time-sharing scenarios are all valid, and the logistics car scene is consistent with the taxi scene, H1~H5 are valid, and H6~H7 are not valid.

### 3.2. Weights of indicators

Integrating the structural equation model path load, degree of fit, and inspection results in each scenario, the weights of all levels of indicators in the final model can be obtained. The first-level index path load and the second-level index path load are both the path load calculated by the AMOS model, and the normalized processing is the weight of each level of index. The normalized formula for the weights of the first-level indicators is as follows:

| Index | $\chi^2$ | $\chi^2/df$ | GFI | AGFI | NFI | CFI | RMR | RMSEA |
|-------|----------|-------------|-----|------|-----|-----|-----|--------|
| Standard | $<3$ | $>0.9$ | $>0.8$ | $>0.9$ | $>0.9$ | $<0.05$ | $<0.08$ |
| Value | 892.374 | 2.335 | 0.806 | 0.845 | 0.903 | 0.906 | 0.049 | 0.081 |

In Figure 1, the blue path line represents the causal path of 7 latent variables such as comfort performance satisfaction and driving performance satisfaction to overall satisfaction. The number on the path represents the path load calculated by AMOS, which is the standardized path coefficient. In Table 2, some of the fitting indicators are not good, but they are very close to the ideal value. Learning from PM Bentler's research [7], in high complexity structural model, some poor fitting indicators are acceptable results. Analyze the hypothesis test results of the model. The P values of H1~H5 meet the requirements. The P values of H6 and H7 are too high and fail the test, the path relationship is cancelled, that is, the hypothesis is not valid. After fitting the remaining three scenarios, it can be found that the assumptions of H1~H7 for the private car and time-sharing scenarios are all valid, and the logistics car scene is consistent with the taxi scene, H1~H5 are valid, and H6~H7 are not valid.
| Scenario | First-level indicator | Path load | Weight | Second-level indicator | Path load | Weight |
|----------|----------------------|-----------|--------|------------------------|-----------|--------|
| Taxi     | CP                   | 0.604     | 0.176  | CP1                    | 0.663     | 0.188  |
|          |                      |           |        | CP2                    | 0.771     | 0.219  |
|          |                      |           |        | CP3                    | 0.842     | 0.239  |
|          |                      |           |        | CP4                    | 0.619     | 0.176  |
|          |                      |           |        | CP5                    | 0.628     | 0.178  |
|          | DP                   | 0.662     | 0.193  | DP1                    | 0.661     | 0.126  |
|          |                      |           |        | DP2                    | 0.812     | 0.155  |
|          |                      |           |        | DP3                    | 0.704     | 0.135  |
|          |                      |           |        | DP4                    | 0.873     | 0.167  |
|          |                      |           |        | DP5                    | 0.829     | 0.159  |
|          |                      |           |        | DP6                    | 0.714     | 0.137  |
|          |                      |           |        | DP7                    | 0.635     | 0.121  |
|          | DS                   | 0.519     | 0.150  | DS1                    | 0.791     | 0.276  |
|          |                      |           |        | DS2                    | 0.708     | 0.247  |
|          |                      |           |        | DS3                    | 0.651     | 0.227  |
|          |                      |           |        | DS4                    | 0.712     | 0.249  |
|          | CE                   | 0.873     | 0.254  | CE1                    | 0.840     | 0.202  |
|          |                      |           |        | CE2                    | 0.805     | 0.192  |
|          |                      |           |        | CE3                    | 0.853     | 0.204  |
|          |                      |           |        | CE4                    | 0.632     | 0.151  |
|          |                      |           |        | CE5                    | 0.532     | 0.127  |
|          |                      |           |        | CD6                    | 0.520     | 0.124  |
|          | SP                   | 0.779     | 0.227  | SP1                    | 0.921     | 0.236  |
|          |                      |           |        | SP2                    | 0.883     | 0.226  |
|          |                      |           |        | SP3                    | 0.852     | 0.218  |
|          |                      |           |        | SP4                    | 0.513     | 0.131  |
|          |                      |           |        | SP5                    | 0.736     | 0.188  |
Table 4. Indicators weights of logistics vehicle scenario

| Scenario     | First-level indicator | Path load | Weight | Second-level indicator | Path load | Weight |
|--------------|-----------------------|-----------|--------|------------------------|-----------|--------|
| Logistics vehicle | CP                    | 0.731     | 0.210  | CP1                    | 0.652     | 0.185  |
|               |                       |           |        | CP2                    | 0.783     | 0.223  |
|               |                       |           |        | CP3                    | 0.828     | 0.235  |
|               |                       |           |        | CP4                    | 0.612     | 0.174  |
|               |                       |           |        | CP5                    | 0.643     | 0.183  |
|               | DP                    | 0.668     | 0.192  | DP1                    | 0.781     | 0.153  |
|               |                       |           |        | DP2                    | 0.812     | 0.159  |
|               |                       |           |        | DP3                    | 0.724     | 0.142  |
|               |                       |           |        | DP4                    | 0.743     | 0.146  |
|               |                       |           |        | DP5                    | 0.649     | 0.127  |
|               |                       |           |        | DP6                    | 0.632     | 0.124  |
|               |                       |           |        | DP7                    | 0.751     | 0.147  |
|               | DS                    | 0.432     | 0.124  | DS1                    | 0.453     | 0.210  |
|               |                       |           |        | DS2                    | 0.459     | 0.214  |
|               |                       |           |        | DS3                    | 0.599     | 0.279  |
|               |                       |           |        | DS4                    | 0.638     | 0.297  |
|               | CE                    | 0.764     | 0.220  | CE1                    | 0.840     | 0.203  |
|               |                       |           |        | CE2                    | 0.754     | 0.182  |
|               |                       |           |        | CE3                    | 0.832     | 0.201  |
|               |                       |           |        | CE4                    | 0.621     | 0.150  |
|               |                       |           |        | CE5                    | 0.563     | 0.136  |
|               |                       |           |        | CD6                    | 0.526     | 0.128  |
|               | SP                    | 0.883     | 0.254  | SP1                    | 0.827     | 0.236  |
|               |                       |           |        | SP2                    | 0.793     | 0.226  |
|               |                       |           |        | SP3                    | 0.744     | 0.218  |
|               |                       |           |        | SP4                    | 0.472     | 0.131  |
|               |                       |           |        | SP5                    | 0.690     | 0.189  |
### Table 5. Indicators weights of private vehicle scenario

| Scenario   | First-level indicator | Path load | Weight | Second-level indicator | Path load | Weight |
|------------|-----------------------|-----------|--------|------------------------|-----------|--------|
| Private vehicle | CP                   | 0.874     | 0.179  | CP1                    | 0.652     | 0.186  |
|             |                       |           |        | CP2                    | 0.782     | 0.222  |
|             |                       |           |        | CP3                    | 0.831     | 0.236  |
|             |                       |           |        | CP4                    | 0.609     | 0.174  |
|             |                       |           |        | CP5                    | 0.641     | 0.182  |
|             | CP                    | 0.623     | 0.127  | DP1                    | 0.651     | 0.123  |
|             |                       |           |        | DP2                    | 0.813     | 0.153  |
|             |                       |           |        | DP3                    | 0.704     | 0.133  |
|             |                       |           |        | DP4                    | 0.874     | 0.165  |
|             |                       |           |        | DP5                    | 0.886     | 0.167  |
|             |                       |           |        | DP6                    | 0.753     | 0.142  |
|             |                       |           |        | DP7                    | 0.631     | 0.119  |
|             | DS                    | 0.949     | 0.194  | DS1                    | 0.973     | 0.266  |
|             |                       |           |        | DS2                    | 0.872     | 0.238  |
|             |                       |           |        | DS3                    | 0.929     | 0.254  |
|             |                       |           |        | DS4                    | 0.883     | 0.241  |
|             | CE                    | 0.764     | 0.156  | CE1                    | 0.843     | 0.200  |
|             |                       |           |        | CE2                    | 0.758     | 0.180  |
|             |                       |           |        | CE3                    | 0.853     | 0.202  |
|             |                       |           |        | CE4                    | 0.651     | 0.154  |
|             |                       |           |        | CE5                    | 0.566     | 0.134  |
|             |                       |           |        | CD6                    | 0.545     | 0.129  |
|             | SP                    | 0.682     | 0.140  | SP1                    | 0.901     | 0.220  |
|             |                       |           |        | SP2                    | 0.873     | 0.213  |
|             |                       |           |        | SP3                    | 0.848     | 0.207  |
|             |                       |           |        | SP4                    | 0.730     | 0.178  |
|             | IS                    | 0.514     | 0.105  | IS1                    | 0.783     | 0.339  |
|             |                       |           |        | IS2                    | 0.698     | 0.301  |
|             |                       |           |        | IS3                    | 0.832     | 0.360  |
|             | TE                    | 0.481     | 0.098  | TE1                    | 0.873     | 0.308  |
|             |                       |           |        | TE2                    | 0.721     | 0.254  |
|             |                       |           |        | TE3                    | 0.634     | 0.223  |
|             |                       |           |        | TE4                    | 0.611     | 0.215  |
### Table 6. Indicators weights of car-sharing scenario

| Scenario       | First-level indicator | Path load | Weight | Second-level indicator | Path load | Weight |
|----------------|-----------------------|-----------|--------|------------------------|-----------|--------|
| Private vehicle| CP                    | 0.874     | 0.179  | CP1                    | 0.652     | 0.185  |
|                |                       |           |        | CP2                    | 0.773     | 0.220  |
|                |                       |           |        | CP3                    | 0.839     | 0.238  |
|                |                       |           |        | CP4                    | 0.621     | 0.176  |
|                |                       |           |        | CP5                    | 0.634     | 0.180  |
|                | DP                    | 0.623     | 0.127  | DP1                    | 0.664     | 0.127  |
|                |                       |           |        | DP2                    | 0.813     | 0.155  |
|                |                       |           |        | DP3                    | 0.703     | 0.134  |
|                |                       |           |        | DP4                    | 0.874     | 0.167  |
|                |                       |           |        | DP5                    | 0.832     | 0.159  |
|                | DS                    | 0.949     | 0.194  | DS1                    | 0.451     | 0.209  |
|                |                       |           |        | DS2                    | 0.463     | 0.214  |
|                |                       |           |        | DS3                    | 0.602     | 0.279  |
|                |                       |           |        | DS4                    | 0.643     | 0.298  |
|                | CE                    | 0.764     | 0.156  | CE1                    | 0.843     | 0.204  |
|                |                       |           |        | CE2                    | 0.752     | 0.182  |
|                |                       |           |        | CE3                    | 0.831     | 0.201  |
|                |                       |           |        | CE4                    | 0.619     | 0.150  |
|                |                       |           |        | CE5                    | 0.558     | 0.135  |
|                | SP                    | 0.682     | 0.140  | SP1                    | 0.923     | 0.236  |
|                |                       |           |        | SP2                    | 0.884     | 0.226  |
|                |                       |           |        | SP3                    | 0.851     | 0.217  |
|                |                       |           |        | SP4                    | 0.513     | 0.131  |
|                | IS                    | 0.514     | 0.105  | IS1                    | 0.512     | 0.324  |
|                |                       |           |        | IS2                    | 0.538     | 0.340  |
|                |                       |           |        | IS3                    | 0.532     | 0.336  |
|                | TE                    | 0.481     | 0.098  | TE1                    | 0.463     | 0.239  |
|                |                       |           |        | TE2                    | 0.471     | 0.243  |
|                |                       |           |        | TE3                    | 0.526     | 0.272  |
|                |                       |           |        | TE4                    | 0.475     | 0.245  |

4. Conclusions

This paper establishes a BEV product quality evaluation satisfaction model for taxis, private vehicle, car-sharing and logistics vehicle scenarios, and determines the index weights. First of all, the first level of BEV product quality satisfaction index system, including 7 major first-level indicators and 34 second-level indicators. Then, 1,500 survey questionnaires were distributed for four scenarios. Subsequently, the reliability and validity of the basic items of the questionnaire were analyzed through SPSS. The validity analysis used a combination of exploratory factor analysis and confirmatory factor analysis. The degrees are all qualified. Finally, using AMOS software to fit the structural equation model of the data of each scene and calculate the index weight based on the factor loading, and the fitting indexes are all qualified. The results show that the hypothesis of the positive influence of information interaction and technological indicators on overall satisfaction in the logistics vehicle and
taxi scenarios does not hold. These two scenarios retain the remaining 5 first-level indicators, and the other two scenarios have 7 first-level indicators.

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