Application of Structural Equation Model in Electric Vehicles
User Evaluation of Charging Infrastructure Determines

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Abstract. On the basis of the user satisfaction questionnaire survey of charging infrastructure, a user satisfaction evaluation model of charging infrastructure based on structural model is constructed. According to the calculated weights of the first-and second-level indicators, the overall satisfaction score is calculated, and the optimization direction for the charging infrastructure is proposed. The results show that users’ satisfaction with the charging infrastructure is acceptable, and the development of all aspects of the charging infrastructure is relatively balanced. Besides, the hardware facilities of the charging station are the priority optimization indicators in the future.

Keywords: Charging infrastructure, quality satisfaction, structural equation model

1. Introduction
In recent years, under the influence of positive factors such as policies, subsidies and technological progress, the proportion of electric vehicles has gradually increased. According to some optimistic predictions of advanced consulting agencies, the proportion of electric vehicles will account for more than 40% in 2030. To a large extent, the level of development of charging infrastructure determines whether electric vehicles can be further promoted in the future. According to the statistics of China Electric Vehicle Charging Infrastructure Promotion Alliance, as of April 2019, the total number of public and private charging piles nationwide has reached 953,000 units, of which 391,000 are public charging piles [1]. As shown by data, the insufficient scale of public charging stations, the unreasonable construction of charging infrastructure, and the low level of charging services have affected the charging experience of users, thus restricting the development of the electric vehicle industry.

In order to solve the above-mentioned problems, this article will examine all the factors that affect the user's charging experience. Based on the survey results of the charging infrastructure user satisfaction questionnaire, the structural equation is used to solve the charging infrastructure user satisfaction evaluation model, and the indicator weights at all levels and the final satisfaction score are calculated to provide a direction for the improvement of the charging infrastructure.

2. Evaluation indicators selection and questionnaire design

2.1. Evaluation indicators selection
Through the research and summary of the literature related to the charging infrastructure, combined with the field research, the factors affecting the user satisfaction of the charging infrastructure are generally
divided into six categories: the availability of charging stations, the hardware facilities of charging stations, charging cost and payment, charging service experience, charging pile functions and charging APP practicality [2, 3].

In order to obtain comprehensive and effective second-level indicators, we interviewed relevant industry experts. For example, NIO experts indicated that for second- and third-tier cities, the number of charging stations is small and the layout lacks systematic planning. The illegal parking of fuel vehicles also reduces the availability of charging stations. According to the results of interviews with after-sales specialists of Xingxing Charging Company, in terms of hardware facilities construction, the main factors affecting user experience are the failure rate of charging piles and the number of charging piles.

Finally, the hierarchical structure of the user satisfaction evaluation model of charging infrastructure is constructed, as shown in the Table 1.

**Table 1.** The hierarchical structure of the user satisfaction evaluation model of charging infrastructure.

| Target layer | First-level indicators                  | Second-level indicators                                        |
|--------------|----------------------------------------|-----------------------------------------------------------------|
|              | 1 The availability of charging stations | 1.1 Charging accessibility                                    |
|              |                                        | 1.2 Layout density                                             |
|              |                                        | 1.3 Illegally parked rate                                      |
|              |                                        | 1.4 Opening hours                                              |
|              |                                        | 1.5 Number of charging piles                                   |
|              | 2 The hardware facilities of charging stations | 2.1 Proportion of fast charging piles                          |
|              |                                        | 2.2 Aging degree of charging piles                             |
|              |                                        | 2.3 Network signal coverage                                    |
|              |                                        | 2.4 Intelligent degree of charging piles                       |
|              |                                        | 2.5 Vehicle fit degree                                         |
|              | 3 Charging cost and payment             | 3.1 Parking fee                                                |
|              |                                        | 3.2 Electricity price                                          |
|              |                                        | 3.3 Service fee                                                |
|              |                                        | 3.4 Payment method                                             |
|              | 4 Charging service experience           | 4.1 Perfection of surrounding facilities                       |
|              |                                        | 4.2 Charging pile failure rate                                 |
|              |                                        | 4.3 After-sales service attitude                               |
|              |                                        | 4.4 After-sales solution ability                               |
|              |                                        | 4.5 Management level                                           |
|              | 5 Charging pile functions               | 5.1 Identification capability                                 |
|              |                                        | 5.2 Screen readability                                         |
|              |                                        | 5.3 Charging mode                                              |
|              |                                        | 5.4 Safety function                                            |
|              |                                        | 5.5 Charging pile body design                                  |
|              |                                        | 5.6 Charging pile gun line design                              |
|              |                                        | 5.7 Operation tips                                             |
|              | 6 Charging APP practicality             | 6.1 Understandability                                          |
|              |                                        | 6.2 Interactive ability                                        |
|              |                                        | 6.3 Information security                                       |
|              |                                        | 6.4 Interface design                                           |
|              |                                        | 6.5 APP security                                               |

**2.2. Questionnaire design**

The questionnaire is composed of three parts: screening questionnaire, specific situation and satisfaction, and personal information. The part of the screening questionnaire is designed to screen out new electric vehicle users who have used the car within one year, and they have the habit of using public charging piles for charging, and the charging frequency is more than one week. In the second part, first
let users evaluate the objective performance of commonly used charging piles, and then evaluate the satisfaction of each second-level indicator based on the objective performance, using Likert's seven-point scale method, 1 point means completely dissatisfied, 7 points means completely satisfied.

3. Analysis of survey results

In this survey, a total of 1,500 questionnaires were distributed online and offline. The subjects of the survey included electric vehicle owners of traditional brands such as Geely, BYD, and Roewe, as well as electric vehicle owners of new car-making forces such as NIO and Xiaopeng, more than 20 brands are involved.

The maximum, minimum, and mean values of the satisfaction rating items are counted, and there are no abnormal values in the results. In addition, the distribution ratio of the sample's personal information, such as gender, family status, and income status, is also statistically analyzed.

3.1. Reliability analysis

Reliability reflects the reliability of survey data. Use SPSS software to analyse the internal consistency of the questionnaire. The internal consistency reliability is measured by the Cronbach's coefficient $\alpha$ coefficient, which has a value of 0 to 1. The $\alpha$ coefficient is higher than 0.8, indicating high reliability; the $\alpha$ coefficient is between 0.7 and 0.8, indicating that the reliability is good; the $\alpha$ coefficient is between 0.6 and 0.7, indicating that the reliability is acceptable; the $\alpha$ coefficient is less than 0.6, indicating that the reliability is not good. Therefore, the $\alpha$ coefficient of each indicator must be above 0.6. The calculation results of the $\alpha$ coefficient of each first-level indicator are shown in Table 2, which are all greater than 0.6, indicating that their reliability is good. For the second-level indicator, the Cronbach's Alpha if Item Deleted should be lower than the corresponding first-level $\alpha$ coefficient, otherwise it means that the reliability of the indicator is low and should be deleted. According to the analysis results, 2.3 network signal coverage, 4.3 after-sales service attitude and 5.7 operation tips should be deleted.

Table 2. Reliability analysis results.

| First-level indicator                                      | $\alpha$ coefficient |
|-----------------------------------------------------------|----------------------|
| 1 The availability of charging stations                   | 0.618                |
| 2 The hardware facilities of charging stations            | 0.658                |
| 3 Charging cost and payment                               | 0.724                |
| 4 Charging service experience                             | 0.641                |
| 5 Charging pile functions                                | 0.727                |
| 6 Charging APP practicality                               | 0.698                |

3.2. Validity analysis

Validity refers to the degree to which a measurement method or tool can accurately measure things. The KMO value in the SPSS software and the Bartlett ball type test were used to verify the validity of the survey data. If the KMO value is above 0.9, it is totally suitable for factor analysis; 0.8-0.9, very suitable; 0.7-0.8, suitable; 0.6-0.7, basically suitable; 0.5-0.6, very reluctant; less than 0.5, not suitable. Therefore, the KMO value should be greater than 0.6 to meet the validity requirements. The calculation results of the KMO value of each first-level indicator are shown in Table 3, all of which are greater than 0.6, indicating that it is suitable for factor analysis.

Table 3. Validity analysis results.

| First-level indicator                                      | KMO value  |
|-----------------------------------------------------------|------------|
| 1 The availability of charging stations                   | 0.700      |
| 2 The hardware facilities of charging stations            | 0.691      |
| 3 Charging cost and payment                               | 0.752      |
| 4 Charging service experience                             | 0.694      |
| 5 Charging pile functions                                | 0.771      |
| 6 Charging APP practicality                               | 0.720      |
According to the practice of Hair et al. [4], indicators with factor loadings lower than 0.5 should be deleted. Except for the three secondary indicators that have been deleted in the reliability analysis, the factor loadings of the remaining secondary indicators are distributed between 0.6 and 0.8, which meets the requirements.

4. Structural equation model construction and verification

4.1. Basic principles of structural equation model

Structural equation models include structural models and measurement models. The structure model describes the relationship between latent variables in the model, as shown in equation (1); the measurement model describes the relationship between latent variables and measurable variables, as shown in equations (2) and (3).

\[
\eta = B\eta + \Gamma \xi + \zeta \\
\xi = \Lambda \xi + \delta \\
y = \Lambda \eta + \varepsilon
\]  

In the formula: \(\eta\) is the endogenous latent variable; \(B\) is the endogenous latent variable coefficient matrix; \(\Gamma\) is the exogenous latent variable coefficient matrix; \(\xi\) is the exogenous latent variable; \(\zeta\) is the random interference term, reflecting the unexplained part of \(\eta\); \(y\) is the observation index of \(\eta\); \(\Lambda \eta\) is the coefficient matrix, which is composed of the factor loading of \(y\) on \(\eta\); \(\varepsilon\) is the measurement error of \(y\); \(x\) is the observation index of \(\xi\); \(\Lambda \xi\) is the coefficient matrix, which is composed of the factor loading of \(x\) on \(\xi\); \(\delta\) is the measurement error of \(x\).

4.2. Model building

4.2.1. Determination of latent variables and measurable variables. According to the theory of structural equation model, the latent variables are 6 first-level indicators, and the corresponding second-level indicators are measurable variables.

4.2.2. Model assumptions. Based on the above analysis, 6 hypotheses are established.

H1: ‘The availability of charging stations’ has a positive and significant impact on ‘overall satisfaction’.
H2: ‘The hardware facilities of charging stations’ has a positive and significant impact on ‘overall satisfaction’.
H3: ‘Charging cost and payment’ has a positive and significant impact on ‘overall satisfaction’.
H4: ‘Charging service experience’ has a positive and significant impact on ‘overall satisfaction’.
H5: ‘Charging pile functions’ has a positive and significant impact on ‘overall satisfaction’.
H6: ‘Charging APP practicality’ has a positive and significant impact on ‘overall satisfaction’.

4.3. Model goodness of fit

Using the AMOS software, the maximum likelihood estimation is used to estimate the model parameters. The calculation results and reference standards [5] of the structural equation model goodness of fit index are shown in Table 4.

| Classification          | Absolute fit | Parsimony fit | Relative fit |
|------------------------|--------------|---------------|--------------|
| Evaluation index       | CMIN/DF      | GFI           | AGFI         | RMSEA        | PGFI          | CFI           | NNFI(TLI)    |
| General value range    | < 3          | [0, 1]        | [0, 1]       | < 0.10       | [0, 1]       | [0, 1]        | /            |
| Best reference standard| < 2          | >0.9          | >0.8         | <0.08        | >0.5         | The closer to 1, the better |
| This model             | 1.69         | 0.964         | 0.901        | 0.038        | 0.532        | 0.798         | 0.812        |
It can be seen from Table 4 that the fitting index of the model meet the requirements of the value range, so the model goodness of fit is qualified.

4.4. Model result
The final path structure of the model is shown in Figure 1. The path coefficient between the measurable variables and the latent variables calculated by AMOS is shown in Table 5.

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Figure 1. Path structure of the model.
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| Hypotheses | Standardized path coefficient | P value | Validation results |
|------------|-------------------------------|---------|--------------------|
| H1         | 0.48                          | ***     | Supported          |
| H2         | 0.88                          | .012    | Supported          |
| H3         | 0.46                          | ***     | Supported          |
| H4         | 0.29                          | ***     | Supported          |
| H5         | 0.25                          | .032    | Supported          |
| H6         | 0.64                          | ***     | Supported          |
```

The P value of hypotheses H1~H6 meet the requirements, indicating that all of the hypotheses are true.

5. User satisfaction evaluation of charging infrastructure

5.1. Weights of indicators
From the structural equation model path load, the weights of all levels of indicators in the final model can be obtained. The first-level indicator path load and the second-level indicator path load are both the path load calculated by the AMOS. After normalization, the weight of the indicator is obtained.
Table 6. Weights of indicators.

| First-level indicator | Path load | Weight | Second-level indicator | Path load | Weight |
|-----------------------|-----------|--------|------------------------|-----------|--------|
| 1                     | 0.48      | 0.160  | 1.1                    | 0.46      | 0.254  |
|                       |           |        | 1.2                    | 0.08      | 0.045  |
|                       |           |        | 1.3                    | 0.04      | 0.020  |
|                       |           |        | 1.4                    | 0.50      | 0.278  |
|                       |           |        | 1.5                    | 0.73      | 0.403  |
| 2                     | 0.88      | 0.293  | 2.1                    | 0.81      | 0.384  |
|                       |           |        | 2.2                    | 0.47      | 0.224  |
|                       |           |        | 2.4                    | 0.41      | 0.196  |
|                       |           |        | 2.5                    | 0.41      | 0.196  |
|                       |           |        | 3.1                    | 0.58      | 0.306  |
|                       |           |        | 3.2                    | 0.71      | 0.371  |
|                       |           |        | 3.3                    | 0.41      | 0.218  |
|                       |           |        | 3.4                    | 0.20      | 0.105  |
| 3                     | 0.46      | 0.154  | 4.1                    | 0.18      | 0.114  |
|                       |           |        | 4.2                    | 0.81      | 0.506  |
|                       |           |        | 4.4                    | 0.45      | 0.279  |
|                       |           |        | 4.5                    | 0.16      | 0.101  |
| 4                     | 0.29      | 0.098  | 5.1                    | 0.69      | 0.240  |
|                       |           |        | 5.2                    | 0.66      | 0.228  |
|                       |           |        | 5.3                    | 0.61      | 0.210  |
|                       |           |        | 5.4                    | 0.43      | 0.148  |
|                       |           |        | 5.5                    | 0.25      | 0.086  |
|                       |           |        | 5.6                    | 0.26      | 0.090  |
| 5                     | 0.25      | 0.086  | 6.1                    | 0.27      | 0.178  |
|                       |           |        | 6.2                    | 0.46      | 0.304  |
|                       |           |        | 6.3                    | 0.47      | 0.312  |
|                       |           |        | 6.4                    | 0.12      | 0.081  |
|                       |           |        | 6.5                    | 0.19      | 0.125  |
| 6                     | 0.64      | 0.215  | 6.1                    | 0.31      | 0.160  |
|                       |           |        | 6.2                    | 0.14      | 0.105  |
|                       |           |        | 6.3                    | 0.27      | 0.178  |
|                       |           |        | 6.4                    | 0.12      | 0.081  |
|                       |           |        | 6.5                    | 0.19      | 0.125  |

5.2. Satisfaction results

Through weighted average of the average satisfaction of each group of second-level indicators, the corresponding first-level indicator satisfaction can be calculated. Similarly, the weighted average of first-level indicator satisfaction can calculate the overall satisfaction result.

Table 7. Satisfaction results.

| First-level indicator | Satisfaction results | Weight |
|-----------------------|----------------------|--------|
| 1 The availability of charging stations | 5.5085(78.69) | 0.160  |
| 2 The hardware facilities of charging stations | 5.2737(75.34) | 0.293  |
| 3 Charging cost and payment | 5.4191(77.42) | 0.153  |
| 4 Charging service experience | 5.3575(76.54) | 0.093  |
| 5 Charging pile functions | 5.3510(76.44) | 0.086  |
| 6 Charging APP practicality | 5.4722(78.17) | 0.215  |
| Overall satisfaction | 5.3906(77.00%) |        |

The user's satisfaction score for the charging infrastructure is 77, indicating that the development of charging infrastructure is acceptable. In addition, the difference in satisfaction with the first-level indicators is relatively small, indicating that the development of all aspects of the charging infrastructure is also relatively balanced. In the future, priority optimization should be given to indicators with larger
weights and relatively small satisfaction, that is, the hardware facilities of charging stations are the primary improvement factor.

6. Conclusion
This paper uses the structural equation to solve the user satisfaction model of the charging infrastructure, which is finally composed of 6 first-level indicators and 28 second-level indicators, and the evaluation indicators are comprehensive and reliable. According to the weights of first-level indicators, the hardware facilities of charging stations, charging APP practicality and charging cost and payment are the three most important indicators for users. Combined with the satisfaction results, we found that the development of charging infrastructure is relatively balanced in all aspects, but the satisfaction score of the hardware facilities of charging stations is less than overall satisfaction score, so it should be the primary improvement factor in the future.

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