J. COMBIN. MATH. COMBIN. COMPUT. 127b (2025) 255--277

Journal of Combinatorial Mathematics and Combinatorial Computing
www.combinatorialpress.com/jcmcc

Charging station siting method based on variable neighborhood genetic algorithm

Huanyong Zhang[1], Guoqing Cheng[1,✉]

[1] School of Business, Jiangnan University, Wuxi, Jiangsu, 214122, China

ABSTRACT

In recent years, the scale of the electric vehicle industry and social ownership are gradually growing, in the case that the charging facilities are not yet able to meet the demand for electric vehicle charging. Aiming at the situation described above, the research of charging station siting supported by variable neighborhood genetic algorithm is proposed. Based on the principle of charging station siting, the objective function and constraints are set, and the design of charging station siting model is realized. It is found that the traditional genetic algorithm, which has the problem of poor search ability, adopts the variable neighborhood genetic algorithm to solve the model. Calculated, this paper's algorithm in the charging demand peak period scenario, to determine the optimal charging station site selection there are four, the two objective function value of 0.94, 0.98, both in the charging peak period or the low peak period, this paper's method compared to the traditional genetic algorithm has a higher superiority.

Keywords: variable neighborhood genetic algorithm, charging station siting model, objective function, constraints

1. Introduction

Electric vehicles (EVs) have received increasing attention from the energy and power industries due to their low operation and maintenance costs and their ability to significantly reduce carbon emissions. The location of new energy EV charging stations is crucial for the popularization and promotion of new energy vehicles [1-3]. Nowadays, the environment is suffering from serious damage, and petroleum fuel, which is one of the non-renewable resources, is decreasing with the increase of automobile ownership [4]. However, a new travel tool, new energy electric vehicle, has emerged, which has the characteristics of cleanliness and higher cost-effectiveness [5]. The travel of new energy electric vehicles cannot be separated from the construction of charging facilities, but the imperfection of charging infrastructure leads to the limitation of the use of electric vehicles [6-7]. Therefore,

✉ Corresponding author.
E-mail address: c2803568296@163.com (G. Cheng).
Received 29 June 2024; Revised 15 September 2024; Accepted 20 January 2025; Published Online 16 April 2025.
DOI: 10.61091/jcmcc127b-016

conducting a reasonable and scientific layout of charging station siting can provide users with convenient charging services and further promote the popularization of new energy electric vehicles. The location of charging stations has an important impact on the urban development and the improvement of traffic conditions [8-9].

Reasonable or not, the location of charging station directly affects the experience of new energy electric vehicles and transportation efficiency. New energy electric vehicle charging station siting has a positive contribution to economic development and sustainable energy utilization [10-11]. The construction and layout of charging infrastructure is a huge project that requires a large amount of capital and resources [12]. With the popularity of power exchange stations, it also causes some impact on the existing charging stations in certain areas, so through scientific and reasonable siting scheme, it can maximize the use of existing resources, reduce the construction cost, lower the price of charging services, and further promote the development of new energy EVs and sustainable energy utilization [13-15]. With the rapid increase in the number of EVs, the growing loads and the access of EV charging stations bring great challenges to the stable operation of the distribution network [16]. Among them, the siting of EV charging stations has a significant impact on the power loss, voltage distribution, and harmonic distortion of the distribution network; therefore, optimizing the siting and capacity allocation of EV charging stations is crucial for maintaining the stable operation of the distribution network [17-18].

Literature [19] envisioned a two-layer planning model with EV range as the core logic, and introduced a heuristic algorithm to further linearize it, and finally the feasibility was verified by two experimental networks. Literature [20] elaborated that the reasonable planning of charging station siting can reduce the cost of electric vehicles, and systematically reviewed the relevant literature research on charging station siting, which made a positive contribution to the reform and innovation of charging station siting. Literature [21] conceptualized a charging station siting decision support framework, focusing on screening charging station siting areas rather than specific locations, and used the proposed framework in practice, making positive contributions to charging station siting work. Literature [22] designed a distributed energy charging station siting model with road network and power grid as the underlying architecture, and then tested the reliability of the proposed charging station siting model by simulation simulation of a network consisting of an IEEE 33-node distribution network and a 25-node transportation system. Literature [23] constructed a total social cost model and a charging station siting optimization framework composed of genetic algorithm, respectively, which effectively solved the problem of minimizing the operating cost under the constraints of power consumption per unit distance of the charging station and the probability of vehicle charging. Literature [24] transformed the charging station siting problem into a two-layer integer planning model based on the range anxiety function, and solved the model by using an adaptive large neighborhood search method, and verified the parameters with reference to the actual road network background. Literature [25] conceptualized a full-coverage model to solve the optimal charging station siting problem and tested it on a benchmark data set, confirming that the proposed model outperforms traditional methods in terms of siting capability. The above research, the proposed charging station siting model has made positive contributions to the charging station siting cause, however, the research exploring the advanced variable-neighborhood genetic algorithm in charging station siting is relatively blank.

In this paper, under the requirement of charging station siting principle, the maximum satisfaction of electric vehicle users and the highest convenience of charging station service are taken as the objective function of this paper's model, in addition to setting the corresponding constraints, the charging station siting model is constructed. When the traditional genetic algorithm is used to solve the model, problems such as weak search ability occur, in order to further enhance the local search ability of the genetic algorithm, variable neighborhood search (VNS) is added on the basis of the traditional genetic algorithm, which constitutes the variable neighborhood genetic algorithm. City A is selected as the case region, and the model of this paper is case analyzed by combining the actual situation of the region.

2. Principles of Electric Vehicle and Charging Station Siting

2.1. Overview of Electric Vehicles and Charging Stations

2.1.1. Overview of Electric Vehicles. An electric vehicle (BEV) is a vehicle that is powered by an on-board battery and meets the requirements of road traffic and safety regulations. In 2001, the key technology project for the independent development of electric vehicles was launched. Driven by the scientific and technological research of the two Five-Year Plans, as well as the implementation of demonstration projects such as the Olympic Games, the World Expo, and the “Ten Cities, One Thousand Vehicles” project, BEVs started from scratch, and have now established a perfect electric vehicle power system technology system and industrial chain. According to the Ministry of Public Security statistics, as of the end of 2023, the national motor vehicle ownership amounted to 453 million vehicles, of which 295 million fuel vehicles, new energy vehicle ownership of 8.12 million, accounting for 2.75% of the total number of cars, pure electric vehicle ownership of 7.25 million, accounting for 89.29% of the total number of new energy vehicles. Excessive emissions of carbon oxides, nitrogen oxides and haze particles and other harmful substances in the exhaust of traditional fuel vehicles have caused serious urban pollution problems. And electric vehicles are almost zero emission, which can greatly reduce the pollution of the environment. In the current global energy crisis and environmental problems are becoming increasingly serious situation, the government and the entire automotive industry are aware of the development trend of energy saving and environmental protection. At present, the development of electric vehicles is in an active period. High-efficiency, low-noise, zero-emission and zero-pollution electric vehicles have advantages in environmental protection and energy saving that cannot be compared with other traditional fuel vehicles.

2.1.2. Overview of Electric Vehicle Charging Stations. Car charging station is a place for charging electric vehicles. With the popularization of electric vehicles, the construction of automobile charging facilities will become the main development trend of the automobile industry and energy industry in the future. According to the data of China Business Industry Research Institute, by the end of 2023, the national public and private charging pile ownership totaled 5,125,700 units, up 72.33% year-on-year, of which 3,888,000 public charging piles, up 61.37% year-on-year, and the public charging piles have 1,935,300 DC charging piles and 1,952,700 AC charging piles. The charging pile with vehicle accessories (private charging pile) 1,236,900 units. The existing vehicle-to-pile ratio is about 4.1:1. According to the international general requirements, to completely solve the problem of inconvenient charging of new energy vehicles, the vehicle-to-pile ratio should reach 1:1, which means that the vehicle-to-pile ratio of new energy vehicles and charging piles has not yet reached the level of planning.

There are three types of charging methods for charging stations: normal charging, rapid charging and battery replacement. The following are three charging methods.

1) Ordinary charging: AC electric vehicle charging pile, also known as “slow charging”, the input voltage is 220V, charging power is generally 9kw, fully charged in about 6-22 hours, mainly used in the community private charging. AC charging pile is small in appearance, there is a portable installation-free socket for direct use, and simple structure, small size, can be wall-mounted on the wall. Electric vehicles generally choose to charge at night, this time for the electricity trough time period, slow charging mode can also be better protection of the battery, you can extend the service life of the battery to a certain extent.

2) Fast charging: also known as “fast charging”, is a kind of electric power system fixed on the outside of the electric vehicle, and connected to the electric power system of the electric power system for non-electric vehicle power system to provide DC power. The input voltage of DC charging station is

380V+15% AC, and the power is usually above 60kw. DC charging can be charged to 80% in half an hour, and then, in order to protect the battery, the current will become smaller, and it will take a longer time to charge to 100%. DC charging piles are suitable for places with urgent charging needs, and fast charging piles are best set up in urban commercial centers or highway service stations and other similar scenarios.
3) Battery Replacement: Adopting the method of replacing the power battery to charge the car battery. That is, when the power battery runs out of power, the fully charged battery is used to replace the battery pack with one that is too low, and the replaced battery is sent to the power station for slow charging and recharging. The advantages of this charging method is that the battery replacement is convenient, short time, in the acquisition of electric vehicles only to buy a bare car, the subsequent battery can be used in a rental mode, this way of centralized management of the battery, regular maintenance, can extend the service life of the battery. The disadvantage is that the set of supporting facilities construction costs are high, and to ensure that all types of models of batteries consistent.

2.2. Principles of charging station site selection

The selection of charging stations must be fully considered to comply with the overall layout of the whole city and the planning of the power network, and also to ensure the balance, quality and stability of the power supply. This paper summarizes the principles of charging station siting in conjunction with relevant government plans and regulations:

2.2.1. User needs-oriented. A reasonable charging station should be constructed to meet the charging needs of the users in the area where it is built. The charging of electric vehicles should take into account both the density of electric vehicles in the city and their driving patterns. Try to ensure that the capacity of the charging station is distributed so that it is proportional to the density of the power system in each area. Therefore, when planning charging stations, it is important to take into account both regional supply and demand, as well as the spatial distribution of the city, so as to adapt to the operational needs of the local power system.

2.2.2. Implementing differentiated services and business models. According to the demand for charging stations in the region, the planning requirements of the region to establish charging stations, to ensure that the configuration of the equipment in each region has reached a reasonable size or a similar degree of density, so as to achieve a balance of charging stations in the region. Taking into account the impact of battery life and traffic congestion and other issues, in order not to affect the user's driving, it is recommended that the service radius of the charging station is set at 153 km. the central charging station service area can radiate a radius of 80 to 160 square kilometers, the service range of 4 to 9 kilometers.

2.2.3. Site selection should take advantage of the situation. Sites should be selected to take advantage of the situation and to economize on the use of land. Consider the diversity of charging stations when considering the construction of a separate central charging station, such as a combination of public charging stations and dedicated charging stations. Public charging stations are usually set up in large business places, hospitals and other areas with high traffic flow, while dedicated charging stations are set up in neighborhoods, service areas and other areas with low traffic flow.

2.2.4. Compliance with the overall urban plan and safety of the road network. The planning and design of charging stations is based on a comprehensive analysis of the needs of charging stations in various regions, while in practical application, the location of charging stations needs to be determined according to the actual situation of the city. The security of the power grid is also fully considered during the construction of the charging station, and the safety of the charging station is ensured during its use by assessing the local demand for electricity at the time of construction.

2.2.5. Compliance with relevant regulations on siting sites. The construction of charging stations should meet national regulations on the safety of charging facilities and should comply with construction-related laws and regulations, the floor area should comply with relevant regulations, and permission from neighboring households and the government must be obtained for construction. In order to ensure the safety of charging stations, charging stations should be set up in places where the power grid, transportation, fire protection and other infrastructures are more complete to ensure the safe operation of charging stations.

3. Model construction and solution

3.1. Charging station siting model

At present, we are in the predevelopment stage of the electric vehicle industry, and electric vehicles have not yet been popularized. In order to popularize electric vehicles and increase the purchase willingness of electric vehicle users, we should prioritize the position of users when selecting the location of charging stations. This subsection stands on the perspective of charging station siting principles, considers the user's satisfaction with the charging station and the service convenience of the charging station to the user, and establishes a charging station siting model based on satisfaction and service convenience. It is summarized as follows:

3.1.1. User satisfaction and convenience of charging station services. The EV user satisfaction function describes the relationship between objective distance and subjective evaluation of EV users. The model of electric vehicle user satisfaction is as follows:

$$F(d_{ij}) = \begin{cases} 1 & d_{ij} \le L_i \\ \frac{1}{2} + \frac{1}{2}\cos\left(\frac{\pi}{U_i - L_i}\left(d_{ij} - \frac{U_i + L_i}{2}\right) + \frac{\pi}{2}\right) & L_i < d_{ij} \le U_i \\ 0 & d_{ij} > U_i \end{cases} \tag{1}$$

In Equation (1), L_i is the lower limit of the distance between demand point i and point j to be taken. U_i is the upper limit of the distance between demand point i and to-be-taken point j. d_{ij} is the distance between demand point i and pending point j. $F(d_{ij})$ is the EV user satisfaction rating value at demand point i. The relationship between EV user satisfaction rating value $F(d_{ij})$ and distance d_{ij} is shown in Fig. 1.

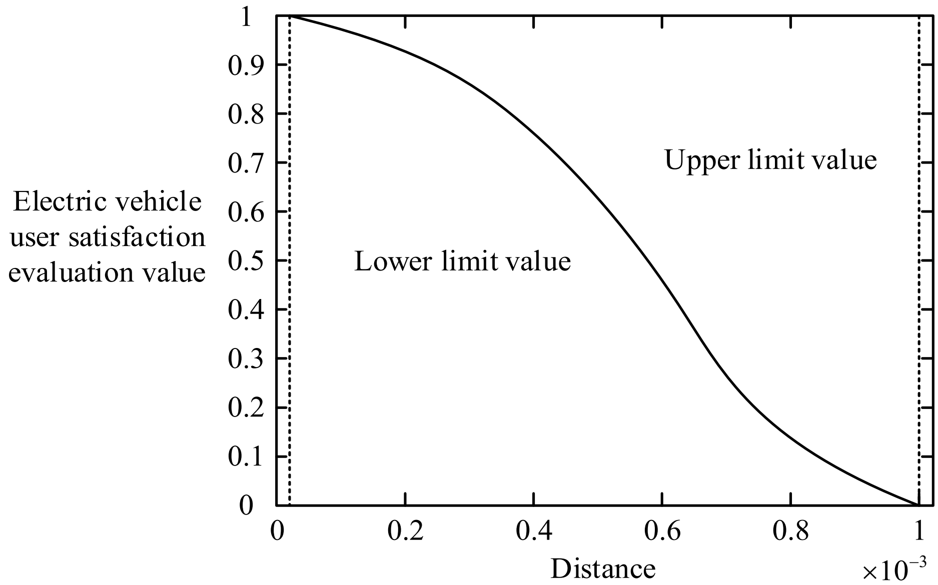

Fig. 1. User satisfaction evaluation function

If $d_{ij} < L_i, F(d_{ij}) = 1$, at this time, the user's satisfaction with the charging station pending pickup point for electric vehicles is the greatest. If d_{ij} is between L_i and U_i, the greater the distance between the demand point and the charging station to be picked up point, the lower the satisfaction of the electric vehicle users with the charging station to be picked up point. The smaller the distance between the demand point and the charging station to be picked up point, the higher the satisfaction of the electric vehicle users with the charging station to be picked up point. If $d_{ij} > U_i$, $F(d_{ij}) = 0$, then the user satisfaction with the electric vehicle charging station to be picked up point is minimized. Electric vehicle user satisfaction is inversely proportional to the distance between the demand point and the charging station to be picked up point.

Unlike power infrastructure such as power plants and substations, EV charging stations, as public infrastructure buildings serving the general public, should provide more convenient charging services for users while meeting the requirements of the overall layout of the city and power grid planning. Considering the maximum time that users can tolerate in searching for charging stations, the service radius of charging stations is determined as follows:

$$R = \frac{TV}{\partial} \tag{2}$$

In Equation (2), T denotes the maximum time a user can tolerate to search for a charging station. v denotes the speed of searching. ∂ denotes the traffic impedance factor. If the distance that can be traveled by an electric vehicle with a remaining charge SOC is less than R, the user's location is not within the service range of the charging station's pending pickup point. Therefore, the constraints of the service radius are:

$$R \leq \frac{20\%E}{W_{100}} \tag{3}$$

In Equation (3), E is the battery power. W_{100} is the 100-kilometer power consumption of electric vehicles. The actual distance of the service radius of the charging station can be converted to the Euclidean distance using Zhou Yuyang's method. The service area of the charging station is $S_j = \pi R^2$. Calculate the number of demand points within the service area of the EV charging station to be taken j as follows:

$$n_{ij} = count\left(S_i\right) \tag{4}$$

In Equation (4), S_i denotes the area of the demand point numbered i, and $S_i \subset S_j$ denotes the area of the demand point included in the area of the electric vehicle charging station surrogate pickup point j. Both subjective and objective factors determine whether the user enters the charging station for charging. The subjective factor is the maximum time the user can tolerate to search for a charging station. The objective factor is the distance an EV can travel with its remaining battery power. Users within the charging station's service area satisfy both the subjective and objective factors, and the service convenience of that EV charging station is determined by counting the demand for EVs that fall within the charging station's service area.

3.1.2. Basic assumptions. A site selection model is developed with the goal of maximizing the satisfaction of electric vehicle users and the convenience of charging station services. In order to facilitate quantitative research, the following assumptions are made in the modeling process:

1) The principle of proximity, users prefer to go to charging stations that are close to their location.
2) The demand point is an area of fixed size.
3) All electric vehicles have the same performance.
4) During the process of going to the charging station, the search speed of electric vehicles remains constant.
5) The demand at the point of demand is the same every day in the study area and is only related to the population size.

3.1.3. Objective function construction and constraints. Symbol Description:

i: Indicates the number of the demand point, $i \in n_i$.

n_i: Indicates the set of demand points.

j: Indicates the number of the point to be taken, $j \in n_j$.

n_j: Indicates the set of points to be taken.

I: Indicates the number of the demand point.

J : Indicates the number of points to be fetched.

a: Indicates the number of demand points in the service area.

P : Indicates the number of charging stations.

Y_{ij}: Decision variable.

Y_j: Decision variables.

Objective function 1: Maximum satisfaction of electric vehicle users.

In the modeling process, the magnitude of electric vehicle users' satisfaction with the charging station's to-be-taken points and the high demand of the demand points themselves are considered. Based on the electric vehicle user satisfaction model and the results of kernel density analysis, the charging station location function with the goal of maximum satisfaction is established as follows:

$$\max f_1 = \sum_{j=1}^{J}\sum_{i=1}^{I} F(d_{ij}) p_i S Y_{ij} Y_j \tag{5}$$

In Equation (5), p_i represents the demand per unit area at demand point i. S represents the area occupied by the demand point. $p_i S$ represents the demand at demand point i. The difference in demand between demand points is only related to p_i.

Objective Function 2: Highest convenience of EV charging station service.

Considering the longest time that users can tolerate in searching for charging stations and the driving distance of electric vehicles with remaining charge, the service radius of the electric vehicle charging station's waiting point is determined, and then the service area of the charging station's waiting point is determined, and the service convenience of the electric vehicle charging station's waiting point is judged by counting the amount of electric vehicles' demand that falls within the charging station's waiting point's service area. If the demand of electric vehicles within the service area of the charging station waiting point is high, the waiting point has high service convenience for electric vehicle users, and the waiting point should be selected for the construction of the charging station. The charging station siting function that aims at the highest service convenience of the charging station for electric vehicles is established as follows:

$$\max f_2 = \sum_{j=1}^{J} \sum_{a=1}^{n_{ij}} p_{ja} S Y_j \tag{6}$$

In Equation (6), $p_j a$ represents the demand per unit area within the service area of the point to be taken j at the demand point numbered a.

Constraints:

1) Satisfying the fact that each electric vehicle charging station's to-be-taken point corresponds to multiple demand points, and each demand point can only correspond to one charging station's to-be-taken point, can be expressed as:

$$\sum_{j=1}^{j} Y_{ij} = 1 \quad \forall i \in n_i, \forall j \in n_j \tag{7}$$

2) Under the condition of high service convenience, meeting the requirements of user satisfaction, and building a station at point j to be picked up to be able to meet the charging demand of electric vehicles, it can be expressed as follows:

$$Y_{ij} \leq Y_j \quad \forall i \in n_i, \forall j \in n_j \tag{8}$$

3) Satisfying that all demand points have their matching charging stations and that the siting plan satisfies the charging needs of all users can be expressed as:

$$\sum_{j=1}^{j} Y_{ij} Y_j \geq 1 \quad \forall i \in n_i \tag{9}$$

4) Determine the capacity of the siting options. The number of charging stations in all siting options can be expressed as:

$$\sum_{j=1}^{j} Y_j = P \quad \forall j \in n_j \tag{10}$$

5) Identify decision variables. To wit:

$$Y_{ij} \in \{0,1\} \quad \forall i \in n_i, \forall j \in n_j \tag{11}$$

In Eq. (11), $Y_{ij} = 1$ means that the user is satisfied with point j. $Y_{ij} = 0$ means that the user is not satisfied with point j.

$$Y_j \in \{0,1\} \quad \forall j \in n_j \tag{12}$$

In Equation (12), $Y_j = 1$ indicates that the service convenience of point j is high. $Y_j = 0$ indicates that point j has a low convenience of service.

3.1.4. Mathematical model description. In summary, the mathematical model expression for charging station siting based on satisfaction and service convenience is as follows:

$$\max f_1 = \sum_{j=1}^{J} \sum_{i=1}^{I} F(d_{ij})\, p_i S Y_{ij} Y_j \tag{13}$$

$$\max f_2 = \sum_{j=1}^{J} \sum_{a=1}^{s_{ij}} p_{ja} S Y_j \tag{14}$$

Constraints:

$$\sum_{j=1}^{j} Y_{ij} = 1 \quad \forall i \in n_i, \forall j \in n_j \tag{15}$$

$$Y_{ij} \le Y_j \quad \forall i \in n_i, \forall j \in n_j \tag{16}$$

$$\sum_{j=1}^{j} Y_{ij} Y_j \ge 1 \quad \forall i \in n_i \tag{17}$$

$$\sum_{j=1}^{j} Y_j = P \quad \forall j \in n_j \tag{18}$$

$$Y_{ij} \in \{0,1\} \quad \forall i \in n_i, \forall j \in n_j \tag{19}$$

$$Y_j \in \{0,1\} \quad \forall j \in n_j \tag{20}$$

Equation (19) indicates that electric vehicle users are most satisfied with electric vehicle charging stations. Equation (20) indicates that charging stations have the highest service convenience for electric vehicle users.

3.2. Model solving based on variable neighborhood genetic algorithm

Since the local search ability of traditional genetic algorithm is not strong, in order to further enhance the local search ability of genetic algorithm, Variable Neighborhood Search (VNS) is added to the traditional genetic algorithm. Variable Neighborhood Search (VNS) is an improved local search algorithm, which optimizes the neighborhood structure by changing the neighborhood structure and searching in different neighborhood structures in order to improve the quality of the solution. In this paper, we design the variable neighborhood genetic algorithm by improving the traditional genetic algorithm to solve the charging station siting problem.

3.2.1. Algorithm solving steps:

1) Parameter setting. Including population size S, maximum number of iterations $L_{\max}$, crossover rate P_c, mutation rate P_m, elite retention ratio P_e, maximum number of searches in variable fields $S_{\max}$, and set iteration termination conditions.
2) Generate initial population. According to the problem scenario and characteristics, determine the coding method, design the coding rules, and generate the initial population.
3) Calculate the degree of adaptation. For the application scenario, design the fitness function to evaluate the quality level of the initial feasible solution and generate the fitness value. The fitness value will determine the survival probability of each individual in the population, i.e., individuals with higher fitness will have a higher possibility of surviving in the population.
4) Selection, crossover, and mutation. High-quality individuals with higher fitness values are selected in the population for continued survival and generation of new populations. Genes on their coding strings are exchanged based on crossover probability and according to specific crossover rules. Change some of the genes on the coding strings of chromosomes according to the mutation probability and according to specific mutation rules.
5) Local search. Perform variable neighborhood search on the chromosomes, calculate the chromosome fitness value before and after optimization and compare, if the chromosome fitness value

after variable neighborhood search is better, then replace the original chromosome, otherwise keep the original chromosome.
6) Generate a new population
7) Judge whether the termination condition is satisfied. If satisfied, output the optimized solution, otherwise, return to the third step.

3.2.2. Algorithm design:
1) Chromosome coding. Assuming that there are M demand points, the first M genetic positions of the chromosome, representing the distribution order of the M demand points, and the model code is the code of the model category corresponding to the demand point, and assuming that there are K types of models, a random integer from 1-K is randomly generated to represent the charging station number. For example, suppose M=7 and K=3, representing 7 demand points with different types of charging stations (outlined above). The specific demand points corresponding to car models are shown in Figure 2 below:

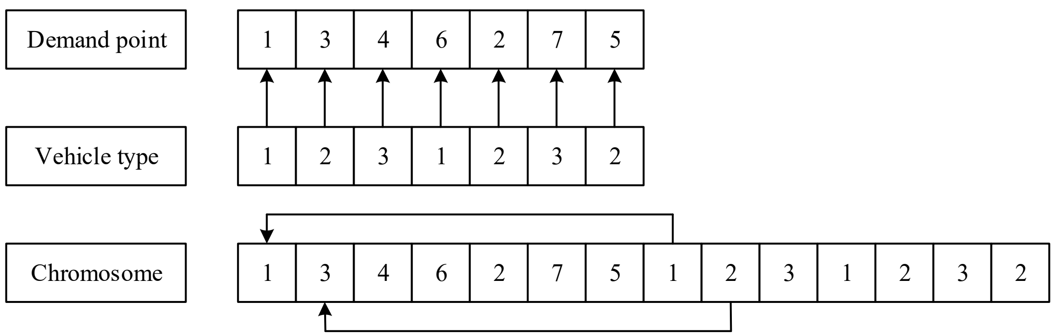

Fig. 2. Encoding method

At the same time, in order to avoid generating infeasible solutions in the process of genetic operation, the coding of chromosomes must satisfy certain constraints, and the appropriate coding method is more likely to generate feasible solutions in the subsequent genetic operation and improve the efficiency of the solution. For this paper, it is necessary to introduce the charging station class coding demand, time window requirement, load limit and so on as constraints. Assuming that there are M charging station demand points and K charging station types to choose from, firstly, the allocation of demand points is carried out, and based on the charging station demand points, time window requirements, and load limitations, the charging station types are gradually allocated to each demand point. Next, the demand points that satisfy all the constraints are filtered out and the charging station selection scheme that meets the constraints is selected.
2) Population initialization. In this paper, the initial population is randomly generated, and the initial population size S is set to 100 considering both solution efficiency and accuracy.
3) Adaptability function. The fitness of an individual refers to the degree of survival of an individual in the population, which is used to distinguish the good and bad of an individual, and the goodness of each individual determines whether it can enter the next generation [26-28]. The fitness of an individual is calculated by the fitness function, and the genetic algorithm evaluates the goodness or badness of a solution not according to the structure of the solution, but according to its fitness value, so it is very important to choose a suitable fitness function. In this paper, the maximization of electric vehicle user satisfaction and the maximization of electric vehicle charging station service convenience are the optimization objectives, therefore, the adaptation degree function is chosen to be set as the inverse of the objective function value. The fitness function is:

$$f_i = \frac{1}{Z_i} \tag{21}$$

where f_i denotes the individual fitness function and Z_i denotes the total cost of the site selection program.

4) Selection operator. The genetic algorithm selects individuals from the current population by means of a selection operator, which determines how to pass the genes from the parent generation to the offspring. The selection is based on the size of the adaptation value of each individual, the larger the adaptation value, the greater the probability that the individual is selected. In this paper, a roulette wheel selection operation is used.

The fitness f_i is calculated for each chromosome and the probability that it will be selected is calculated p_i:

$$p_i = \frac{f_i}{\sum_{i=1}^{n} f_i}, i = 1, 2 \ldots n \tag{22}$$

Divide the disk into n intervals based on the probability p_i, with the center angle of each sector proportional to p_i. Then, the cumulative probability P_i of each point is calculated, and a random number a is generated within [0, 1], and if $P_j - 1 < a < P_j$, the chromosome j is selected to enter the offspring population, and the above operation is repeated n times. Through elite retention, individuals with higher fitness values are retained based on a set ratio, and the elite group that emerges during the evolution of the population is directly copied to the next generation, thus avoiding the destruction of good genes. In this paper, the elite retention ratio P_e is set to 0.13.

5) Crossover operator. Crossover operator, also known as recombination, works by combining the genetic information of two parents in order to produce a new generation of chromosomes. In this paper, partial matching crossover is used for the operation, and the crossover probability P_c is set to 0.62. For example, two chromosomes A and B are randomly selected in the population, and each chromosome has a length of 9. Then, a random gene segment 3448 is selected on chromosome A, and similarly, a gene segment 8306 is selected at the same location on chromosome B. The two gene segments are extracted and interchanged to generate the parental chromosomes A_1 and B_1, and the duplicate genes in them are deleted to obtain two zygotic chromosomes A_2, B_2. The process of partial matching crossover operation is shown in Fig. 3:

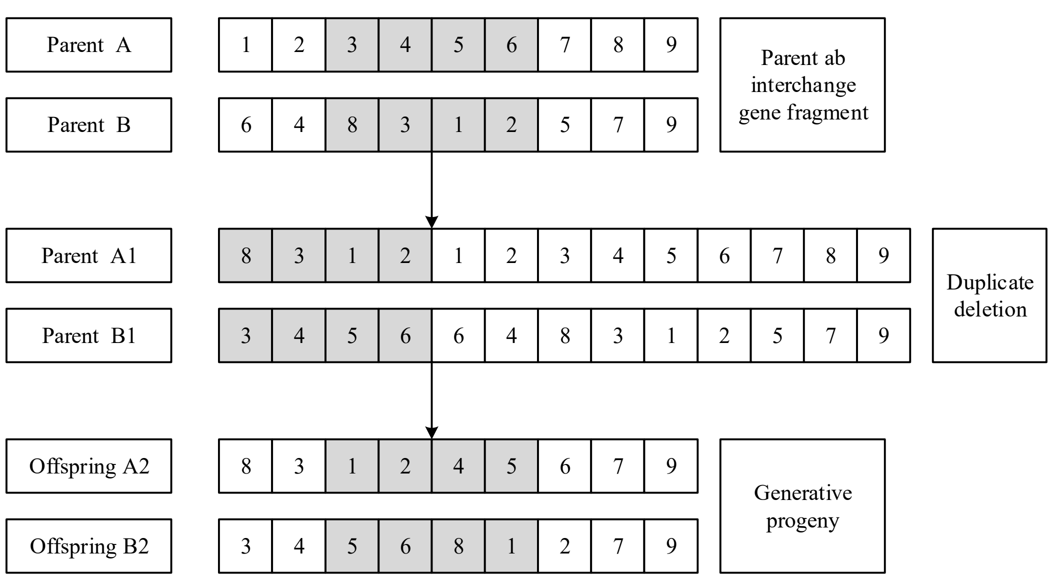

Fig. 3. Partial matching cross diagram

6) Mutation operator. The genetic algorithm imitates the process of gene mutation through mutation operation, and carries out mutation operations such as exchange, inversion, etc., on the gene values on the random gene loci of random individuals, and replaces the old gene values with the new gene values, in order to prevent the population from converging prematurely and falling into the local optimum. In this paper, reverse mutation is used for the operation, and the mutation probability P_m is set to 0.1. The specific operation process is shown in Fig. 4:

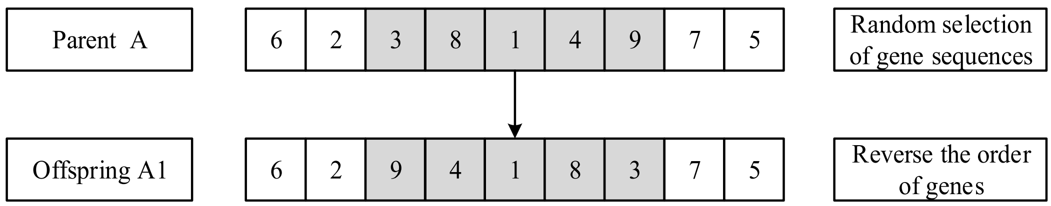

Fig. 4. Schematic inversion variation

If the chromosome fitness value of the offspring is better compared to the parent, the mutation operation is accepted, otherwise, the mutation is not feasible and the mutation is repeated.

7) Variable Neighborhood Search. Neighborhood search using VNS in genetic algorithm can effectively extend the search range and prevent premature convergence. In this paper, the following two neighborhood structures are used:

(1) Insertion Neighborhood: two different positions a and b are randomly selected in the chromosome, and position a is located before position b. Remove a and insert the gene of its position before b to form a new gene sequence. Taking chromosome A as an example, the procedure is shown in Figure 5:

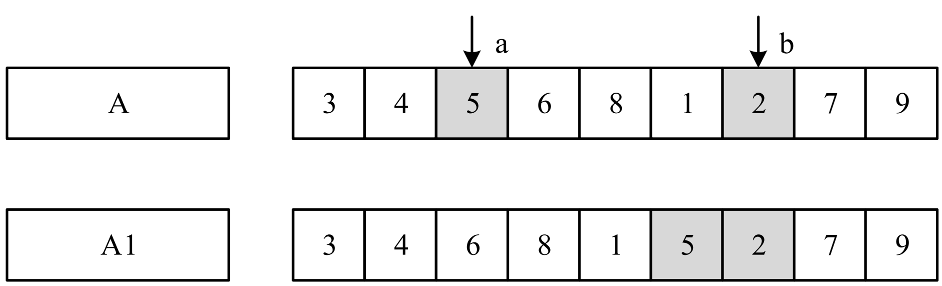

Fig. 5. Insert neighboring city structure diagram

(2) Swap neighbor: randomly select two positions a and b in the chromosome, swap the genes at a and b to form a new gene sequence. Taking chromosome A as an example, the specific operation process is shown in Figure 6:

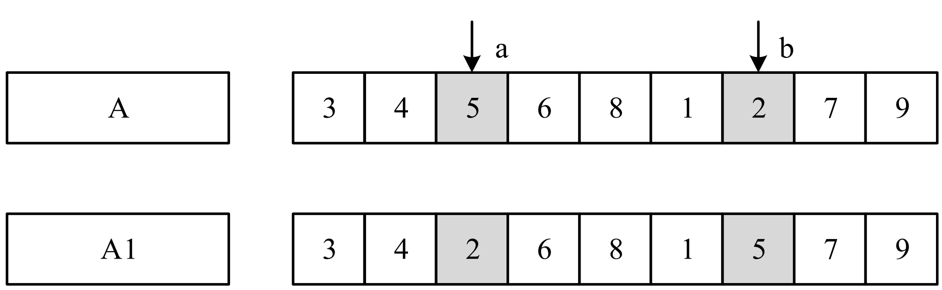

Fig. 6. Schematic diagram of the neighborhood structure of Swap

After the variable neighborhood search operation, calculate the chromosome fitness value before and after optimization and compare, if the chromosome fitness value after variable neighborhood search is better, replace the original chromosome, otherwise continue to try the variable neighborhood search for up to S_{max} time, and in this paper, set S_{max} to 7 times.

8) Termination. Reach the set number of iterations, terminate the operation. In this paper, the number of iterations L_{max} is set to 100.

4. Charging station siting case study

In order to effectively evaluate and validate the effectiveness of the charging station siting model, this paper collects a large amount of data related to charging station siting and processes them accordingly. The possibility of the research method is verified according to the examples shown, and then the optimal solution for the planning and siting of charging stations within the city is obtained.

4.1. Site planning area

This time, City A was used as the study population. City A is located in the northwestern part of Province B and the lower impact plain of the Yellow River, and the area of this region is 10,348 square kilometers. The city has 2 districts, 2 county-level cities, and 7 counties, which are District C, District D, City E, City F, County G, County H, County I, County J, County K, County L, and County M. The map of the administrative area is created by GIS software, and Fig. 7 shows the location map of the administrative area. Only 118 charging stations and 647 charging piles exist in this regional space, and only 106 charging stations and 612 charging piles exist within the city, and the values of vehicle ownership and GDP of the region from 2015 to 2023 were obtained from the Bureau of Statistics of City A, as shown in Table 1, and the area of each region and the number of population are shown in Table 2. After data collection and data analysis, the emergence of power exchange cabinets is only in succession in City A during 2024, and there are only about 103 charging stations in the urban area, and with the growth of the penetration rate of electric vehicles, there is a need to build more charging stations and power exchange stations, and because the range served by the establishment of the power exchange station affects the user's choice of charging the car, the site selection of the power exchange station has to be carried out first, and according to the range of the service of the power exchange station, the Screening the charging station alternative points in the region, and then according to the remaining charging station alternative points for charging station siting model solution, to get the optimal solution of charging station siting.

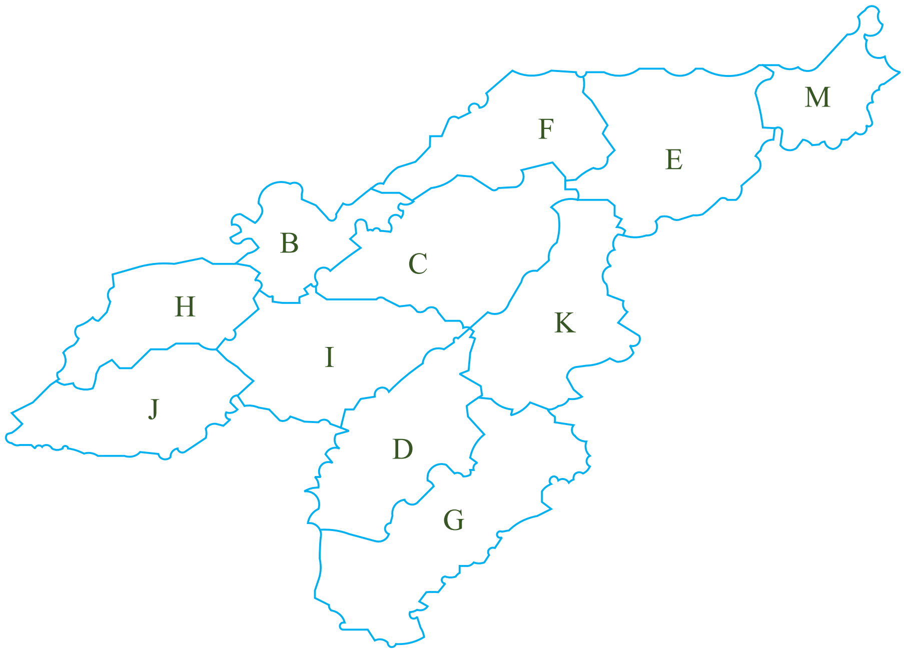

Fig. 7. Area and population of each region

Table 1. 2015-2023 GDP and car ownership of the city

A given year	Car ownership (10,000 units)	GDP (100 million yuan)
2015	60.49	2176.4
2016	73.57	2302.3
2017	88.34	2429.1
2018	91.82	2605.1
2019	99.37	2728.3
2020	102.87	2891.9
2021	107.04	3016.2
2022	122.63	3074.5
2023	132.52	3479.36
Total	878.65	24703.16

Table 2. Basic information of each region

Region	Registered population (10,000)	Land area (sq. km)	Registered population density (person/square kilometer)
B	71.16	1167	609.77
C	63.23	1406	449.72
D	54.76	1008	543.25
E	53.53	986	542.90
F	53.89	876	615.18
G	48.62	826	588.62
H	44.47	537	828.12
I	58.74	1016	578.15
J	46.56	1038	448.55
K	39.06	739	528.55
L	33.57	504	666.07

4.2. Case data organization and analysis

4.2.1. Electricity demand. Because of the large difference between the charging mode of private cars and cabs, this paper takes the charging demand of private car users as the survey data. Because the random forest method can reduce the risk of data fitting and improve the overall prediction accuracy, and in practice, users generate charging demand for the uneven distribution of points, the number of large differences in size, etc., and each factor that affects the user's choice of charging is independent of each other, so this paper uses the random forest algorithm to predict the user's demand for the smaller number of demand and the demand for similar points to be Fusion. Random forest method is used to establish the daily charging demand, the distribution of power required for adjacent trips, the spatial and temporal distribution of parking, and the meteorological parking distribution model for the prediction of user charging demand.

Random forest is a model composed of many decision trees, each of which is constructed by randomly extracting training data and feature subsets, and has the ability to handle continuous and categorical variables by combining multiple decision trees to make predictions together. In the prediction stage, the prediction results of each decision tree are evaluated to obtain the final prediction value. It has good robustness to outliers and noise, which improves the accuracy and stability of the site selection model.

In this paper, for the specific coordinates of the parking point, the parking moment, the parking duration and the remaining power, all are assumed to obey a uniform distribution in the sub-interval in which they are located, and it is assumed that the full electric range of urban electric vehicles are all 4300km. The number of trees is set to 100. The maximum depth of the decision tree takes the value 100. The minimum number of samples required for internal node repartitioning is 4. The minimum sample weight of the leaf nodes is 0, and the weighting problem is not considered. The random seed is set so that the training set is the same no matter how many times the sub-test set is run, and its predicted random forest results are shown in Table 3. The mean absolute error MAE (2.59), the root mean square error RMSE (3.12) and the correlation coefficient R^2 (0.9234) between the predicted and actual values are finally calculated. The overall fitting accuracy of the results of the prediction of user charging demand is more than 90%, which indicates that the constructed user demand prediction model and the set parameter values are more accurate.

Table 3. Predicted random forest outcomes

N	Real	Predict	N	Real	Predict	N	Real	Predict	N	Real	Predict
1	244	240	26	669	676	51	53	54	76	121	124
2	112	117	27	537	534	52	532	528	77	234	236
3	335	334	28	611	614	53	589	593	78	256	253
4	441	441	29	67	66	54	268	270	79	220	222
5	93	92	30	293	294	55	393	399	80	103	99
6	676	673	31	366	372	56	655	659	81	525	529
7	228	226	32	265	265	57	44	43	82	435	439
8	155	152	33	457	455	58	412	417	83	167	169
9	481	481	34	369	370	59	294	290	84	440	443
10	593	592	35	222	217	60	113	114	85	653	653
11	671	671	36	320	319	61	444	446	86	68	68
12	390	394	37	457	458	62	585	582	87	681	681
13	354	356	38	427	429	63	439	435	88	313	313
14	221	227	39	231	231	64	391	388	89	474	473
15	481	481	40	117	122	65	27	25	90	83	80
16	9	16	41	347	345	66	442	447	91	637	637
17	411	414	42	431	428	67	55	57	92	445	438
18	455	457	43	288	286	68	390	385	93	400	390
19	48	56	44	293	293	69	53	55	94	697	698
20	92	92	45	449	451	70	567	566	95	50	50
21	503	505	46	478	483	71	666	671	96	69	69
22	660	661	47	1	1	72	460	462	97	228	232
23	635	640	48	278	280	73	629	624	98	71	73
24	213	206	49	680	681	74	577	579	99	489	487
25	305	304	50	147	146	75	265	268	100	638	638

Due to some things are more urgent, there may be too late to charge the situation, then it is necessary to consider the replacement of the battery mode, assumed to be 20% probability, through the random forest model to get the number of demand points in each region, the coordinates of the location of the demand in the region is shown in Table 4, the coordinates of the demand points in each region and the number of predicted demand is shown in Table 5.

Table 4. Location coordinates of demand in this region

Region	Quantity demanded	X(°)	Y(°)
B	296	37.67	117.17
C	384	36.69	116.48
D	249	37.15	116.79
E	227	36.87	116.57
F	184	36.47	115.49
G	208	37.34	116.39
H	547	37.38	116.26
I	234	37.36	116.59
J	186	37.09	116.37
K	118	37.16	116.04
L	88	37.69	117.34

Table 5. Coordinates of demand points and forecast demand quantities for each region

Serial number	X	Y	Charge demand (times)	Replacement demand
1	37.7672	116.4056	54	21
2	37.7255	117.2158	36	14
3	37.5994	117.2265	28	11
4	37.7426	117.2258	36	13
5	37.6366	116.7965	44	18
6	37.5916	116.8009	44	18
7	37.4557	116.3007	37	16
8	37.4347	116.3177	68	21
9	37.4765	116.3387	38	16
10	37.3269	116.5786	26	17
11	37.3279	116.6116	48	14
12	37.1978	116.8765	16	4
13	37.2185	116.0664	56	16
14	36.9605	115.9949	38	16
15	37.1769	116.4748	12	4
16	37.2049	116.4746	57	19
17	36.9604	116.6819	38	16
18	37.0306	116.6666	56	13
19	36.7804	116.7709	17	7
20	36.7576	116.8239	49	15
Total			798	289

4.2.2. Distribution of alternative sites in the region. Alternative point locations are selected in areas where the surrounding traffic conditions are more convenient, and road access is more attractive for users to travel. Densely populated areas, where the number of users with charging needs is higher. Areas with landmark buildings, such as shopping malls, parks, offices, etc., corresponding to more charging demand. Alternative point area should be established in the area of high traffic flow and traffic smoothness, to ensure the convenience of travel and balance of income and expenditure. Alternative points for power exchange stations are selected in areas with large demand for power exchange stations to ensure that the demand for power exchange is met. The location of alternative points of newly added charging stations should also consider the location of existing charging stations, the regional demand points, alternative point locations are shown in Figure 8. It can be clearly seen that the demand for charging stations in the regions of B, C, D, E, F, G and I is much larger than other regions, which provides theoretical support for the charging station location model solution analysis.

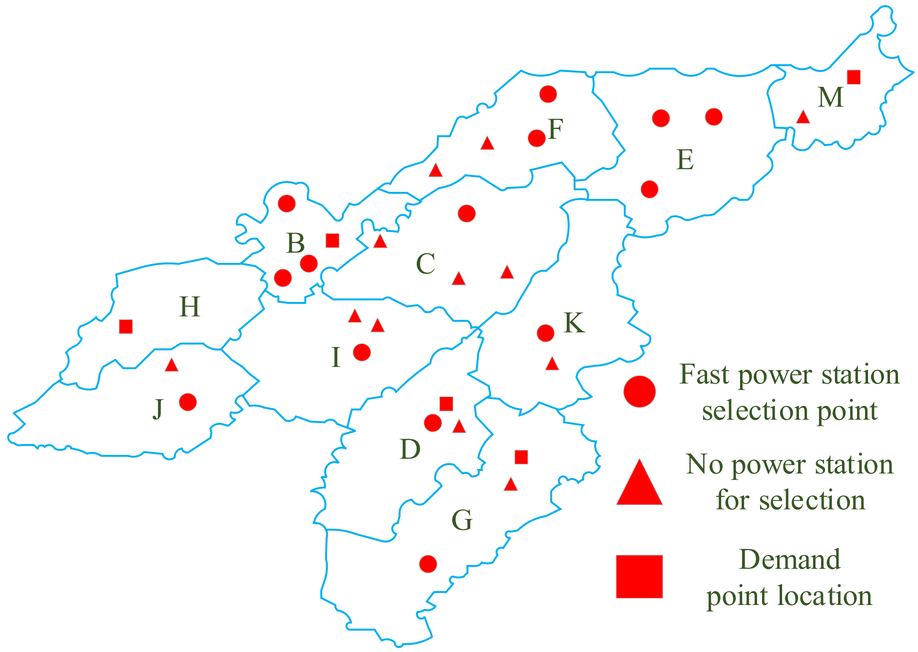

Fig. 8. Location of regional demand point and alternative point

4.3. Example Analysis of Electric Vehicle Charging Station Siting Model Solution

The coordinates of the charging station demand points and the number of electric vehicle users have been given in the previous section, and the algorithm of this paper (Variable Domain Genetic Algorithm) is used to solve the charging problem under the low and peak charging periods with the goal of user satisfaction and charging station service convenience, and compared with the Genetic Algorithm, to validate the superiority of this paper's algorithm for solving the site selection problem.

4.3.1. Arithmetic simulation during low peak hours. It is assumed that the level of the charging station is the same, and the amount of service for electric vehicles in a day is the same, all based on the maximum scale, which means that 40 electric vehicles can be served in a day. User satisfaction and the convenience of charging station service are targeted, and the improved genetic algorithm is used to solve the problem, and compared with the traditional genetic algorithm to verify the superiority.

The site selection based on genetic algorithm during the low peak of charging demand is shown in Fig. 9, and there are three optimal charging station sites, the coordinates from left to right are candidate points B (7.79, 6.06), D (9.87, 4.07), and E (15.81, 8.07), and the values of the two objective functions are 0.63 and 0.75, respectively.

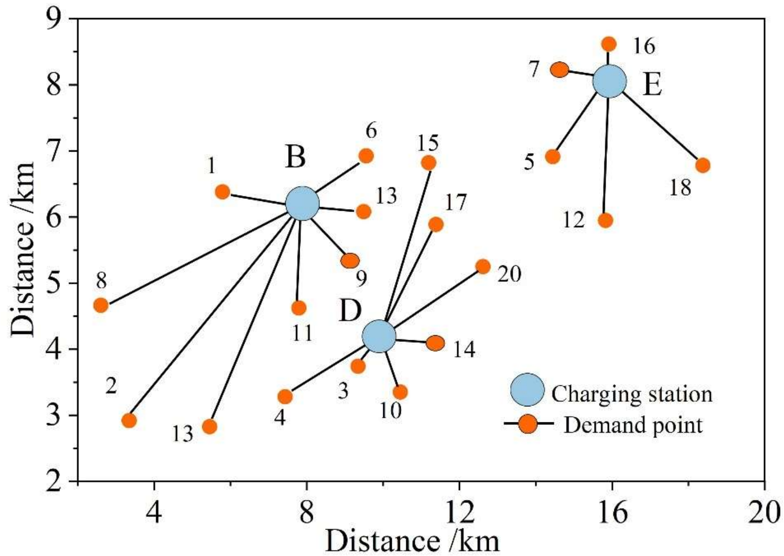

Fig. 9. Location of low peak charging demand based on genetic algorithm

The site selection based on the algorithm of this paper during the low peak of charging demand is shown in Fig. 10, and there are three optimal charging station sites, and the coordinates from left to right are the candidate points C (6.28, 5.09), E (15.81, 8.07), and F (9.87, 4.09), and the value of the objective function in this study is 0.91 and 0.96, respectively.

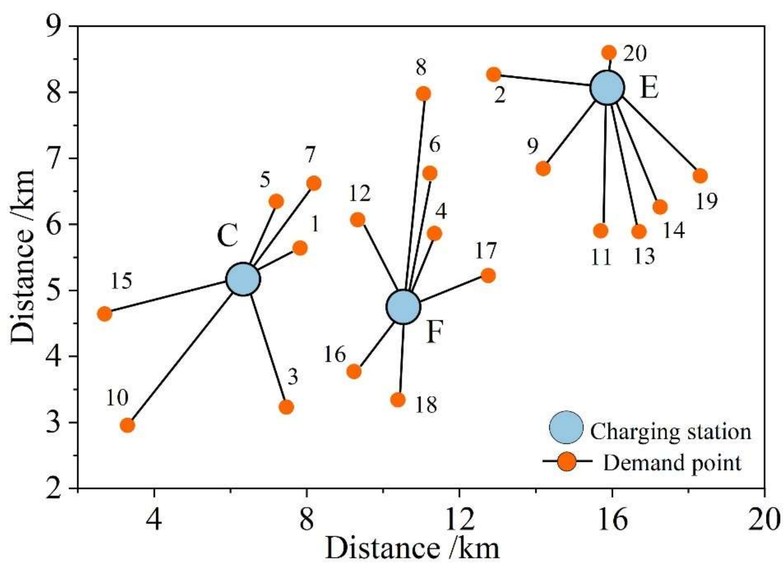

Fig. 10. Location of low peak charging demand based on the algorithm in this paper

In the stage of low user charging demand, with the same amount of service at each charging station, the traditional genetic algorithm builds three charging stations with objective function values of 0.63 and 0.75, respectively. The method in this paper also builds three charging stations, but with objective function values of 0.91 and 0.96, respectively. Fig. 11 demonstrates the optimal charging station siting problem, in which (a) ~ (b) are the user satisfaction and charging station service convenience, and the comparison of the evolutionary trajectories of the traditional genetic algorithm and the improved genetic algorithm. From the figure, it can be observed that the algorithm in this paper is able to obtain a better solution within a smaller number of iterations. Specifically, the traditional genetic algorithm shows signs of convergence within the 30th generation, whereas the improved genetic algorithm starts converging earlier, within the 20th generation. This observation proves the superiority of this paper's algorithm in terms of efficiency and performance, providing a more effective solution for optimal siting of electric vehicle charging stations.

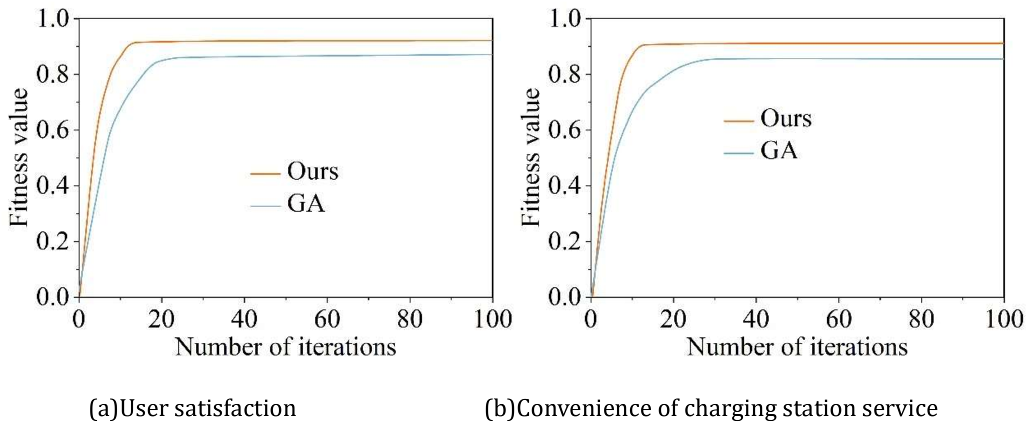

Fig. 11. Algorithm comparison

4.3.2. Peak Time Algorithm Simulation. Without considering the scale of the charging station, the location of the charging station is determined according to the user demand. The objective function is unchanged, and the algorithm in this paper is used to solve the problem, and compared with the genetic algorithm to verify the superiority of the model.

The site selection based on genetic algorithm during the peak charging demand is shown in Fig. 12, and there are five optimal charging station sites, with the coordinates from left to right as candidate points B (6.18, 5.09), E (7.79, 6.07), G (10.54, 4.65), I (15.79, 5.67), and A (17.56, 6.18), with the objective function values of 0.82, respectively, 0.87.

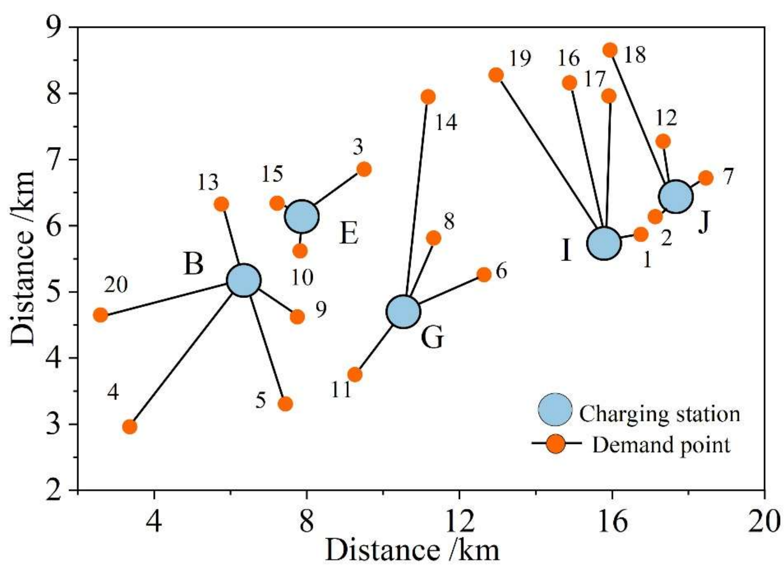

Fig. 12. Location of peak charging demand based on genetic algorithm

The site selection based on the algorithm of this paper during the peak charging demand is shown in Fig. 13. There are four optimal charging station sites, and the coordinates from left to right are candidate points B (6.28, 5.09), C (10.54, 4.64), D (15.87, 8.07), and F (17.56, 6.28), with corresponding objective function values of 0.94 and 0.98.

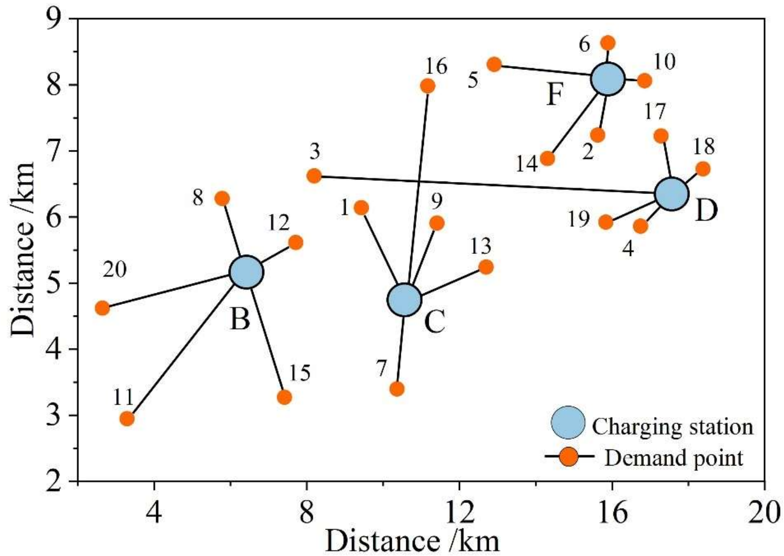

Fig. 13. The location of peak charging demand is based on the algorithm in this paper

The algorithm comparison results are shown in Figure 14. The user charging demand for more phases, in the case of the same amount of service at each charging station, the traditional genetic algorithm built five charging stations, the objective function value of 0.82, 0.87. The algorithm in this paper also builds four charging stations, the corresponding objective function value of 0.94, 0.98. And it can be seen that the traditional genetic algorithm starts to converge within 30, while the improved genetic algorithm starts to converge in 27 generations. Therefore, it is proved that the genetic algorithm in this paper is more superior.

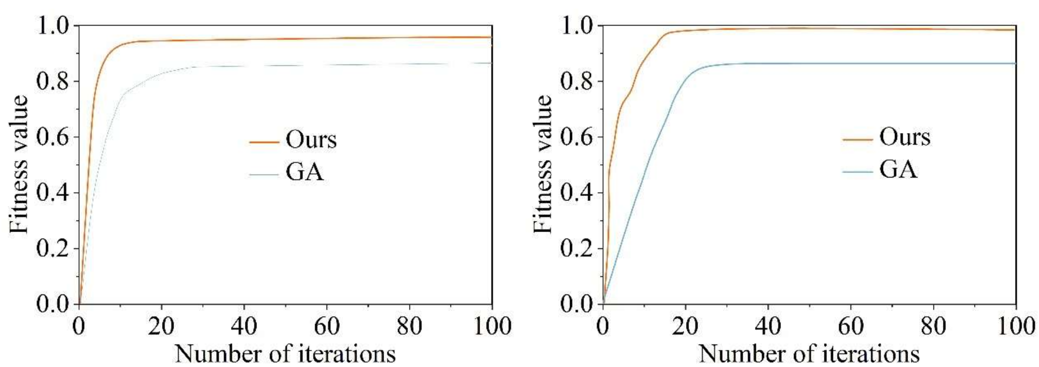

Fig. 14. Algorithm comparison

5. Conclusion and outlook

5.1. Conclusion

In this paper, according to the principle of charging station siting, the basic assumptions are put forward, the objective function and constraints are determined, and the task of constructing the charging station siting model is completed. Aiming at the problem that the local search ability of traditional genetic algorithm is not strong, it is proposed to use variable neighborhood genetic algorithm to solve the model. In order to discuss the superiority of the algorithm in this paper, 11 areas (B~M) in City A are taken as the study area to conduct case studies on the charging station siting model. The objective function values calculated by this algorithm are better than the traditional genetic algorithm in both low and peak charging periods, which confirms that the power station siting model based on the variable neighborhood genetic algorithm has high-quality practical application effects.

5.2. Discussion

This article studies the problem of electric vehicle charging station siting, which has certain reference value for the layout of charging facilities and charging station capacity setting. However, there are still some problems in the article that need to be further explored and studied:

1) The research in this paper does not take into account the limitation of land resources, this paper only carries out the site selection and does not carry out specific planning for the layout of charging station facilities, the reality is that there are limitations on the use of land resources, it is not possible to meet the construction of the maximum charging station requirements in any area. In the future research can consider the charging station area limitations will be combined with the charging station site selection and facility layout optimization research.

2) Considering the limitation of the data base of this paper - covering the charging demand of only 20 locations, the follow-up work is planned to use a wider range of real data and expand the scope of the experiment to include more locations and vehicles in order to improve the reliability and comprehensiveness of the experiment.

References

[1] Guo, L., Hu, P., & Wei, H. (2023). Development of supercapacitor hybrid electric vehicle. Journal of Energy Storage, 65, 107269.

[2] Zahedi, R., hasan Ghodusinejad, M., Aslani, A., & Hachem-Vermette, C. (2022). Modelling community-scale renewable energy and electric vehicle management for cold-climate regions using machine learning. Energy Strategy Reviews, 43, 100930.

[3] Zheng, C., Wang, Y., Liu, Z., Sun, T., Kim, N., Jeong, J., & Cha, S. W. (2021). A hybrid energy storage system for an electric vehicle and its effectiveness validation. International Journal of Precision Engineering and Manufacturing-Green Technology, 1-16.

[4] Raja, V. B., Raja, I., & Kavvampally, R. (2021, December). Advancements in battery technologies of electric vehicle. In Journal of Physics: Conference Series (Vol. 2129, No. 1, p. 012011). IOP Publishing.

[5] Sidharthan Panaparambil, V., Kashyap, Y., & Vijay Castelino, R. (2021). A review on hybrid source energy management strategies for electric vehicle. International Journal of Energy Research, 45(14), 19819-19850.

[6] Kchaou-Boujelben, M. (2021). Charging station location problem: A comprehensive review on models and solution approaches. Transportation Research Part C: Emerging Technologies, 132, 103376.

[7] Ma, T. Y., & Xie, S. (2021). Optimal fast charging station locations for electric ridesharing with vehicle-charging station assignment. Transportation Research Part D: Transport and Environment, 90, 102682.

[8] Ahmad, F., Iqbal, A., Ashraf, I., & Marzband, M. (2022). Optimal location of electric vehicle charging station and its impact on distribution network: A review. Energy Reports, 8, 2314-2333.

[9] Csiszár, C., Csonka, B., Földes, D., Wirth, E., & Lovas, T. (2020). Location optimisation method for fast-charging stations along national roads. Journal of Transport Geography, 88, 102833.

[10] Gong, D., Tang, M., Buchmeister, B., & Zhang, H. (2019). Solving location problem for electric vehicle charging Stations—A sharing charging model. IEEE access, 7, 138391-138402.

[11] Luo, X., & Qiu, R. (2020). Electric vehicle charging station location towards sustainable cities. International journal of environmental research and public health, 17(8), 2785.

[12] Ren, X., Zhang, H., Hu, R., & Qiu, Y. (2019). Location of electric vehicle charging stations: A perspective using the grey decision-making model. Energy, 173, 548-553.

[13] Yang, B., Li, J., Shu, H., Cai, Z., Tang, B., Huang, X., & Zhu, M. (2022). Recent advances of optimal sizing and location of charging stations: A critical overview. International Journal of Energy Research, 46(13), 17899-17925.

[14] Huang, Y., & Kockelman, K. M. (2020). Electric vehicle charging station locations: Elastic demand, station congestion, and network equilibrium. Transportation Research Part D: Transport and Environment, 78, 102179.

[15] Liu, H., Li, Y., Zhang, C., Li, J., Li, X., & Zhao, Y. (2022). Electric vehicle charging station location model considering charging choice behavior and range anxiety. Sustainability, 14(7), 4213.

[16] Tian, Z., Hou, W., Gu, X., Gu, F., & Yao, B. (2018). The location optimization of electric vehicle charging stations considering charging behavior. Simulation, 94(7), 625-636.

[17] Chen, Y. W., Cheng, C. Y., Li, S. F., & Yu, C. H. (2018). Location optimization for multiple types of charging stations for electric scooters. Applied Soft Computing, 67, 519-528.

[18] Brandstätter, G., Leitner, M., & Ljubić, I. (2020). Location of charging stations in electric car sharing systems. Transportation Science, 54(5), 1408-1438.

[19] He, J., Yang, H., Tang, T. Q., & Huang, H. J. (2018). An optimal charging station location model with the consideration of electric vehicle's driving range. Transportation Research Part C: Emerging Technologies, 86, 641-654.

[20] Kizhakkan, A. R., Rathore, A. K., & Awasthi, A. (2019, December). Review of electric vehicle charging station location planning. In 2019 IEEE Transportation Electrification Conference (ITEC-India) (pp. 1-5). IEEE.

[21] Asamer, J., Reinthaler, M., Ruthmair, M., Straub, M., & Puchinger, J. (2016). Optimizing charging station locations for urban taxi providers. Transportation Research Part A: Policy and Practice, 85, 233-246.

[22] Li, C., Zhang, L., Ou, Z., Wang, Q., Zhou, D., & Ma, J. (2022). Robust model of electric vehicle charging station location considering renewable energy and storage equipment. Energy, 238, 121713.

[23] Zhou, G., Zhu, Z., & Luo, S. (2022). Location optimization of electric vehicle charging stations: Based on cost model and genetic algorithm. Energy, 247, 123437.

[24] Guo, F., Yang, J., & Lu, J. (2018). The battery charging station location problem: Impact of users' range anxiety and distance convenience. Transportation Research Part E: Logistics and Transportation Review, 114, 1-18.

[25] Kınay, Ö. B., Gzara, F., & Alumur, S. A. (2021). Full cover charging station location problem with routing. Transportation Research Part B: Methodological, 144, 1-22.

[26] Zhou You,Yongming Bian,Yifan Zhang & Li Chen. (2025). An intelligent optimization algorithm with novel fitness function for high-performance PMSM FOC. Alexandria Engineering Journal286-296.

[27] Li Yuan & Li Dexin. (2024). Study on the Countermeasures to Improve the Public Outdoor Leisure and Fitness Function on the Two Rivers and Four Banks in the Main Urban Area of Chongqing. Journal of Architectural Research and Development(6),51-57.

[28] Subhash Chandra Das,Md. Al Amin Khan,Ali Akbar Shaikh & Adel Fahad Alrasheedi. (2024). Interval valued inventory model with different payment strategies for green products under interval valued Grey Wolf optimizer Algorithm fitness function. Egyptian Informatics Journal100561-100561.