Proceedings of the 4th International Conference on Financial Technology and Business Analysis
DOI: 10.54254/2754-1169/2025.31083

# *Research on the Location and Layout of Centralized Charging and Battery Swapping Stations for Electric Bicycles Based on Charging Demand*

**Rong Liu[1], Jiajia Chen[1*]**

[1]*School of Economics and Management, Chongqing Jiaotong University, Chongqing, China*
**Corresponding Author. Email: chenjiajia@mails.cqjtu.edu.cn*

***Abstract.*** Aiming at the current charging dilemma of electric bicycles, this paper proposes a method for determining the location and capacity of centralized charging and battery swapping stations. Based on POI data, this study identifies hotspots of charging and battery swapping demand in the research area, constructs a comprehensive model targeting the minimization of operators' costs and users' time costs, and employs the simulated annealing-particle swarm optimization (SA-PSO) hybrid algorithm to solve the model for obtaining the locations of the stations and the configuration quantity of equipment. Through case analysis, the results of location and capacity determination for centralized charging and battery swapping stations in the research area are obtained, providing theoretical reference for electric bicycle charging and battery swapping operators.

***Keywords:*** Electric bicycles, Location and capacity determination, POI clustering, Charging piles, Battery swapping cabinets

## 1. Introduction

With the proposal of the strategic goal of building a green and low-carbon travel system in the 14th Five-Year Plan, electric bicycles have rapidly become an important means of transportation in Chinese residents' daily lives due to their unique advantages of meeting residents' short-distance travel needs and being low-carbon and environmentally friendly. According to industry data, by the end of 2024, the social ownership of electric bicycles in China had reached 400 million. While electric bicycles are experiencing rapid growth, fire safety accidents caused by improper charging occur frequently, seriously endangering people's lives and property safety. The reasonable layout of centralized charging and battery swapping stations for electric bicycles provides an efficient and feasible solution to address the "difficulty in charging" for residents in communities without conditions to build charging facilities and electric bicycle users in urgent need of charging during travel.

Existing research on energy supplement facilities for electric bicycles is relatively scarce, and the available studies mainly focus on electric bicycle battery swapping cabinets. For example, regarding the location and capacity determination of battery swapping cabinets for electric bicycles in food delivery scenarios, some scholars predicted the temporal and spatial distribution of battery swapping

DOI: 10.54254/2754-1169/2025.31083

demand based on POI data clustering and simulated delivery routes, and combined with the NSGA-II algorithm to optimize the location and capacity configuration of battery swapping cabinets, thereby improving food delivery efficiency [1]; some scholars studied the relationship between battery swapping demand and POI density based on battery swapping enterprise data, POI data, and food delivery demand data, and proposed a POI clustering-based location strategy for electric bicycle battery swapping cabinets according to the research results, effectively reducing enterprise costs [2]; other scholars simultaneously focused on the location optimization of electric bicycle battery swapping cabinets and the optimization of delivery routes, proposed a joint optimization model, and optimized the location of battery swapping cabinets through the particle swarm optimization (PSO) algorithm while considering the coordinated optimization of delivery routes, further improving the efficiency of the battery swapping process and reducing delivery costs [3]. However, in relevant studies, consumers' charging and battery swapping demand is difficult to obtain directly. Researchers analyzed the battery swapping data of a certain battery swapping enterprise, clustered battery swapping cabinets using K-means, and then adopted the ARIMA model for short-term battery swapping demand prediction [4]. The research results provide data support for the location and capacity determination of battery swapping enterprises.

Although electric bicycles are essentially different from electric vehicles in various aspects, relevant successful experiences can still be drawn from them in terms of commercial operation, charging and energy supplement, etc. [2]. Scholars at home and abroad have established different models based on various energy supplement forms such as charging stations [5], battery swapping stations [6], mobile charging stations [7], and hybrid charging stations [8] to meet the energy supplement needs of different users in different scenarios. Drawing on the relevant research results of the location of energy supplement facilities for electric vehicles, this paper considers the characteristics of electric bicycles and conducts research on the location and capacity determination of centralized charging and battery swapping stations for electric bicycles, providing theoretical reference for operators of electric bicycle charging and battery swapping facilities.

## 2. Construction of the location model

### 2.1. Assumptions

- It is assumed that each alternative site meets the construction requirements.
- It is assumed that all charging piles in the centralized charging and battery swapping stations are fast-charging piles, and the single charging time is 1 hour.
- It is assumed that the battery specifications of electric bicycles in the research area are the same and match the battery capacity in the battery swapping cabinets.
- It is assumed that each demand point only goes to the nearest centralized charging and battery swapping station for energy supplement.

### 2.2. Objective function

From an economic perspective, the construction of centralized charging and battery swapping stations for electric bicycles mainly involves the interests of two subjects: operators and users. Therefore, drawing on existing research results, this paper establishes a model for minimizing the comprehensive cost $F$ of centralized charging and battery swapping stations, which consists of the

DOI: 10.54254/2754-1169/2025.31083

operators' construction and operation costs $F_1$ and the users' time costs $F_2$, from the perspectives of operators and users. The objective function is as follows:

$$minF = F_1 + F_2 \tag{1}$$

### 2.2.1. Operator costs

Investing in the construction of public charging and battery swapping stations for electric bicycles, the operator's costs generally include the fixed construction costs of public charging and battery swapping stations, the purchase costs of charging and battery swapping equipment, the operation costs after construction and commissioning, and the operation loss costs caused by the inability to meet user needs due to the capacity limitation of service facilities. Therefore, the operator's costs $F_1$ can be divided into construction costs $C_1$, operation costs $C_2$, and operation loss costs $C_3$.

$$F_1 = C_1 + C_2 + C_3 \tag{2}$$

$$C_1 = \sum_{i=1}^{I} X_{ij} \left[\frac{r(1+r)^n}{(r+1)^n-1}\left(G_{ij} + S_{ij}{*}Q_{1ij} + H_{ij}{*}Q_{2ij}\right)\right] \tag{3}$$

$$C_2 = \sum_{i=1}^{I} X_{ij}\left(A{*}C_1\right) \tag{4}$$

$$C_3 = \sum_{i=1}^{I} \sum_{k=1}^{K} P_{ik}{*}Y_{ik}{*}X_{ij} \tag{5}$$

$$P_{ik} = \begin{cases} 0, l_i \le Q_{ij} \\ \lambda(l_i - Q_{ij}), l_i > Q_{ij} \end{cases} \tag{6}$$

$$Q_{ij} = Q_{1ij} + Q_{2ij} \tag{7}$$

Among them, $I$ is the set of candidate sites for public charging and battery swapping stations for electric bicycles, $I = (1,2,3...i)$ . $j$ is the grade of public charging and battery swapping stations, $j \in (1,2,3)$ . $X_{ij}$ is a binary decision variable, which $X_{ij}$ takes the value of 1 when a public charging and battery swapping station of grade is $j$ built at the candidate site $i$ ; if no public charging and battery swapping station is built at the candidate site $i$, it takes the value of 0. $r$ is the discount rate, and $n$ is the service life of the charging and battery swapping station. $G_{ij}$ is the fixed construction cost of the charging and battery swapping station, $S_{ij}$ is the unit price of charging equipment in the $i$ -th charging and battery swapping station of grade $j$ , $H_{ij}$ is the unit price of battery swapping equipment in the $i$ -th charging and battery swapping station of grade $j$ , $Q_{1ij}$ is the number of charging equipment in the $i$ -th charging and battery swapping station of grade $j$ , and $Q_{2ij}$ is the number of battery swapping equipment in the $i$ -th charging and battery swapping station of grade . $Q_{ij}$ is the total number of charging and battery swapping equipment in the $i$ -th charging and battery swapping station of grade $j$ . $A$ is the conversion coefficient. $K$ is the set of charging and battery swapping demands, $K = (1,2,3...k)$ . $P_{ik}$ is the penalty cost for demand $k$ at site $i$ . $Y_{ik}$ is a binary decision variable, which takes the value of 1 when the charging and battery swapping demand $k$ goes to site for charging and battery swapping, otherwise it takes

DOI: 10.54254/2754-1169/2025.31083

the value of 0. $\lambda$ is the demand penalty coefficient, and $l_i$ is the charging and battery swapping demand at site $i$ .

### 2.2.2. User costs

When electric bicycle users go to charging and battery swapping stations for energy supplement, the user costs mainly consider the path time loss cost when users travel to the charging and battery swapping stations and the waiting time cost for services after arriving at the charging and battery swapping stations. However, since the battery swapping process is very short, there is rarely a queuing phenomenon, so queuing is not considered for users who perform battery swapping. Therefore, the user costs $F_1$ can be divided into path travel time costs $T_1$ and waiting time costs $T_2$ for charging.

$$F_2 = T_1 + T_2 \tag{8}$$

$$T_1 = 365 \sum_i^I \sum_k^K d_{ik} Y_{ik} \beta / v_{ik} \tag{9}$$

$$T_2 = 365 \sum_i^I \sum_k^K \frac{(Q_{1ij} * \rho_{ij})^{Q_{ij}} * \rho_{ij}}{Q_{1ij}! * (1-\rho_{ij})^2 * b} * P * \beta \tag{10}$$

$$\rho_{ij} = \frac{b}{Q_{1ij} * \varepsilon} \tag{11}$$

$$P = \left[ \sum_{h=0}^{Q_{1ij}-1} \frac{1}{h!} * \left( \frac{b}{\varepsilon} \right)^h + \frac{1}{Q_{1ij}!} * \frac{1}{1-\rho_{ij}} * \left( \frac{b}{\varepsilon} \right)^{Q_{1ij}} \right]^{-1} \tag{12}$$

In the above formulas, $d_{ik}$ represents the distance between site $i$ and demand $k$ , and $v_{ik}$ is the speed of demand $k$ when traveling to site $i$ . $\beta$ represents the unit time cost of electric bicycle users. $\rho_{ij}$ is the average utilization rate of charging equipment in site $i$ , $b$ is the number of vehicles arriving for charging at the charging and battery swapping station per hour, and $P$ is the probability that the charging equipment in the charging and battery swapping station is idle. $\varepsilon$ is the number of vehicles completing charging services at the charging and battery swapping station per hour.

### 2.2.3. Constraints

$$\sum_i^I Y_{ik} = 1, \forall k \in K \tag{13}$$

$$Y_{ik} \leq X_{ij}, \forall i \in I, \forall k \in K \tag{14}$$

$$I_{max} \leq I \leq I_{min} \tag{15}$$

$$\sum_k^K Y_{ik} \leq Q_{ij}, \forall i \in I \tag{16}$$

Formula (13) indicates that a charging and battery swapping demand can only be served by one site. Formula (14) indicates that only built sites can provide charging and battery swapping services. Formula (15) indicates that there are constraints on the sites in the research area. Formula (16) indicates that the demand volume served by the site must meet the capacity limit.

## 3. Empirical research

This study takes Wuhou District of Chengdu City as the research area, with an administrative area of 75.36 square kilometers. The district has a permanent population of 1.2247 million, and a large number of electric bicycles in the administrative area, which provides a research foundation.

### 3.1. Analysis of charging and battery swapping demand

Points of Interest (POI) are data used to describe specific locations in geospatial information, which have been widely used in location layout research in recent years [9]. Existing studies have found that the demand for energy supplement facilities is positively correlated with the surrounding POI density [2]; the higher the POI density in an area, the greater the charging and battery swapping demand. Therefore, this paper uses POI data to analyze the charging and battery swapping demand points of electric bicycles. The POI data of Wuhou District obtained by crawling Amap are divided into residential land attributes, commercial land attributes, office land attributes, and public service land attributes according to categories. Then, the research area is divided into 100m*100m grids using ArcGIS software, totaling 7,226 grids. Based on the POI data of different category attributes, the grids are classified by functional attributes, resulting in 4,610 grid areas with functional attributes, including 1,432 commercial areas, 1,008 public service areas, 973 employment areas, and 1,197 residential areas. The distribution of functional attribute grids is shown in Figure 1:

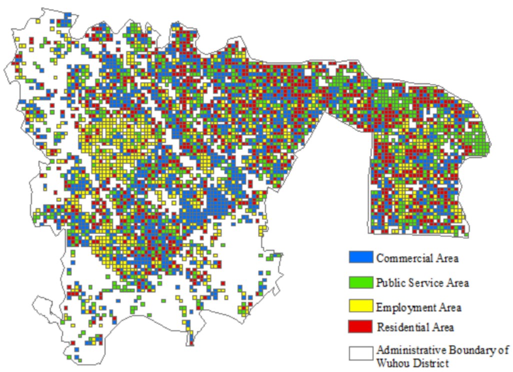


Figure 1. Functional attribute grid division map

The charging and battery swapping demand varies among different functional land uses. Generally, residential land generates the highest charging and battery swapping demand, while commercial land generates less charging and battery swapping demand [8]. The charging and battery swapping demand of each grid is calculated according to the charging and battery swapping demand weights of different functional land uses, and the kernel density analysis of charging and battery swapping demand is carried out in the research area. The analysis results are shown in Figure 2.

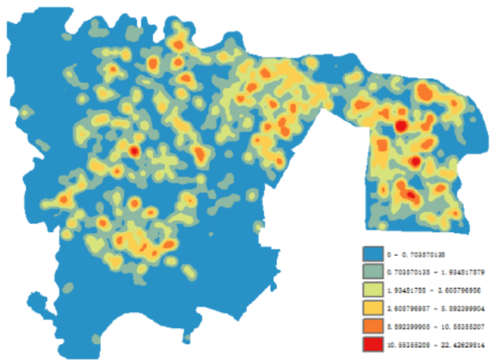

Figure 2. Kernel density map of charging and battery swapping demand

Based on the obtained POI data and charging and battery swapping demand weight data, clustering is performed according to the charging and battery swapping demand volume using the DBSCAN clustering method. Areas with high demand density have relatively more clusters. The results show 62 clusters, representing 62 charging demand clusters. Then, the K-means clustering algorithm is used to calculate the cluster centers of the 62 clusters, which also represent 62 alternative sites for centralized charging and battery swapping stations. The analyzed alternative sites for charging and battery swapping stations are shown in Figure 3:

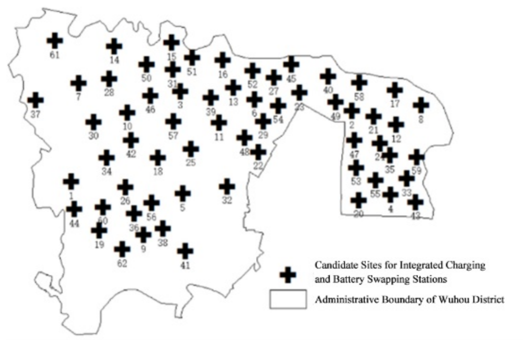


Figure 3. Spatial distribution map of alternative centralized charging and battery swapping stations

### 3.2. Model parameter setting

For the relevant parameters involved in the location and capacity model of centralized charging and battery swapping stations for electric bicycles, since the state has not yet issued official classification standards for charging and battery swapping stations, this paper refers to the issued classification data of electric vehicle charging and battery swapping stations and the data of built electric bicycle charging and battery swapping stations for setting. Charging stations are divided into three grades: Grade I charging stations include 24 charging piles and 5 battery swapping cabinets, with a construction cost of 234,000 yuan and a daily service capacity of 500 vehicles. Grade II charging stations include 12 charging piles and 3 battery swapping cabinets, with a construction cost of 167,000 yuan and a daily service capacity of 280 vehicles. Grade III charging stations include 10 charging piles and 1 battery swapping cabinet, with a construction cost of 101,000 yuan and a daily service capacity of 150 vehicles. All battery swapping cabinets are 12-compartment battery swapping cabinets. The model parameters are shown in Table 1:

DOI: 10.54254/2754-1169/2025.31083

Table 1. Parameter table of the location and capacity model for centralized charging and battery swapping stations

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $r$ | 3% | $v_{ik}$ | 0.4km/h |
| $n$ | 10 | $\beta$ | 0.6 Yuan/min |
| $S_{ij}$ | 100 | $A$ | 30% |
| $H_{ij}$ | 36000 | $\lambda$ | 10 |

### 3.3. Model results

According to the previous research content, this paper sets the number of centralized charging and battery swapping stations to be built as 30, and uses MATLAB software to solve the model. The results show that when the number of centralized charging and battery swapping stations is 30, the construction cost of the stations is 811,000.64 yuan, the operation cost is 243,300.19 yuan, the operation loss cost is 66,750.00 yuan, the path travel time cost is 3,838,943.65 yuan, and the waiting time cost for charging is 135,109.83 yuan, with a total cost of 5,095,103.66 yuan. According to the solution results, the corresponding locations and grade configurations of the candidate points for centralized charging and battery swapping stations are shown in Table 2 and Figure 4.

Table 2. Location and capacity results

| Site | Grade | Site | Grade | Site | Grade | Site | Grade | Site | Grade | Site | Grade |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 15 | 3 | 23 | 3 | 30 | 3 | 38 | 3 | 49 | 1 |
| 5 | 3 | 17 | 2 | 25 | 3 | 31 | 3 | 39 | 1 | 50 | 3 |
| 8 | 3 | 19 | 2 | 27 | 2 | 34 | 3 | 42 | 3 | 52 | 1 |
| 9 | 3 | 21 | 1 | 28 | 2 | 35 | 1 | 43 | 3 | 55 | 1 |
| 10 | 3 | 22 | 3 | 29 | 1 | 36 | 2 | 47 | 2 | 57 | 3 |

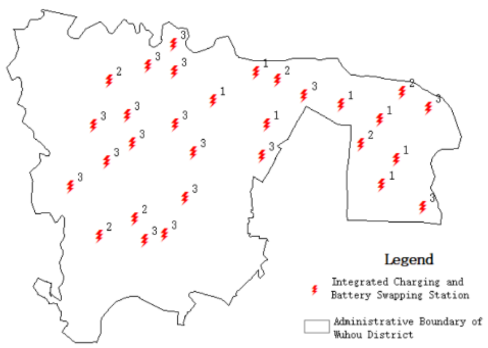


Figure 4. Spatial distribution map of built stations

DOI: 10.54254/2754-1169/2025.31083

## 4. Conclusions

This paper conducts research on the location and capacity determination of centralized charging and battery swapping stations for electric bicycles. A comprehensive cost minimization model centered on operators' construction, operation, and operation loss costs as well as users' travel and waiting time costs is established, and an empirical analysis is carried out in combination with the demand scenario of Wuhou District, Chengdu City. The SA-PSO hybrid optimization algorithm is used to solve the model to obtain the locations and capacities of the stations. The results show that when 30 centralized charging and battery swapping stations for electric bicycles are built, the total cost under the optimized scheme is 5.0951 million yuan. This study provides theoretical support and practical reference for the scientific planning of electric bicycle charging and battery swapping facilities. However, the model does not consider the impact of factors such as traffic flow and power grid load fluctuations on station location. Future research will further integrate multi-source data and deepen the research on multi-subject collaborative optimization to enhance the applicability and decision support capability of the model.

## References

[1] Sun, X. H., & Huang, C. Y. (2024). Empirical study on location and capacity determination of battery swap cabinets for food delivery electric bicycles. Journal of Transportation Systems Engineering and Information Technology, 24(1), 230-239+252.
[2] Shuai, C. Y., Xu, G., He, M., et al. (2021). Location of electric bicycle battery swap cabinets under uncertain demand based on urban POI clustering. Journal of Chongqing University of Technology (Natural Science), 35(7), 169-175.
[3] Zheng, H. J. (2024). Collaborative optimization of battery swap cabinet location and vehicle routing in food delivery scenarios [Doctoral dissertation, Zhejiang University of Finance & Economics].
[4] Shuai, C. Y., Yang, F., Ouyang, X., et al. (2021). Data-driven prediction of electric bicycle battery swap demand. Journal of Transportation Systems Engineering and Information Technology, 21(2), 173-179.
[5] Shuai, C., Ruan, L., Chen, D., et al. (2025). Location optimization of charging stations for electric vehicles based on heterogeneous factors analysis and improved genetic algorithm. IEEE Transactions on Transportation Electrification, 11(1), 4920-4933.
[6] Wang, X. (2024). Research on battery swap demand prediction and location based on ride-hailing orders and POI analysis [Doctoral dissertation, Chongqing Jiaotong University].
[7] Zhang, Y., Liu, X., Wei, W., et al. (2020). Mobile charging: A novel charging system for electric vehicles in urban areas. Applied Energy, 278, 115648.
[8] Bin, T. (2024). Modeling and solution for location and capacity determination of hybrid charging and battery swap stations for electric vehicles [Doctoral dissertation, Chongqing Jiaotong University].
[9] Li, H., Tong, P., & Zhang, X. (2022). Method for determining the location of highway passenger transportation hubs using POI data and the Dijkstra Algorithm in large city. Mathematical Problems in Engineering, 2022, 1-12.