Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 13, No. 3, 2024

Summary of Research on Electric Vehicle Charging Station Planning

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Abstract: Electric vehicles (EV), as a low-carbon and environmentally friendly means of transportation, have rapid evolution in recent years. The insufficient and uneven distribution of charging infrastructure has become a significant factor limiting the progress of electric vehicles. This paper reviews the current research results from two aspects of public and private transportation, focusing on the model construction of charging station location and the selection and optimization of solving algorithms. In the aspect of public transportation, the charging schedule of night station charging and BOT mode operation of fast charging facilities are introduced. Private transportation mainly introduces a variety of charging station location models, such as the model based on user random behavior, the model based on user dynamic demand, and analyzes their advantages and disadvantages; The algorithm and optimization method of solving the model are discussed and analyzed. The findings indicate that in building the urban charging station model, taking into account the interests of society, charging station contractors, and users is essential, and take into account the price of urban land, the price of electricity at different times, and the flow of vehicles, so as to make the model that better aligns with the actual situation. The research offers a valuable reference for the investigation of EV charging station planning.

Keywords: Electric vehicle; Charging station planning; Particle swarm optimization; Charging requirements.

1. Foreword

At present, due to the increasingly serious problems of global warming and environmental pollution, electric vehicles, as a low-carbon and environmentally friendly means of transportation, have experienced rapid development in recent years. In recent years, Due to the ongoing advancements and development in electric vehicle technology, coupled with the relentless promotion of national policies, the electric vehicle market has witnessed swift growth. According to statistics, according to the report of the International Energy Agency (IEA) in 2022, by 2021, In China, the sales volume of electric vehicles has attained 3.3 million, surpassing the worldwide sales figure of electric vehicles in 2020, which was 3 million [1] . Electric vehicles have not only successfully promoted the transformation and upgrading of the automobile industry, but also brought new development opportunities for the traditional automobile industry, and also made positive contributions to decreasing greenhouse gas emissions, enhancing urban air quality, and fostering sustainable development.

However, the popularization and further development of electric vehicles have also encountered obstacles, among which the insufficient number and uneven distribution of charging infrastructure has become one of the key factors restricting its further development. As an important support for the operation of electric vehicles, the number, layout and charging efficiency of charging stations directly affect the charging convenience and satisfaction of electric vehicle users, which in turn affects the promotion and application of electric vehicles. According to statistics, in 2021, the number of electric vehicles held in China has reached 7.94 million, while the number of charging piles is only 2.617 million, but the actual number of public charging piles is only 1.147 million, far from achieving the preset goal [2] of "pile 1:1". Therefore, how to scientifically plan the location determination for electric vehicle charging stations, so that choosing the right location for charging stations can optimally fulfill users' charging requirements, while controlling the cost and improving the convenience of charging, has become the focus of current scholars' research.

Ev charging station planning is a complex issue involving multiple interests, which needs to consider user needs, charging convenience, social interests, charging station contractor interests and many other aspects [3]. At the sametime, factors such as the price of different plots in each city, the price of electricity at different times, and the traffic flow at different intersections also need to betaken into account to bring the model closer to reflecting the actual situation. Therefore, after the successful construction of the urban charging station model, it is still necessary to select the appropriate solution algorithm and refine it to enhance the precision and effectiveness of the resolved charging station planning.

This paper will start from two aspects of public transportation and private transportation, divided into the following three parts: (1) Introduce the problem of charging station planning in the field of public transportation, and discuss the research results of charging scheduling and BOT mode operation of fast charging facilities; (2) It discusses the arrangement of charging stations within the private transportation sector, mainly introduces a variety of charging station location models such as the model based on user random behavior and the model based on user dynamic demand, and analyzes their advantages and disadvantages; (3) Then the algorithm and optimization method of solving the model are discussed and analyzed. Based on the above three parts, this paper summarizes some research results about the recent planning of electric vehicle charging stations.

2. Public Transport

2.1. Charging schedule at night yard and station

Public transport is different from private transport. Public transport vehicles have specified operating hours and routes when they are in operation. Therefore, within the realm of public transportation, electric bus charging station planning possesses its own distinctiveness and intricacy. The vehicles of public transportation have the significant characteristics of large number, long operation time and large charging demand. The planning of public transport charging stations should not only meet the charging demand of vehicles, but also consider the construction cost, operation efficiency and the impact on urban traffic.

Nighttime station charging is an effective charging scheduling method. This is because the operation time of most buses is generally between 6:00 and 22:00. At night, buses usually stop at fixed stops and can use this idle time to recharge. Charging at night cannot only make full use of idle time, but also avoid the peak period of charging during the day and reduce charging costs. At the sametime, nighttime charging can also take advantage of low electricity prices to further

reduce operating costs.

In addition, since a single charging pile can meet the charging needs of more than one electric bus, it is not necessary to set all the bus stations as night charging stations, so that some electric buses can stop at non-charging stations and wait for other electric buses that are charging to complete the charging, and accept unified scheduling to the charging station for charging. In this way, the effect[4] of a charging station charging pile parking space serving multiple electric buses can be realized.

Therefore, night station charging has been widely used in the arrangement of charging stations in the public transportation sector.

2.2. Fast charging facilities in BOT mode

In addition to charging at night terminals, quick charging facilities can also be used to charge electric buses. Instead of charging at night stops, buses can be charged at the fast charging facilities during the day. In this case, the bus does not need to stay at a certain fast charging facility for a long time, and can go as it is charged. And because the bus operation has the characteristics of a specific route, that is, the fast charging facilities are set up at the first place and the destination of the route, so that the electric buses can use the facilities to charge during the interval of operation. Therefore, the fast charging facility is of great significance to the charging of public transportation.

However, even if the use of fast charging facilities will significantly improve the charging efficiency of electric buses, the investment of quick charging facilities per unit is very expensive, and the bus operators are likely to lack the experience and expertise related to fast charging planning and operation during the process of bus electrification, and may face the problem[4] of limited capital budget. Therefore, for bus operators,a very practical way is to seek the BOT (build-Operate-transfer) model[5] .

BOT, or "build-operate-transfer" model, is a collaboration between public and private sectors approach. The government can provide land and certain policy support to attract private capital to invest during the building of charging stations. During the operation period, private enterprises have the responsibility for operating and maintaining the charging stations and receive certain benefits. After the contract expires, charging stations can be transferred to the government or other agencies to continue operation. This approach can not only reduce the financial pressure on the government, but also introduce a market competition mechanism and enhance the effectiveness of building and managing charging stations. Under the BOT model, the government and enterprises can jointly share risks, realize resource sharing and complementary advantages, and promote the construction and expansion of electric vehicle charging facilities within the public transportation industry.

2.3. Other considerations

When planning charging stations in the public transportation sector, you also need to Think about the configuration of charging stations and the installation of the charging apparatus. The distribution of charging stations. should match the location of public transport lines and stations to ensure that vehicles can be easily and quickly charged. At the same time, the configuration of charging devices should also be selected and optimized according to the type of public transport vehicles and their charging needs. For example, for vehicles that need fast charging, high-power charging devices can be configured; For vehicles that need long-term parking, multiple charging plugs can be configured to meet the charging needs of different vehicles.

In addition, when planning charging stations in the public transportation sector, It is also essential to take into account the interplay and coordination between charging stations and smart grids. Smart grid can realize intelligent management and optimized scheduling of charging stations, and improve charging efficiency and reliability. For example, using smart grids for charging scheduling can reasonably arrange charging time and electricity according to the grid load and electricity price, reducing charging costs and the impact on the grid.

3. Private Transportation

3.1. Based on spatial-temporal distribution of charging demand

3.1.1. Influencing factors of spatial and temporal dissemination

(1) Types of electric vehicles Private transportation vehicles are mainly divided into private cars and taxis

(2) The functional division of urban areas is mainly divided into residential areas, commercial areas, work areas and public service areas

(3) User behavior habits The traveling time of electric vehicles is shown in Figure 1

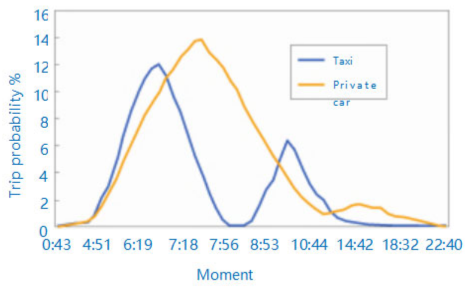

Figure 1. Probability distribution curve of electric vehicle travel time[5]

3.1.2. Charging demand forecasting process

According to the references[6], the specific process is as follows

(1) Firstly, data such as urban road network structure, traffic flow at different periods, vehicle type and quantity are introduced.

(2) Generate the initial SOC, initial position Oi and initial time ts corresponding to each vehicle by Monte Carlo method.

(3) In the urban traffic network, vehicles find the corresponding period transfer probability matrix according to the ts path at the initial time to generate the destination Dj, and use Dijkstra algorithm to plan the driving path.

(4) In the simulation process of EV driving, the real-time road speed is calculated according to the speed-flow model, and the EV electricity is updated in real time according to the unit mileage energy consumption model for each section to determine whether the charging threshold is reached. Once the threshold is reached, record the position of the period and charge nearby.

(5) Compute the EV charging requirements for each node during various time intervals in order to accomplish the forecasting of spatial-temporal distribution of charging demand.

The flowchart is shown in Figure 2

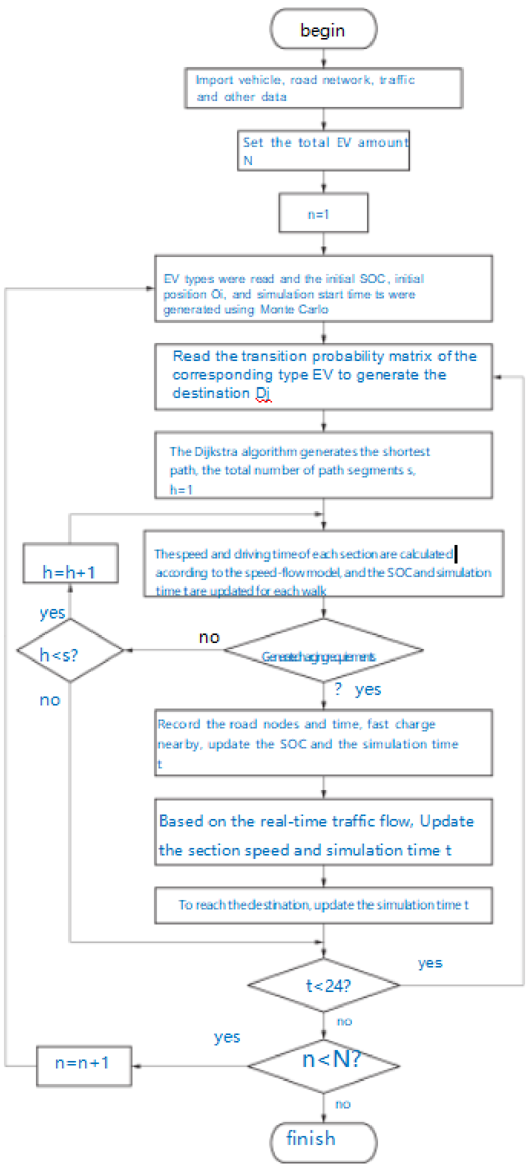

Figure 2. Prediction process of EV charging demand[6]

Dijkstra algorithm:

The Dijkstra algorithm was proposed by Dutch computer scientist Edsger W. Dijkstra in 1956. An algorithm is employed to determine the shortest route within a graph, capable of computing the shortest path from a single node to all other nodes. This algorithm works for both directed and undirected graphs that contain non-negative weights.

Steps:

1) Initialization Phase: Choose the beginning node in the graph, assign a shortest path estimate of 0 to this starting node, and set the shortest path estimate for every other node to infinity. Additionally, mark every node as not yet visited.

2) Assign the current node: Determine the node with the smallest estimated distance from the set of unvisited nodes and designate it as the current node..

3) Update the estimate: For each adjacent node of the current node, calculate the path length through the current node to that adjacent node. If the calculated path length is less than the current estimate for that adjacent node, update the estimate for that adjacent node and set its predecessor node to the current node.

4) Iterate Steps 2 and 3: Continue repeating Steps 2 and 3 until all nodes are marked as accessed.

5) Calculate the shortest path: After the algorithm is finished, the shortest path from the starting point to any node can be obtained by backtracking the predecessor node.

3.2. Consider the user's dynamic charging needs

3.2.1. Building the model

The travel chain can better simulate the travel characteristics of private cars and use Dijkstra algorithm to simulate the travel process of private cars, compute the distance between users and charging stations, as well as the distance to the final destination after charging, select the shortest path, and develop a charging station model that takes into account the changing demands of users [7].

3.2.2. Solving the model

The following steps are required in the solving process [7] :

1) Consider the constraints of charging pile configuration, queue waiting time and coverage strength of charging station;

2) Based on the number of charging stations M, a list of potential charging station locations and their combinations is provided, and the candidate station site combination meeting the constraint is screened out.

3) Through dynamic simulation of charging station demand model by Monte Carlo method, the fast charging demand information of charging station of candidate station combination was obtained;

4) Utilizing queuing theory, particle swarm optimization is applied to determine the optimal capacity configuration for charging stations, aiming to minimize the objective value. The process must meet the constraint conditions of sum.

5) Based on the computation of the yearly overall economic cost F for each combination of candidate charging station locations, The ideal planning for the combination of charging station locations and their respective capacities is derived from the model.

3.2.3. Analysis of results

The model based on the dynamic charging demand of users is not the lowest compared with other schemes, but the comprehensive cost is the most advantageous. The model can fully consider the interests of users and charging station operators.

3.3. Consider the user's random behavior

3.3.1. User charging decision-making behavior

The user's charging decision-making behavior is divided into taxi and private car. Taxi is generally in the state of seeking passengers and carrying passengers. Taxi drivers will choose the nearest charging station to charge and find passengers as soon as possible.

Private cars, on the other hand, generally, the distance between the present location and the charging station is taken into consideration, along with the distance from the charging station to the final destination. The queuing theory model can be used to establish the charging station selection model of taxis and private cars [8].

In the process of building the model, the sum of the construction cost, operation and maintenance cost, the total social cost is determined by selecting the user's travel cost and the cost incurred by the charging station on the distribution network. The flowchart is shown in Figure 3:

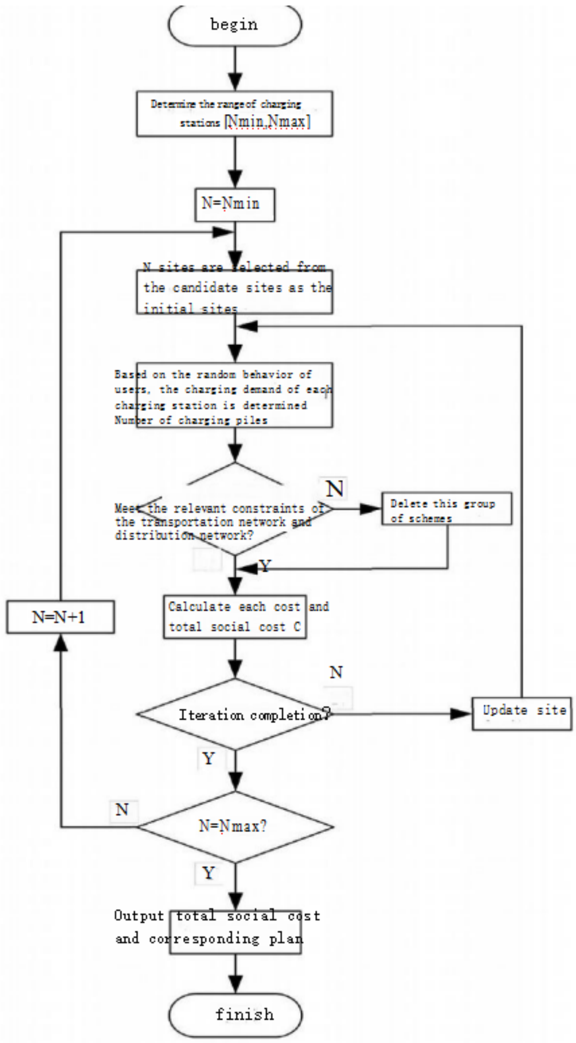

Figure 3. Charging station planning flowchart [8]

4. Model Solving

4.1. Particle Swarm algorithm

The particle swarm algorithm is primarily employed in current research on EV charging station planning to address the established model for urban charging stations.

4.1.1. The concept of particle swarm optimization

Particle Swarm Optimization (PSO), also known as particle swarm optimization (PSO), Is a new Evolutionary Algorithm (EA) developed in recent years by J. Kennedy and R. C. Eberhart. PSO algorithm belongs to a kind of evolutionary algorithm, similar to simulated annealing algorithm, it also starts from random solutions, finds the optimal solution through iteration, and evaluates the quality of the solution through fitness, but it is simpler than genetic algorithm rules, and it does not have the "Crossover" and "Mutation" operation of genetic algorithm. It finds the global optimal by following the optimal value found in the current search. Due to its benefits of straightforward implementation, high accuracy, and rapid convergence, this algorithm has garnered attention within academic circles and has proven its superiority in addressing real-world issues. Particle swarm optimization falls under the category of parallel algorithms.

4.1.2. Principle of PSO algorithm

PSO emulates the behavior of birds in a flock by creating a massless particle that possesses merely two attributes: velocity and position, velocity indicating how fast it is moving, and position, indicating the direction it is moving. In the search space, each particle independently seeks out the optimal solution and documents it as its present individual extreme value, and shares the individual extreme value with other particles in the whole particle swarm, and it identifies the optimal individual extreme value as the present global optimal solution for the entire particle swarm. Every particle within the swarm modifies its velocity and position based on its discovered current individual extreme value and the current global optimal solution that is shared by the entire swarm.

4.1.3. Steps of PSO algorithm

1) Initialize particle swarm: Randomly generate a swarm of particles and randomly assign an initial position and speed to each particle.

2) Determine the fitness value for each particle by utilizing the problem's fitness function.

3) Revise the individual optimal position: Evaluate the fitness of each particle's present position against its historical optimal position, and if the current position is superior, update the individual optimal position accordingly.

4) Update the group optimal position: Examine the individual optimal positions of all particles and choose the one with the highest fitness as the global optimal position.

5) Adjust the velocity and position of each particle: Adjust the velocity and position of each particle by considering both its individual historical optimal position and the global optimal position.

6) Evaluate the termination criteria: Determine if the termination condition has been satisfied, for instance, if the maximum number of iterations has been reached or if a satisfactory solution has been found.

7) Iterative search: If the termination criteria have not been met, return to step 3 and repeat the process until they are satisfied.

4.1.4. Advantages and disadvantages of PSO

Advantages:

Straightforward and uncomplicated to execute: The principle of the particle swarm algorithm is straightforward and simple to program as well as implement.

Strong global search ability: By enabling particles to cooperate and share information, the algorithm achieves a better balance between global and local search.

Fast convergence: Through the collaboration and information exchange among particles, the algorithm strikes a more effective equilibrium between global and local search capabilities.

It is suitable for solving optimization problems in multidimensional space.

Disadvantages:

1) It is prone to getting trapped in local optima: In the context of complex or high-dimensional problems, particle swarm optimization might get stuck in local optimal solutions, preventing it from discovering the global optimal solution.

2) Sensitive parameter setting: the performance of the algorithm is greatly affected by parameters such as inertia weight and acceleration factor, and these parameters need to be set reasonably to obtain better optimization results.

4.2. Optimization Method

The basic particle swarm optimization algorithm tends to converge towards local optimal solutions during the early stages of iteration and fluctuation around the global optimal solution during the later stages of iteration [9], There is a need to enhance the algorithm in order to boost its computational speed and global search capabilities. [10].

4.2.1. Optimization of genetic algorithm

Considering the propensity of PSO to become trapped in local optima, a genetic algorithm is selected to optimize PSO. The global searching capability of GA is employed to decrease the likelihood of PSO getting stuck in local optima.

The specific steps areas follows:

1) Initialize

Particle swarm initialization: To begin, randomly assign the initial position and velocity of the particle swarm according to the problem's dimensions and constraints. Each particle's position signifies a potential solution, and the velocity represents the direction and rate at which the particle will move through the solution space.

Genetic algorithm parameter setting: At the same time, Determine the pertinent parameters for the genetic algorithm, including the population size, crossover rate, and mutation rate, etc.

2) Fitness evaluation

Assess each particle within the swarm and compute its corresponding fitness value. The fitness function, tailored to the specific requirements of the problem, is utilized to evaluate the quality of the solution that each particle represents.

3) Update the particleswarm

Adjust the velocity and position of each particle in accordance with the typical procedure of the particle swarm algorithm. This process typically entails each particle keeping track of its personal best position and the global best position, along with employing iterative update equations for its velocity and position.

4) Genetic manipulation

Selection operation: Choose a subset of particles from the refreshed particle swarm to serve as the parent population for the genetic algorithm. Particles are selected based on their fitness values, with those exhibiting higher fitness having a greater likelihood of being chosen.

Cross operation: Cross operation is performed on the selected parent particle to generate a new child particle. The crossover operation simulates the genetic recombination during biological evolution and helps to generate new regions of solution space.

Mutating operation: Mutating operation is performed on the child particle to randomly change certain characteristics of the particle with a certain probability. The mutation operation enhances population diversity and aids in preventing the algorithm from converging to a local optimum.

5) Iterative optimization

Repeat the fitness assessment, particle swarm update, and this process continues until a predefined termination condition is satisfied, which could be reaching the maximum number of iterations, a fitness value reaches a certain threshold, or other specific convergence criteria are met.

6) Result output

Output the optimal particle and its corresponding solution as the optimization result. This optimal solution was found through the combined action of genetic algorithm and particle swarm algorithm, combining the advantages of both algorithms.

4.2.2. Multi-objective particle swarm algorithm

Multi-objective particle swarm optimization (MOPSO) algorithm is a commonly used optimization algorithm. It is a multi-objective optimization algorithm proposed by Coello etc. [11] in 2002. By combining PSO algorithm with Pareto idea,The MOPSO algorithm is expanded to handle multi-objective optimization problems.

The primary goal of the multi-objective improved particle swarm (MOIPSO) algorithm's optimization process is to enable particles within the swarm to continually update their positions and velocities by leveraging information shared among them, In this way, the particles progressively approach the global optimal solution, ultimately achieving it [12].

The solution steps of MOIPSO algorithm areas follows [13]:

1): The velocity, position and Archive set of each particle areinitialized;

2): Compute the objective function value for each particle in the intermediate population, store the non-dominated solutions in the Archive set based on their domination relations, and initialize the personal best (pbi) and global best (gbi) values for each particle;

3): Particles' velocities and positions are updated in accordance with the respective update formulas;

4): Compute the objective function value for the particle and compare it to its personal best (pbi) from the previous iteration, andre-adjust i;

5): Refresh the Archive set and ascertain the present global optimal solution (gbi);

6): Assess whether the termination condition has been met; if so, output all optimal solutions contained within the Archive set, otherwise return 3).

Multi-objective improved particle swarm optimization has many advantages:

1) MOIPSO algorithm can process multiple objective functions at the same time, and identify a collection of Pareto optimal solutions.; 2) The solution possesses diversity, which helps maintain the variety within the solution set and prevents convergence to a local optimum; 3) Fast convergence, MOIPSO algorithm also shows a fast convergence speed when solving multi-objective optimization problems.

5. Summary and Prospect

This paper summarizes the research progress of EV charging station planning, discusses the model construction of charging station location and the selection and optimization of solving algorithm from two aspects of public transportation and private transportation. In the aspect of public transportation, the paper introduces the research results of charging schedule of night station charging and fast charging facilities under BOT mode. In terms of private transportation, it mainly introduces a variety of charging station location models such as the model based on user random behavior and the model based on user dynamic demand, and evaluates their respective strengths and weaknesses. At the same time, the algorithm and optimization method of solving the model are discussed and analyzed.

The findings indicate that when developing the urban charging station model, it is essential to take into account the interests of society, charging station contractors, and users, and take into account the price of land in the city, the price of electricity at different times, the flow of vehicles and other factors to make the model more close to the actual situation. At the sametime, taking the user's behavior and demand into account when constructing The model is capable of enhancing the efficiency of the charging station and reduce the comprehensive cost. By taking these factors into consideration, EV charging stations can be planned more scientifically and reasonably to meet the growing charging demand, improve the convenience of charging, and promote the popularity and development of EV.

In the future research, the problems and challenges of EV charging station planning can be further explored. More diversified ways to build charging stations can be considered, such as transforming and upgrading existing gas stations, parking lots and other resources. Simultaneously, it is crucial to ensure the coordination between EV charging station planning and urban transportation planning and land use planning, etc., to ensure that the layout and construction of charging stations meet the overall requirements and standards of urban development.

In addition, geographical factors can also be taken into account, such as the temperature and humidity in different latitude and longitude areas have a significant gap, and the demand for charging of electric vehicles in these areas is also different. Furthermore, the planning of charging stations should be adapted accordingly to cater to the needs of local users.

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