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# Research on the Rationality of New Energy Vehicle Charging Station Layout and User Demand Satisfaction

## -- Based on the Investigation and Analysis in Shanghai

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## Abstract

**With China's carbon neutrality strategy, Shanghai's charging facilities face layout imbalance and low efficiency. The paper constructs a "space–behavior–perception" framework using multi-source data and a 2026 survey (254 questionnaires; 219 valid core samples). The results show that Shanghai's charging facilities present a "central concentration, ring diffusion" pattern, classified into regulation, maintenance, and development zones. The paper identifies three distinct user groups: battery-swap-preference type, high-frequency slow-charging-dependent type, and medium-frequency fast-charging-satisfied type. The high-frequency slow-charging-dependent group exhibits the lowest satisfaction, especially in charging convenience and cost. The most prominent charging anxiety scenarios are occupied chargers, equipment failure, and peak-time queuing. Overall satisfaction across seven dimensions ranges from 3.00 to 3.12, with information accuracy scoring highest (3.12) and operation and maintenance lowest (2.94). All satisfaction dimensions are positively correlated, with spatial accessibility and charging convenience acting as core and hub dimensions, respectively. Importantly, information accuracy partially mediates the relationship between charging convenience and operation and maintenance, accounting for 45.10% of the total effect, revealing a "leveraging effect." These findings suggest that charging facility optimization should shift from mere expansion to quality improvement, prioritizing information accuracy and systematic enhancement of spatial accessibility and convenience. The study provides a theoretical and empirical basis for charging infrastructure layout optimization in megacities.**

## Keywords

**Charging station layout; User satisfaction; Spatial analysis; Cluster analysis; Mediation effect; New energy vehicles.**

## 1. Introduction

With the continuous advancement of China's "carbon neutrality" strategy, the new energy vehicle industry has achieved explosive growth. In 2025, the production and sales of new energy vehicles in China reached 16.626 million and 16.49 million respectively, with year-on-year growth rates of 29% and 28.2% respectively. It has ranked first globally for 11 consecutive years [1]. The rationality of the layout of charging facilities as the core supporting infrastructure is directly related to the sustainable development of the industry. As a pioneering front for the promotion of new energy vehicles, Shanghai, despite the dense construction of charging facilities, still faces two major challenges: "difficulty in finding charging stations for users" and "difficulty in generating profits for enterprises". There are also structural contradictions such

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as unbalanced regional layout, insufficient supply in residential areas, and low operation and maintenance efficiency [2][3][4].

### 1.1. Discussion on the Current Research Status and Gaps

The current research includes the optimization of charging facility layout [5][6][7] and the analysis of user charging behavior and satisfaction [8]. There is a gap between these two directions. The layout model lacks behavioral variables. While the satisfaction study lacks spatial cross-validation. It is difficult to identify problem areas. For large cities such as Shanghai, the research is lack about combining spatial assessment with residents' satisfaction and studies the internal mechanism of their interaction.

### 1.2. Theoretical Analysis Framework

The paper constructs a theoretical framework including "space - behavior - perception", which consists of three paths. The first path is from Space to Behavior: differences in the density of functional areas influence the charging methods and frequencies. The second path is from Behavior to Perception: charging characteristics directly affect satisfaction. The third path is the Information Mediation: the accuracy of information buffers the negative experiences caused by insufficient maintenance. This framework conducts all subsequent analyses.

### 1.3. Research Objectives and Innovation Points

The paper takes Shanghai as the research object. Based on the above framework, the paper employs comprehensive methods including multi-source data, kernel density estimation, K-prototype clustering, and mediation effect testing. The aim is to: evaluate the spatial layout of charging stations and their matching degree with functional areas; identify user groups and behavior patterns; and test the mediation effect of information accuracy. The innovation lies in the two-way coupling of spatial assessment and satisfaction analysis. For the first time, the "leveraging effect" of information accuracy has been verified on a large-scale scale of Shanghai, a megacity, providing a basis for the transformation of charging facilities from "existence" to "excellence".

## 2. Data Sources and Research Methods

### 2.1. Data Sources and Processing

The data sources of this study include: official statistics, municipal "Lianlian Charging" platform data, data from third-party operators, POI and road network data. Data processing involves data cleaning, coordinate conversion (WGS-84), and spatial matching. All spatial analysis data are uniformly converted to the WGS-84 coordinate system and spatially overlaid with the boundaries of the 16 administrative districts in Shanghai.

### 2.2. Questionnaire Survey: Theoretical Basis and Design Logic

In March 2026, a combined online and offline sampling method was used to conduct stratified sampling of new energy vehicle users in the 16 administrative districts of Shanghai. The paper distributed 254 questionnaires and collected 219 valid questionnaires (core samples). The questionnaire design followed the "space - behavior - perception" framework. The questionnaire design covered user profile (location), charging behavior (cluster analysis), satisfaction evaluation (a 7-item Likert scale with information accuracy as a mediating variable), and challenges diagnosis (cross-validation). As Cronbach's $\alpha = 0.936$, KMO = 0.944, cumulative variance explanation rate 72.307%, the scale had good reliability.

### 2.3. Analytical Methods

Spatial assessment was conducted using kernel density estimation and buffer analysis; user groups were identified through K-modes clustering; correlations between dimensions were

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202611_9(11).0003

explored through Pearson correlation analysis; the three-step regression method and bootstrap method were used for the mediation effect test.

### 2.4. "Assessment Criteria for Dynamic Vehicle-Pole Ratio in Shanghai"

The dynamic vehicle-charging station ratio means the proportion between the number of new energy vehicles staying in a certain area within a specific period and the number of charging guns available for charging services in that area. If the ratio is high, the potential charging demand exceeds the supply. If the ratio is low, the charging supply exceeds the demand. In order to consider the balance of each period, the paper cites the average dynamic vehicle-charging station ratio (abbreviated as $B_i$). $B_i$ means the average of the dynamic vehicle-charging station ratios during the reference period (from 7 a.m. to 12 midnight). The calculation formula is as follows:

$$B_i = \frac{1}{18}\sum_{h=7}^{24}\frac{H_i}{Q_i} \quad (1)$$

$H_i$: the number of operating vehicles with a parking duration of more than 30 minutes within a certain time period in the i-th town (any one of the 215 towns)

$Q_i$: the number of DC fast charging guns built in the high-quality public charging stations (public charging stations with 5 or more DC fast charging guns) in the $i$-th town.

If the average dynamic charging station ratio shows "no ratio", it indicates that there are no high-quality public charging stations in this area and the average dynamic charging station ratio would be expressed as "none".

## 3. Analysis of the Current Layout of Charging Stations in Shanghai

### 3.1. Overall Characteristics of Spatial Distribution

Shanghai's electric vehicles were approximately 1.775 million by the end of 2025 and there were about 270,400 public and dedicated charging stations. Shanghai's charging facilities presented a "central concentration, ring diffusion" pattern. According to the ratio, Shanghai are categorized three zones: "Development zone", "Maintenance zone", and "Regulation zone", as shown in Fig. 1. The zone with the average dynamic vehicle-charging station ratio in the range of [2.4, ∞) or "no ratio" is evaluated as a Development zone; the zone in the range of [1, 2.4) is evaluated as Maintenance zone; and the zone in the range of (0, 1) is evaluated as Regulation zone. This indicator can effectively reflect the spatial matching degree of charging supply and demand in each town and support layout diagnosis.

### 3.2. Structural Characteristics

#### 3.2.1. Composition of Public and Specialized Charging Poles

In April 2026, there were a total of 204,800 public and specialized charging poles in Shanghai, among which 123,700 were public poles (60.4%) and 81,200 were specialized poles (39.6%) [9]. Public poles are for temporary charging of social vehicles, while specialized poles serve specific fleets such as buses, logistics, and taxis. Public poles account for over 60%, reflecting a public service orientation; specialized poles account for nearly 40%, with stable scenario-based demands, and overall public and specialized aspects are taken into account.

#### 3.2.2. Distribution of Fast Charging and Slow Charging

Among public charging poles, there are 43,900 DC fast charging points (35.5%), and among specialized charging poles, there are 14,200 DC fast charging points (17.5%); the total number of DC fast charging points in the city is 58,100 (28.4%), and AC slow charging accounts for 71.6%. Fast charging is concentrated in core business districts, transportation hubs, and

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expressway service areas, while slow charging is mainly in residential communities and office parks. The proportion of DC fast charging in public charging facilities increased from 20.6% in 2020 to 42.2%, with an average rated power increase of 37.6% [10]. Overall, slow charging is dominant, with fast charging as a secondary option, but there is a shortage of fast charging in the far suburbs. There still exist peak demand and pressure for long-distance charging in Shanghai.

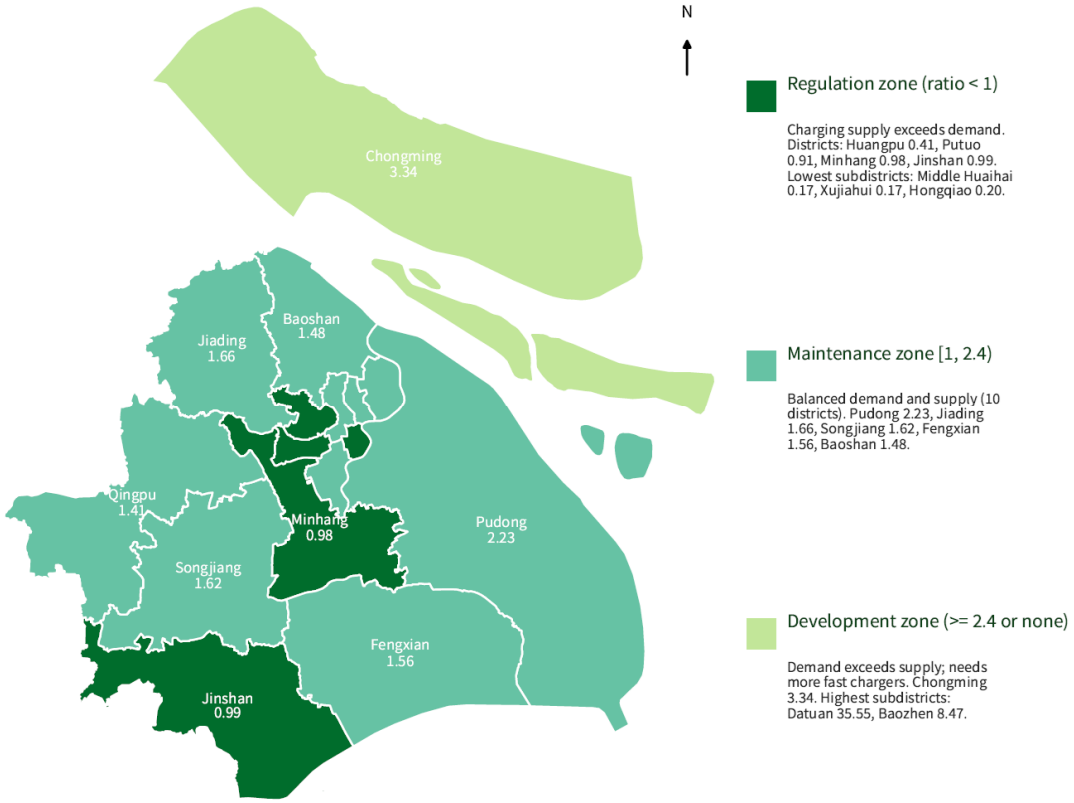



**Figure 1.** "Development zone", "Maintenance zone", and "Regulation zone" of Charging Stations in Shanghai in 2025

## 4. Empirical Analysis of User Needs and Satisfaction

### 4.1. Descriptive Statistics of the Sample

Among the valid samples, the types of vehicle owners, vehicle models, residential/work areas, charging frequencies, etc. all exhibit significant structural characteristics. Among the 254 returned questionnaires, 50.39% are owners/direct drivers of Shanghai's new energy vehicles, 43.70% are the occasional users of family/friend vehicles, and only 5.91% have never used new energy vehicles. This shows that the demand for charging stations has shifted from "minor experimentation" to "mass necessity". In the core sample (n=219), the proportion of pure electric vehicles and plug-in hybrid vehicles is basically the same (49.54% vs 50.46%), and the layout should meet the dual needs of "slow charging for replenishment" and "fast charging for emergency".

The respondents' permanent/main activity areas are highly concentrated in the central urban area, with Xuhui District (28.44%), Changning District (26.15%), and Huangpu District (23.39%) accounting for more than 78%, and the proportion of suburban areas is less than 4%. The charging frequency is mainly "once every 2-3 days" (39.45%), with a proportion of 20.64% for once a day or more, and most are operational vehicles.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202611_9(11).0003

## 4.2. Characteristics of User Charging Behavior

The charging time of users shows the feature of "mainly at night, covering all time periods": the proportion of charging at night (23:00-7:00) is 69.72%, at noon (11:00-14:00) is 61.93%, in the morning (7:00-11:00) is 60.55%, and the evening peak (18:00-23:00) is 47.71%. The charging methods are mainly household private charging stations (63.30%) and unit/company dedicated charging stations (61.01%), followed by public fast charging stations (58.26%) and public slow charging stations (52.75%), and the proportion of battery swap stations is 39.91%. The information acquisition channels are mainly mobile maps/charging APPs (66.51%), previous experience/familiar stations (65.60%), and temporary decisions based on roadside signs (65.14%).

## 4.3. Cluster Analysis of User Groups

The K-Prototype clustering algorithm was used to classify 219 valid samples, and the clustering variables cover core indicators such as charging methods, charging frequency, charging duration, various satisfaction levels, and layout issue cognition. The samples were divided into 3 distinct user groups (as shown in Table 1), with relatively even distribution and good clustering effect. Through chi-square tests and comparison with the clustering centers, significant differences were found in multiple indicators among the three groups ($p<0.05$).

The comparison of charging behavior characteristics of each clustering group is shown in Table 2. Cluster_1 (37.9%) is the "battery swap station preference type", with the highest usage rate of battery swap stations (54.22%), and the main charging frequency is once a week; Cluster_2 (27.4%) is the "high-frequency slow charging dependent type", with the usage rate of public slow charging stations reaching 73.33%, and the proportion of charging once every 2-3 days is 65.00%, having the highest dependence on slow charging stations; Cluster_3 (34.7%) is the "medium-frequency fast charging satisfied type", with the highest proportion of charging once a week (40.79%), and the proportion of charging duration of 30 minutes-1 hour is the highest (56.58%).

**Table 1.** Frequency Distribution of Clustering Categories

| Clustering Category | Frequency | Percentage (%) |
|---|---|---|
| Cluster_1 | 83 | 37.90 |
| Cluster_2 | 60 | 27.40 |
| Cluster_3 | 76 | 34.70 |
| Total | 219 | 100 |

**Table 2.** Comparison of Charging Behavior Characteristics of Each Clustering Group

| Variables | Options | Cluster_1 (n=83) | Cluster_2 (n=60) | Cluster_3 (n=76) |
|---|---|---|---|---|
| Usage rate of public slow charging stations | Usage | 30.12% | 73.33% | 60.53% |
| Usage rate of swap stations | Usage | 54.22% | 31.67% | 30.26% |
| Charging once every 2-3 days | Yes | 27.71% | 65.00% | 31.58% |
| Charging once a week | Yes | 27.71% | 10.00% | 40.79% |
| Charging duration of 30 minutes-1 hour | Yes | 51.81% | 25.00% | 56.58% |

Difference in satisfaction evaluation is shown in Table 3. The satisfaction rates of various items in Cluster_2 are generally lower than 20%, among which the satisfaction rate of charging convenience is only 6.67%, and the satisfaction rate of charging cost is only 5.00%, which is the

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lowest satisfaction among all groups and is the key focus of charging facility optimization. The satisfaction rates of Cluster_3 are all over 65%, with the highest satisfaction.

**Table 3.** Comparison of satisfaction evaluation distribution of each clustering group

| Variables | Score (satisfaction rate) | Cluster_1 (n=83) | Cluster_2 (n=60) | Cluster_3 (n=76) |
|---|---|---|---|---|
| Spatial accessibility | 4-5 points (satisfied) | 22.89% | 15.00% | 81.58% |
| Layout balance | 4-5 points (satisfied) | 26.50% | 20.00% | 73.69% |
| Charging convenience | 4-5 points (satisfied) | 24.10% | 6.67% | 76.32% |
| Charging cost | 4-5 points (satisfied) | 18.07% | 5.00% | 75.00% |
| Charging speed | 4-5 points (satisfied) | 27.71% | 16.67% | 65.79% |
| Information accuracy | 4-5 points (satisfied) | 25.30% | 16.66% | 82.89% |
| Operation and maintenance | 4-5 points (satisfied) | 28.92% | 11.66% | 71.05% |

The differences in cognition of layout issues among each clustering group are shown in Table 4. Cluster_2 pays the most attention to the problem of "tight parking spaces in the core area" (50% agree), which is significantly higher than other groups; Cluster_3 pays more attention to "unreasonable ratio of fast and slow charging" (23.68% agree).

**Table 4.** Differences in cognition of layout issues among each clustering group

| Variables | Options | Cluster_1 (n=83) | Cluster_2 (n=60) | Cluster_3 (n=76) |
|---|---|---|---|---|
| Core area charging piles are many but parking spaces are tight | Agree | 22.89% | 50.00% | 31.58% |
| Unreasonable ratio of fast and slow charging | Agree | 13.25% | 5.00% | 23.68% |

## 4.4. Core pain points and "charging anxiety"

All respondents have varying degrees of charging anxiety, as shown in Fig. 2. The most prominent anxiety scenario is "the APP shows there are charging piles, but upon arrival, it is occupied by fuel vehicles or fully charged vehicles" (69.27%), followed by "charger failure/offline and unable to use" (67.43%) and "long queuing time during peak hours" (67.43%), and charging speed mislabeling (59.17%), and cost opacity (47.25%) are secondary anxiety scenarios.

The respondents believe that the biggest problem with the current charging station layout in Shanghai is that "there are too many charging stations in the core areas but the parking spaces are tight" accounting for 33.49% (the highest), and "there are too few charging stations in the suburbs/new residential areas, resulting in insufficient coverage" accounting for 25.69% (the second), reflecting the "dual contradiction" of the charging station layout in Shanghai: mismatch of charging station locations (too many in core areas but too few parking spaces), and insufficient supply in the suburbs (few charging stations but high demand).

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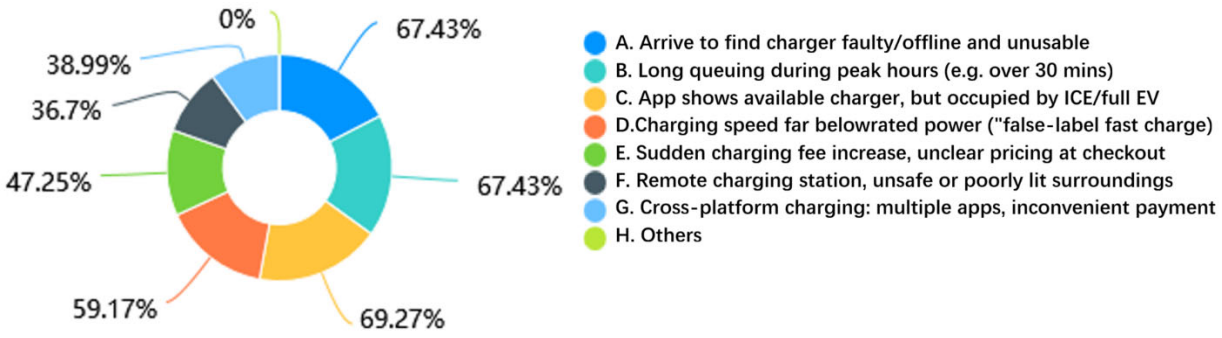



**Figure 2.** Distribution Map of User Charging Anxiety Scenarios Encounter Rate

## 4.5. Satisfaction Degree and Satisfaction Evaluation

The survey sets up a Likert 5-level scale question (1 = very dissatisfied, 5 = very satisfied) in 7 core dimensions (space accessibility, layout balance, charging convenience, charging cost, charging speed, information accuracy, operation and maintenance). The reliability test shows that the scale's Cronbach's α coefficient is 0.936, the KMO value is 0.944 ($p < 0.001$), and the cumulative variance explanation rate is 72.307%. The scale is reliable and valid.

The overall satisfaction mean analysis is shown in Table 5. The average satisfaction scores of the 7 dimensions are all within the range of 3.0 - 3.12, and the overall level is "average". The highest score is for information accuracy (3.12), the lowest is for operation and maintenance (2.94), and the scores of the other dimensions are in sequence: space accessibility (3.09), charging speed (3.07), layout balance (3.06), charging convenience (3.00), and charging cost (3.00).

**Table 5.** Satisfaction Mean of Each Dimension

| Evaluation Dimension | Satisfaction Mean | Evaluation Grade |
|---|---|---|
| Information Accuracy | 3.12 | General |
| Space Accessibility | 3.09 | General |
| Charging Speed | 3.07 | General |
| Layout Balance | 3.06 | General |
| Charging Convenience | 3.00 | General |
| Charging Cost | 3.00 | General |
| Operation and Maintenance | 2.94 | General |

Regional Difference Test shows that the satisfaction of suburban users in "layout balance" (central urban area 3.15 vs suburbs 2.82, difference 0.33) and "space accessibility" (central urban area 3.18 vs suburbs 2.79, difference 0.39) is significantly lower than that of urban area users ($p < 0.05$).

## 4.6. Correlation Analysis of Satisfaction Dimensions

To explore the internal correlation among the satisfaction dimensions and reveal whether there is a synergistic effect in users' perception of different aspects of charging facilities, this paper uses Pearson correlation analysis to test the correlation of the seven satisfaction dimensions (Q11-Q17). The mean values, standard deviations, and correlation coefficient matrices of each dimension are shown in Table 6.

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**Table 6.** Comparison of Satisfaction Evaluation Distribution of Each Cluster Group

| Dimension | Average Value | Standard Deviation | Q11 | Q12 | Q13 | Q14 | Q15 | Q16 | Q17 |
|---|---|---|---|---|---|---|---|---|---|
| Q11 Space Accessibility | 3.096 | 1.301 | 1 | | | | | | |
| Q12 Layout Balance | 3.068 | 1.320 | 0.693** | 1 | | | | | |
| Q13 Charging Convenience | 3.000 | 1.327 | 0.765** | 0.686** | 1 | | | | |
| Q14 Charging Cost | 3.005 | 1.225 | 0.711** | 0.692** | 0.703** | 1 | | | |
| Q15 Charging Speed | 3.082 | 1.257 | 0.680** | 0.571** | 0.685** | 0.616** | 1 | | |
| Q16 Information Accuracy | 3.132 | 1.298 | 0.756** | 0.664** | 0.732** | 0.669** | 0.665** | 1 | |
| Q17 Operation Maintenance | 2.950 | 1.307 | 0.696** | 0.608** | 0.669** | 0.628** | 0.619** | 0.685** | 1 |

Note: ** indicates a significant correlation at the 0.01 level (two-tailed). The sample size N = 219.

The analysis results show that there is a significant positive correlation between each pair of the seven satisfaction dimensions ($p < 0.01$), with the correlation coefficients ranging from 0.571 to 0.765. All correlation coefficients are positive, indicating a synergistic enhancement effect among the dimensions of satisfaction - the higher the evaluation of one dimension by users, the more likely the evaluation of other dimensions will also be higher.

Based on the absolute value of the correlation coefficient for interpretation ($|r| \geq 0.7$ indicates a highly correlated relationship, $0.4 \leq |r| < 0.7$ indicates a moderately correlated relationship), five highly correlated dimension combinations were identified, as shown in Table 7.

**Table 7.** Highly Correlated Satisfaction Dimension Combinations

| Ranking | Dimension Combination | Correlation Coefficient | Explanation |
|---|---|---|---|
| 1 | Spatial Accessibility & Charging Convenience | 0.765 | Parking location quantity perception is highly correlated with the smoothness of the charging process |
| 2 | Spatial Accessibility & Information Accuracy | 0.756 | Parking location quantity sufficiency is highly correlated with the accuracy of the APP information evaluation |
| 3 | Charging Convenience & Information Accuracy | 0.732 | Charging smoothness is highly correlated with information accuracy |
| 4 | Spatial Accessibility & Charging Cost | 0.711 | Parking location quantity perception is strongly correlated with the acceptance of costs |
| 5 | Charging Convenience & Charging Cost | 0.703 | Charging smoothness is significantly correlated with cost satisfaction |

From the results of Table 7, the following patterns can be observed:

First, spatial accessibility is the core fundamental dimension that affects the user's overall experience. Spatial accessibility is highly correlated with charging convenience ($r = 0.765$), information accuracy ($r = 0.756$), and charging cost ($r = 0.711$), indicating that the perception of parking location quantity is the prerequisite for users to evaluate other service dimensions.

Second, charging convenience is the hub that connects other experience dimensions. Charging convenience, as the core indicator of the process experience, is highly correlated with spatial

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accessibility (r = 0.765), information accuracy (r = 0.732), and charging cost (r = 0.703), indicating that the improvement of convenience can lead to an overall improvement in users' evaluation of multiple services.

Third, the satisfaction dimensions exist significant synergy effect. The correlation coefficients are all positive and are moderate or higher correlation strength. This indicates that user satisfaction is a systemic construct. This finding suggests that an overall improvement effect like "pulling one string to move the whole thing" can be achieved by addressing key shortcomings such as "inaccurate information" and "poor operation and maintenance".

In conclusion, the strong correlation between satisfaction dimensions indicates that charging facility optimization should not solve problems in isolation but adopt a systematic strategy. Among them, spatial accessibility as the fundamental dimension, and charging convenience as the hub dimension, should be the priority focus of optimization work.

# 5. Layout Rationality Comprehensive Evaluation and Problem Diagnosis

## 5.1. Cross-analysis of Layout Cognition and Charging Anxiety Scenarios

To analyze the intrinsic relationship between users' cognition of charging facility layout issues and the charging anxiety scenarios they actually encounter, this paper conducted a multiple-choice - multiple-choice cross-analysis of Q19 ("What do you think is the biggest problem with the current charging facility layout in Shanghai?") and Q18 (seven types of charging anxiety scenarios).

Table 8 and Fig. 3 present the frequency distribution of users' experiences in each anxiety scenario based on different layout problem cognitions. The chi-square test results showed that $\chi^2 = 9.695$, $p = 0.996 > 0.05$, indicating that there is no statistically significant difference in the encounter rate of anxiety scenarios among different problem cognition groups, that is, there is no obvious correlation between the two multiple-choice questions, and the percentage selection distribution is relatively uniform.

**Table 8.** Cross-analysis Table of Charging Anxiety and Layout Cognition (Frequency/Percentage)

| Q19 Layout Cognition Issues | Q18-A Charging Facility Failure | Q18-B Peak-time Queuing | Q18-C Oil Vehicle Occupation | Q18-D Speed Mislabeling | Q18-E Fee Incompleteness | Q18-F Environmental Unsecurity | Q18-G Cross-platform Inconvenience |
|---|---|---|---|---|---|---|---|
| Q19-A Core Area Lots with Few Parking Spaces | 47(32.0%) | 51(34.5%) | 52(34.4%) | 45(34.9%) | 40(38.5%) | 26(32.1%) | 28(32.9%) |
| Q19-B Insufficient Coverage in the Suburbs | 40(27.2%) | 37(25.0%) | 40(26.5%) | 35(27.1%) | 32(30.8%) | 16(19.8%) | 24(28.2%) |
| Q19-C Inappropriate Ratio of Fast and Slow Charging | 21(14.3%) | 22(14.9%) | 18(11.9%) | 19(14.7%) | 11(10.6%) | 14(17.3%) | 10(11.8%) |
| Q19-D Information Isolation | 23(15.6%) | 20(13.5%) | 22(14.6%) | 16(12.4%) | 11(10.6%) | 14(17.3%) | 15(17.6%) |
| Q19-E Lack of Guidance Signs | 16(10.9%) | 18(12.2%) | 19(12.6%) | 14(10.9%) | 10(9.6%) | 11(13.6%) | 8(9.4%) |
| Total | 147(100%) | 148(100%) | 151(100%) | 129(100%) | 104(100%) | 81(100%) | 85(100%) |

Note: The numbers in the table are the frequency of experiencing each anxiety scenario, and the percentage in parentheses is the proportion of the problem cognition group in the total number of people experiencing each anxiety scenario. Chi-square test: $\chi^2 = 9.695$, $p = 0.996$.

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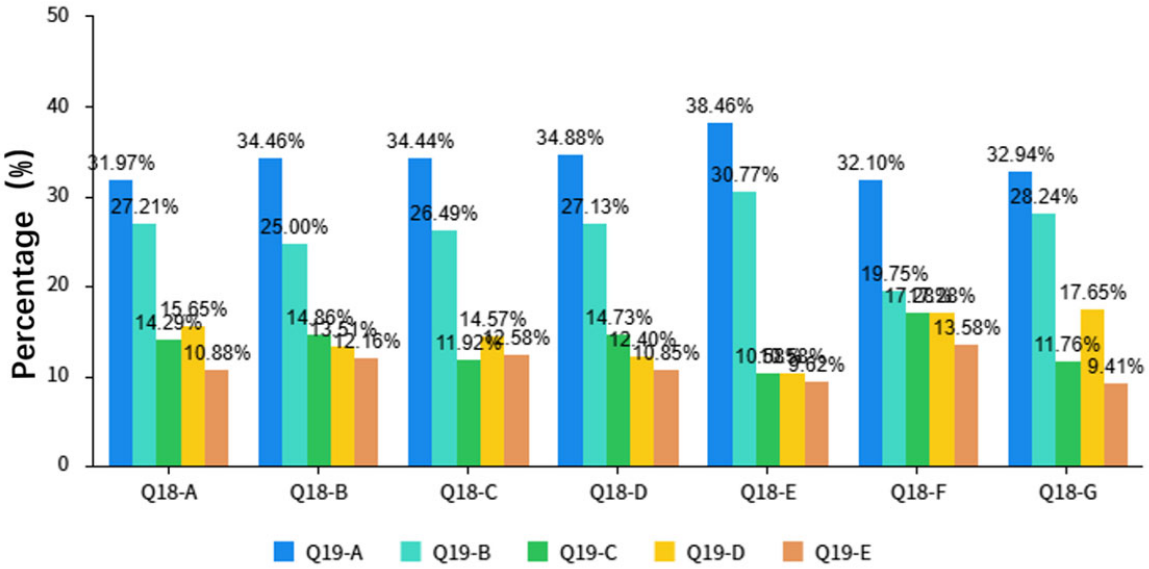



**Figure 3.** Distribution Map of User Charging Anxiety Scenarios Encounter Rate

Although the chi-square test did not show a significant difference (p = 0.996), from the percentage distribution, different problem cognition groups still exhibit different characteristics:

(1) Users who think "core area lots with few parking spaces" have the highest proportion in all anxiety scenarios, especially in "fee incompleteness" (38.5%), "speed mislabeling" (34.9%), "peak-time queuing" (34.5%), and "oil vehicle occupation" (34.4%), accounting for more than 34% in all, indicating that they face multiple anxieties;

(2) Users who think "insufficient coverage in the suburbs" have a relatively high proportion in "fee incompleteness" (30.8%) and "cross-platform inconvenience" (28.2%), only lower than those in the core area.

(3) Users who believe that "the ratio of fast charging and slow charging is unreasonable" have a higher proportion of "speed mislabeling" compared to other situations;

(4) Users who consider "information isolation" are more prominent in "oil vehicle occupation" (14.6%) and "environmental insecurity" (17.3%);

(5) Users who believe "lack of guidance signs" have a relatively balanced proportion in all scenarios (9.4% - 13.6%).

In conclusion, "pole position mismatch" in the core area is the focus where multiple dimensions of anxiety are concentratedly manifested. The optimization should shift from the previous "step-by-step expansion" to the future "improvement of the quality of existing resources". Urgently demand transparency in charging costs and integration of information are needed by suburban users . At the same time, Operational norms and platform construction are also necessary for suburban users.

## 5.2. Correspondence Analysis of Charging Anxiety and New Charging Station Demand

To explore the intrinsic relationship between user charging anxiety scenarios and the preference for new charging station locations, this paper conducted a multiple-choice - multiple-choice correspondence analysis of Q18 (charging anxiety scenarios) and Q20 (new station preferences). The results are shown in Table 9 and Fig. 4. The chi-square test shows that $\chi^2 = 6.430$, $p = 1.000 > 0.05$, indicating that there is no significant statistical correlation between the two, and charging anxiety is a universal problem.

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Although there is no significant correlation overall, by analyzing the proportion of users' preferences for new stations in each anxiety scenario, it is found that regardless of the type of anxiety, users' preferences for new stations are highly concentrated in "surrounding large residential communities" (37.61%) and "industrial parks/office buildings concentration areas" (35.78%). These two scenarios cover over 70% of the charging demand and are the core priority directions for subsequent charging station layout.

**Table 9.** Cross-summation Table of Charging Anxiety and New Station Preferences (Frequency/Percentage)

| Q20 New Station Preferences | Q18-A Charging Facility Failure | Q18-B Peak-time Queuing | Q18-C Oil Vehicle Occupation | Q18-D Speed Mislabeling | Q18-E Fee Incompleteness | Q18-F Environmental Unsecurity | Q18-G Cross-platform Inconvenience |
|---|---|---|---|---|---|---|---|
| Q20-A Large Residential Community Surroundings | 54(36.7%) | 51(35.2%) | 56(37.1%) | 46(35.7%) | 35(34.0%) | 25(31.3%) | 30(35.3%) |
| Q20-B Industrial Parks/Office Buildings Concentration Areas | 55(37.4%) | 52(35.9%) | 53(35.1%) | 43(33.3%) | 33(32.0%) | 26(32.5%) | 31(36.5%) |
| Q20-C Shopping Mall/Shopping Center Parking Lot | 42(28.6%) | 44(30.3%) | 47(31.1%) | 43(33.3%) | 35(34.0%) | 29(36.3%) | 25(29.4%) |
| Q20-D Expressway Service Area and Entrances | 26(17.7%) | 33(22.8%) | 29(19.2%) | 24(18.6%) | 20(19.4%) | 16(20.0%) | 17(20.0%) |
| Q20-E Public Parking Lot | 26(17.7%) | 23(15.9%) | 21(13.9%) | 22(17.1%) | 16(15.5%) | 10(12.5%) | 14(16.5%) |
| Q20-F Ridesharing/Vehicle Rental Concentrated Parking Points | 15(10.2%) | 15(10.3%) | 17(11.3%) | 17(13.2%) | 11(10.7%) | 9(11.3%) | 12(14.1%) |
| Total | 147(100%) | 148(100%) | 151(100%) | 129(100%) | 104(100%) | 81(100%) | 85(100%) |

Note: Chi-square test result: $\chi^2 = 6.430$, $p = 1.000 > 0.05$.

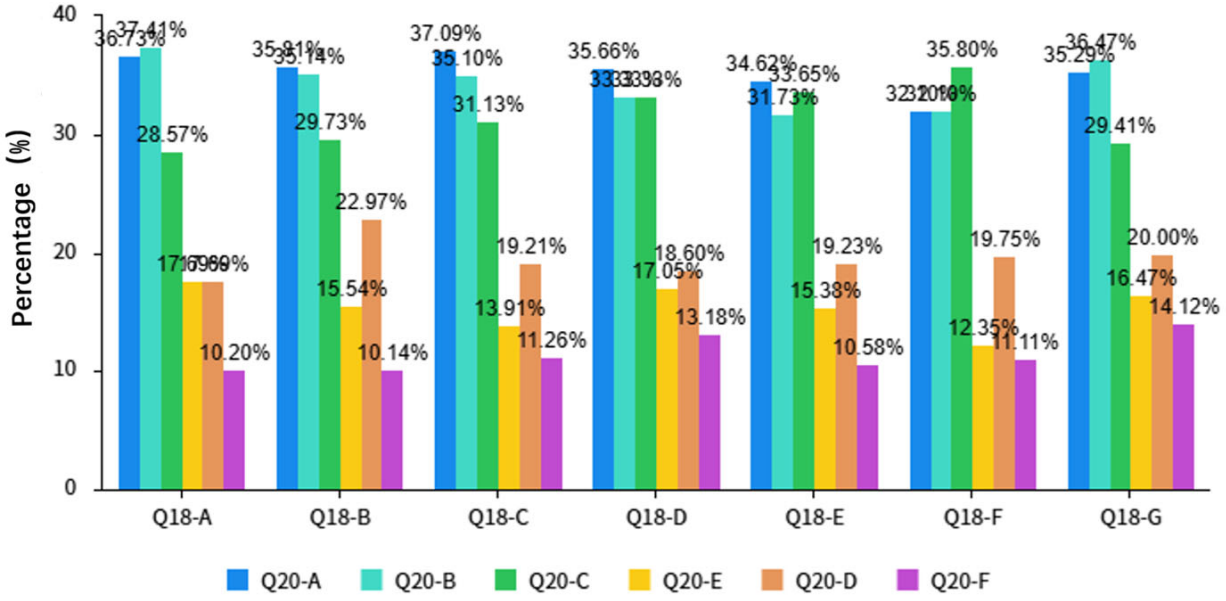



**Figure 4.** Cross-summary Chart of Charging Anxiety and Preference for New Charging Stations

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### 5.3. Analysis of the Mediating Effect of Information Accuracy between Operational Maintenance and Charging Convenience

The previous analysis indicates that operational maintenance (Q17) is the dimension with the lowest user satisfaction (2.94 points), and the score for charging convenience (Q13) is only 3.00 points, while information accuracy (Q16) is the dimension with the highest score (3.12 points). To further explore the internal influence mechanism among these three dimensions, this paper takes operational maintenance as the dependent variable, charging convenience as the independent variable, and information accuracy as the mediating variable, and constructs a mediating effect model for analysis.

The results of the mediating effect analysis are shown in Table 10 and 11. All three regression models reached a significant level ($p < 0.001$). The total effect c was 0.651 ($p < 0.01$), the indirect effect a × b was 0.294 (Bootstrap 95% CI does not include 0), and the direct effect c' was 0.358 ($p < 0.01$). Information accuracy plays a partial mediating role between charging convenience and operational maintenance, and the mediating effect accounts for 45.10% of the total effect.

This result indicates that information accuracy is the key bridge connecting charging convenience and operation perception. Even if the operation status of the charging facilities is poor, if the information service platform can accurately provide information such as the status and fault information, it can to some extent alleviate users' dissatisfaction with operation issues; improving the quality of information services has an "leveraging effect", not only can it directly improve the satisfaction of information accuracy, but also can indirectly improve users' evaluation of operation and convenience through the intermediary path.

**Table 10.** Results of Mediating Effect Analysis of Information Accuracy

| Model | Dependent Variable | Independent Variable | Unstandardized Coefficient (B) | t-value | Model Fit ($R^2$) |
|---|---|---|---|---|---|
| 1 | Q17 | Constant | 0.981** | 6.018 | 0.440 |
| | | Q13 | 0.651** | 13.044 | |
| 2 | Q16 | Constant | 0.989** | 6.652 | 0.531 |
| | | Q13 | 0.711** | 15.619 | |
| 3 | Q17 | Constant | 0.573** | 3.443 | 0.517 |
| | | Q13 | 0.358** | 5.272 | |
| | | Q16 | 0.413** | 5.934 | |

**Table 11.** Summary of Mediating Effect Test Results

| Path Q13→Q16→Q17 | Effect value | Standard error | 95% Bootstrap CI | Effect proportion |
|---|---|---|---|---|
| Total effect (c) | 0.651** | 0.050 | - | - |
| Indirect effect (a×b) | 0.294 | 0.060 | [0.186, 0.423] | 45.10% |
| Direct effect (c') | 0.358** | 0.068 | - | 54.90% |

Note: ** indicates $p < 0.01$.

## 6. Conclusion

The paper constructs a “space–behavior–perception” framework and taking Shanghai as the object, it uses methods such as multi-source data fusion, spatial analysis, K-Prototype clustering, Pearson correlation analysis, and mediation effect test to evaluate the characteristics of

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charging station layout, users' charging behaviors, and satisfaction. The main conclusions are as follows:

First, Shanghai's spatial distribution of charging facilities exhibits "central concentration, ring diffusion" pattern, classified into regulation zone where supply exceeds demand, maintenance zone with relatively balanced supply and demand, and development zone where demand exceeds supply. This indicates that the spatial mismatch between charging supply and demand remains a prominent issue.

Second, user groups are differentiated, and the pain points focus on operation and maintenance. Users are divided into three categories: "station preference type" (37.9%), "high-frequency slow charging reliance type" (27.4%), and "medium-frequency fast charging satisfaction type" (34.7%). Among them, the satisfaction of the "high-frequency slow charging reliance type" is the lowest (the satisfaction rate of charging convenience is 6.67%). The core pain points are: "fuel vehicles/maintained vehicles occupying space" (69.27%), "charging station failure" (67.43%), and "queueing during peak hours" (67.43%). Among them, "fuel vehicles/maintained vehicles occupying space" has the strongest negative correlation with charging convenience ($r = -0.186$, $p < 0.05$). The proportion of pure electric and plug-in hybrid vehicles is the same, and the nighttime charging proportion is the highest (69.72%). Home private charging stations and unit charging stations are the main charging methods.

Third, information accuracy has a leverage effect, and residential and working areas are the optimization priorities. Information accuracy plays a partial mediating role between charging convenience and operation and maintenance, with an effect ratio of 45.10%. Users' preference for new charging stations is concentrated in "around large residential communities" (37.61%) and "industrial parks/office areas" (35.78%), which cover over 70% of the charging demand and are the core direction for subsequent layout.

Based on the above conclusions, this paper proposes the following optimization suggestions: Firstly, in terms of spatial layout, implement "quality improvement in the core area and blind spots in the suburbs", with the core area shifting from incremental expansion to optimization of existing resources, and the suburbs prioritizing the supplementation of blind spots in large residential communities and industrial parks around; Secondly, in terms of operation and maintenance, focus on "oil vehicle occupation, charging station failure, and queueing" as the three major pain points, promote intelligent locks, establish operation and maintenance standards, implement appointment charging and off-peak pricing; Thirdly, in terms of information services, strengthen platform integration, increase the frequency of charging station status updates, break information silos, and achieve "one network query, one-click payment"; Finally, in terms of precise policy implementation, optimize differently for the three groups of users, with a focus on improving the slow charging layout in residential areas for the "high-frequency slow charging reliance type" group.

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