THE OPTIMAL CONFIGURATION OF CHARGING PILES FOR NEW ENERGY VEHICLES IN SHIZONG COUNTY: AN INVESTIGATION

By
Mr. Wenchao ZHOU

A Thesis Submitted in Partial Fulfillment of the Requirements
for Master of Engineering ENGINEERING MANAGEMENT
Department of INDUSTRIAL ENGINEERING AND MANAGEMENT
Silpakorn University
Academic Year 2023

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โดย

Mr.Wenchao ZHOU

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิศวกรรมศาสตรมหาบัณฑิต

สาขาวิชาการจัดการงานวิศวกรรม แผน ก แบบ ก 2 ปริญญามหาบัณฑิต

ภาควิชาวิศวกรรมอุตสาหการและการจัดการ

มหาวิทยาลัยศิลปากร

ปีการศึกษา 2566

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By	Mr. Wenchao ZHOU
Field of Study	ENGINEERING MANAGEMENT
Advisor	Sitichai Saelem, Ph.D.

Faculty of Engineering and Industrial Technology, Silpakorn University in Partial Fulfillment of the Requirements for the Master of Engineering

.... Dean of Faculty of Engineering and Industrial Technology
(Assistant Professor Arunsri Leejeerajumnean, Ph.D.)

Approved by

.... Chair person
(Associate Professor Choosak Pornsing, Ph.D.)

.... Advisor
(Sitichai Saelem, Ph.D.)

.... External Examiner
(Thanongsak Thepsonthi, Ph.D.)

650920041 : Major ENGINEERING MANAGEMENT
Keyword : New energy vehicles, Public charging station, optimized layout, Particle Swarm Optimization

With the deepening of the "sustainable development" strategy, environmental and resource protection has become a key focus that countries are committed to maintaining. Faced with the energy crisis and environmental degradation, finding environmentally friendly new energy has become an important issue for national development. In the past, excessive policies that pursued rapid economic development at the cost of sacrificing the environment highlighted environmental issues such as pollution, photochemical smog, water pollution, acid rain, and rising global temperatures. However, in addition to the continuous increase in global population and economic growth, the destruction of the natural environment and unhealthy lifestyles also pose risks to traditional energy. In this context, electric vehicles, as a strategic emerging industry that China focuses on supporting, have emerged to cater to a series of new concepts and policies such as carbon footprint, low-carbon economy, low-carbon development, low-carbon lifestyle, and low-carbon cities. As a necessary basic supporting equipment for new energy vehicles, the convenience of charging piles is the key to promoting the sustainable development of new energy vehicles, directly restricting the popularization of new energy vehicles. At present, the number of new energy vehicle charging stations in China has gradually increased, but the problem of low usage due to the unreasonable distribution of charging stations urgently needs to be solved. In this case, this article studies how to reasonably optimize public services The layout of charging stations is aimed at solving the challenges that affect the sustainable development of the new energy vehicle market. This article takes the layout optimization of new energy vehicle public charging piles in Shizong County as an example for analysis. The particle swarm optimization algorithm is used to obtain the optimal layout plan and propose management suggestions. By studying and optimizing the layout of charging stations, on the one hand, the reliability and rationality of the constructed model system theory are demonstrated, and on the other hand, the research results provide reference for decision-making in the new energy vehicle industry, assisting in the construction of charging facilities for new energy vehicles, thereby promoting the development of the new energy vehicle industry, making the research both theoretical value and practical significance.

ACKNOWLEDGEMENTS

This paper is impossible to finish. Many people's encouragement and support. I would like to take this opportunity to sincerely thank the professors who gave me valuable guidance in the process of writing my thesis.

First of all, I would like to express my heartfelt thanks to my tutors Prof. Choosak Pornsing and Prof. Sittichai Saelem. I would like to express my heartfelt thanks to them for their profound guidance and sincere help. Their advice is to carefully consider the choice of topic early in my writing and during the process, and to conduct a series of related research. During the writing process, they spent a lot of time guiding me in the right direction and giving me a lot of useful advice. It was with their great help that I was able to finish my thesis on time.

In addition, I would like to express my heartfelt thanks to Silpakorn University for its postgraduate Engineering Management program. Their tireless guidance provided me with an excellent environment to learn and grow, which will certainly have a profound impact on my later life.

In addition to this, I would like to thank every student of Silpakorn University's Graduate program in Engineering Management. They share their knowledge with me and help me when I encounter any difficulties in my thesis. In the process of writing my thesis, they tried their best to give me valuable advice.

I then deeply thank my dear parents for their encouragement, understanding and endless love in my life, none of which would be possible without their selfless sacrifice and tireless support.

Dear professors, classmates and friends, you have made my life colorful and unforgettable. I hope that my existence has meaning for you, that we can get together often, and that we both have a good future.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

With the deepening of the 'sustainable development' strategy, environmental and resource protection has become the focus that all countries are committed to maintaining. How to find environmentally friendly new energy in the face of the energy crisis and environmental degradation has become an important topic for national development. In the past, excessive policies that pursued rapid economic development at the cost of sacrificing the environment have highlighted environmental issues such as pollution, photochemical smog, water pollution, acid rain, and rising global temperatures. However, in addition to the increasing global population and continuous economic growth, the destruction of the natural environment and unhealthy lifestyles have also put conventional energy at risk. In this context, a series of new concepts and policies such as carbon footprint, low-carbon economy, low- carbon development, low-carbon lifestyle, and low-carbon city have emerged. The so-called low-carbon economy mainly refers to a form of economic development guided by the concept of sustainable development through various means as technological innovation, institutional innovation, industrial transformation, and new energy development, to minimize the consumption of high-carbon energy such as coal and oil, reduce greenhouse gas emissions, and achieve a win-win situation between economic and social development and ecological environment protection. The term low-carbon economy was first seen in the 2003 UK Energy White Paper 'Our Energy Future: Creating a Low Carbon Economy'. As a pioneer of the First Industrial Revolution and an island country with limited resources, the UK is fully aware of the threats to energy security and climate change. It is transitioning from a self-sufficient energy supply to an era mainly relying on imports. According to the 2003 consumption model, it is expected that 80% of the UK's energy will have to be imported by 2020. In August 2010, China officially confirmed the pilot work of low-carbon industry construction in 5 provinces and 8 cities, achieving the development policy of gradually spreading from the pilot to the whole country.

As the main product of carbon dioxide and exhaust emissions, fuel- powered vehicles have also become the primary material for transformation under the implementation of low-carbon economic policies. Electric vehicles, also known as new energy vehicles, have undoubtedly become the key to meeting environmental needs and balancing people's lifestyles. Using electricity as a low-pollution and low-emission new energy source to provide power for cars, effectively alleviates resource shortages, greenhouse effects, and other issues. Transforming all electrical energy into mechanical energy through electric motors to provide power for automobiles can effectively solve the problems of oil resource shortage and environmental pollution. Therefore, the new energy vehicle industry has become a strategic emerging industry in China, especially pure electric vehicles,a key national development industry. In 2020, renowned German automotive industry expert Dudenhoff pointed out in the German Automotive Research Center Report that due to Tesla's reasons, China may once again become a leader in the electric vehicle market by the end of this year. According to our prediction, this trend will not change in the next 50 years. Meanwhile. Dudenhoe believes that the total number of electric vehicles willreach 6 million by 2025, and the European Union will still be second.

To achieve the rapid development of the electric vehicle industry, the Chinese government has successively introduced multiple policies. For example, in 2007, the country issued the New Energy Vehicle Production Access Management Rules, which standardized the definition of new energy vehicles and industry standards; In 2014, the Announcement on Exemption from New Energy Vehicle Purchase Tax stipulated the exemption from New Energy Vehicle Purchase Tax; In 2017, the Ministry of Industry and Information Technology and other departments issued the Parallel Management Measures for Average Fuel Consumption and New Energy Vehicle Credits of Passenger Car Enterprises and the New Energy Vehicle Carbon Quota Management Measures, indicating the adoption of a market-oriented approach to promote the development of the new energy vehicle industry, replacing previous financial and tax subsidies. With the support of relevant national policies, many domestic automobile manufacturers have invested a large amount of manpower, finance, and resources, promoting the rapid development of China's electric vehicle industry.

However, at present, the rapid development of electric vehicles has also encountered a series of problems that cannot be ignored: firstly, due to the immature research technology, the range of electric vehicles is relatively short, and they cannot travel long distances in a short period of time like gasoline vehicles, only suitable for daily commuting. Secondly, there are still problems with the unreasonable layout of public charging facilities, difficulty in building piles in some residential areas, non-standard operation of the charging market, and inadequate maintenance of facilities. As of the end of 2020, the cumulative number of charging infrastructure in China was 1.681 million, including 807000 public charging stations, a year-on-year increase of 56.4%; The number of private charging stations (equipped with charging facilities) was 874000, a year- on-year increase of 24.3%. The trend of the number of charging stations in China in recent years is shown in Figure 1.1.

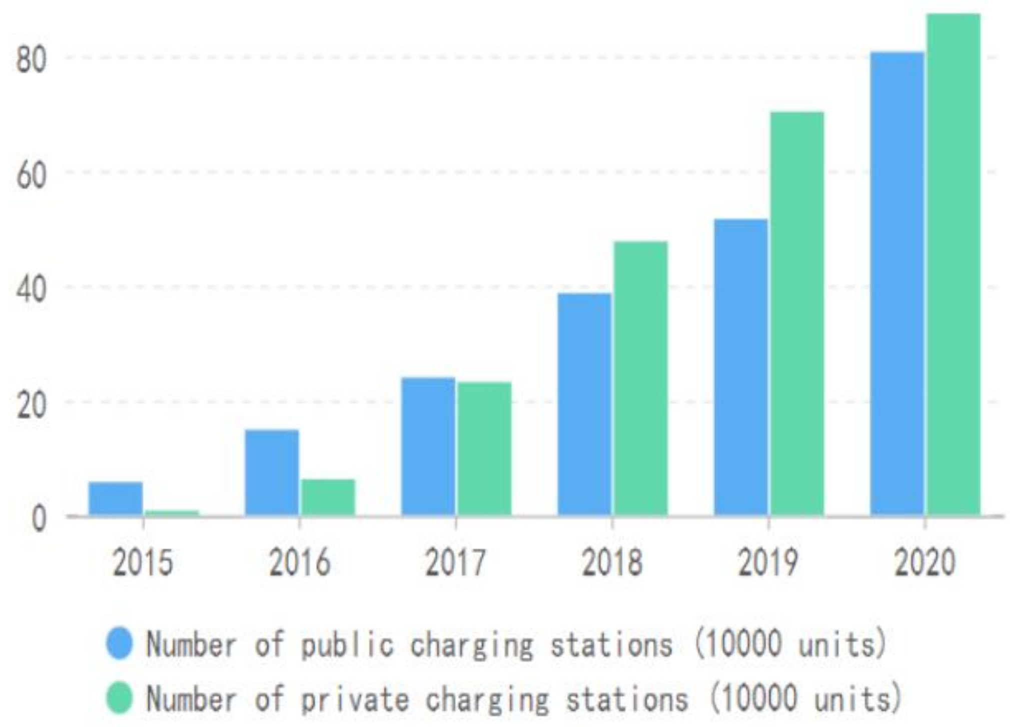

Figure 1.1 Trend of nationwide charging stations

Source: Ministry of public security and prospective industry research institute

1.2 Research Objective

1. Based on the existing number and location of public charging piles in Shizong County, this study explores the problems existing in the configuration of public charging piles in Shizong County;

2. Explore the views of residents in Shizong County on new energy vehicles, so as to determine the demand for public charging piles;

3. Combined with the local traffic situation and urban development planning, explore the optimal configuration scheme of public charging piles in Shizong County, and obtain suggestions on the reasonable setting of public charging piles.

1.3 Research Significance

1. This research can provide a theoretical basis for the promotion of "carbon peaking", "carbon neutrality" and "New Energy Vehicle Industry Development Plan". The development of the new energy vehicle industry requires not only the production of a large number of new energy vehicles, but also the manufacturing of corresponding supporting equipment and the construction of corresponding supporting facilities. Due to the fact that the construction of supporting facilities and equipment is not only a matter of quantity supply, but also a problem of optimizing configuration schemes, this study focuses on optimizing infrastructure configuration, which can provide a reference for corresponding practices.

2. This study can provide valuable solutions for the problems faced in the charging process of new energy vehicles. Provide a scientific optimization plan for the planning and layout of new energy vehicle charging facilities in Shizong County, which can promote the landing and implementation of new energy vehicle charging facility projects.

3. This study will build a new mathematical model and design corresponding solving algorithms for the layout optimization problem of new energy vehicle charging stations based on existing research. Provide a specific theoretical basis for research in the field of location selection and planning of new energy vehicle charging facilities.

CHAPTER 2
LITERATURE REVIEW

By searching, summarizing, and analyzing relevant literature in the field, it can be found that international literature on the configuration and layout of electric vehicle charging facilities first appeared in the 1970s. In the 1990s, this issue was favored by many scholars, and different experts and scholars have studied it from different perspectives. Chinese literature first appeared in the 1990s and many papers appeared in the early 21st century. Due to the diversity of research backgrounds and demand, the configuration and layout of charging stations remain one of the research hotspots in the new energy industry globally.The rest of this chapter is organized as follows:

1. Overview of Public Charging Stations for New Energy Vehicles
2. Research on the Layout of Charging Stations
3. Overview of charging station development in different countries
4. Analysis of Factors Influencing the Layout of Public Charging Stations
5. Principles for the layout of public charging stations
6. Summary of this chapter

2.1 Overview of Public Charging Stations for New Energy Vehicles

2.1.1 The concept of new energy vehicles

New energy vehicles are a concept that corresponds to traditional energy vehicles. New energy vehicles refer to new structures and technologies formed by integrating advanced technologies of vehicles using unconventional automotive fuels (including natural gas, liquefied petroleum gas, methanol, ethanol, and bio liquid fuels) as the power source.

New energy vehicles are mainly divided into pure electric vehicles (BEVs), hybrid electric vehicles (HEVs), fuel cell electric vehicles (FCEVs), hydrogen powered vehicles (HPVs), etc.,see Table 2.1. Compared to traditional energy vehicles, new energy vehicles mainly rely on electricity to drive, while traditional vehicles rely on gasoline combustion to provide power. Traditional energy vehicles are internal combustion engine vehicles that use gasoline, diesel, and other fuels as their carriers; The carrier of new energy vehicles is vehicles powered by clean and renewable energy. The biggest difference and difference between the two is that new energy electric vehicles mainly rely on electricity to drive, while traditional cars are powered by gasoline combustion. Compared to traditional fuel powered vehicles, new energy vehicles have obvious advantages but also certain disadvantages, see Table 2.2.

Table 2.1 New energy vehicles classification

Number	Type	Definition	Main vehicle product representatives	Notes
1	BEVs	Completely powered by rechargeable batteries, the car is driven by an electric motor	BYD Song NIO ES8 GAC New Energy GE3	This article mainly studies the optimization of the configuration of charging stations for new energy vehicles. Therefore, the new energy vehicles discussed in this article are limited to pure electric vehicles that require charging stations and mainstream small and medium-sized hybrid models. Buses and taxis are not included in the scope of this study.
2	HEVs	Oil electric hybrid vehicle, structurally equipped with both an electric motor and an engine	Toyota Camry Lei Ling from SAIC Honda Accord Hybrid Series	
3	FCEVs	By relying on the chemical reactions in fuel cells to provide electricity for cars and drive them, the energy generated in the chemical reactions is converted into electrical energy to drive the car	Unproduction	
4	PVs	Also known as hydrogen internal combustion vehicles, they generate driving force through the combustion of hydrogen and oxygen	Unproduction	

Source:Regulations on the Administration of New Energy Vehicle Production Enterprises and Product Access（2017）

Table 2.2 Advantages and disadvantages of new energy vehicles

Number	Advantage	Disadvantages
1	No exhaust emissions during driving, no environmental pollution, and high energy efficiency	Poor overcharging and discharging performance, expensive price
2	Almost no noise is generated during driving	Short range
3	Purchasing vehicles can enjoy government subsidy support	Battery has a lifespan issue
4	Low charging cost	Insufficient number of charging locations and taking a long time to complete charging

2.1.2 Charging station concept

The new energy vehicle charging station is a supporting facility that provides electricity for new energy vehicles, equivalent to a fuel dispenser, which can charge various types of new energy vehicles. According to the installation method, installation location, number of charging interfaces of the charging station, charging method and speed, it can be divided into the following categories , see Table 2.3.

Table 2.3 Types of main charging station equipment

Number	Classification method	Charging Station Type	Introduce
1	The installation method	Floor mounted charging station	Installed in parking spaces not close to walls
		Wall mounted charging station	Installed in parking spaces near walls
2	The installation location	Public charging station	Built in a public parking lot to provide
			public charging needs for social vehicles and charge a certain charging fee
		Dedicated charging station	Built in the company's own parking lot for the use of enterprise personnel, usually covered by the company's electricity bill
		Self use charging station	A charging device built on a personal parking space and belonging to private users, with the owner personally responsible for the electricity cost

Table 2.3 Types of main charging station equipment

Number	Classification method	Charging Station Type	Introduce
3	The number of charging interfaces of the charging station	One pile, one filling	Each charging station is equipped with a charging interface, which can only be used by one vehicle at a time
		One pile with multiple charges	Each charging station is equipped with multiple charging interfaces, which can be used by multiple vehicles at the same time
4	The charging method and speed	AC slow charging pile	See continuation table
		DC fast charging pile	
		AC fast charging pile	

Table 2.3 Types of main charging station equipment (Continued）

Number	Charging Station Type	Rated voltage	Rated current	Rated power	Charging time per 100 kilometers
1	AC slow charging pile	220V	32A	7kW	2.4 hours
2	DC fast charging pile	500V	120A	60kW	0.3 hours
3	AC fast charging pile	380V	63A	40kW	0.43 hours

2.2 Research on the Location of Charging Stations

2.2.1 Research on New Energy Vehicles

Faced with the global shortage of traditional fossil energy supply and the severe situation of deteriorating ecological environment quality caused by excessive use of energy, exploring the development of new energy vehicles has gradually become a focus of the automotive industry in various countries around the world. Governments around the world generally support new energy vehicles, and car manufacturers also prioritize new energy vehicles for their next development. The exploration of new energy vehicle projects has become a hot topic for many scholars to study. Regarding the research on new energy vehicles, Chen Yi and Kong Deyang (2014) combined EU policies to study a series of strategic goals and policy regulations formulated by the German government, and conducted a comprehensive coordinated layout. At the same time, in combination with the current development trend of new energy vehicles in China, by drawing on the development experience of Japan and Truss, which are currently well developed in the field of new energy vehicles, we have deeply explored the difficulties faced by the domestic new energy vehicle industry (Li, 2017), and then proposed the countermeasures that the administrative incentive policy should be combined with the actual promotion goal of new energy vehicles. First, according to the promotion goal of new energy vehicles and combining costs Regarding factors such as infrastructure and supporting facilities, it is recommended to adjust the proportion of relevant subsidies in a moderate and timely manner to make the subsidy policy more scientific and reasonable. Secondly, it is necessary to strengthen the construction of infrastructure such as charging piles and optimize the layout of charging piles. China should establish a long-term layout for the development of this industry, strengthening policy support, increasing investment in research and development, and accelerating the layout of supporting facilities.

2.2.2 Research on the Location of charging stations

This research mainly studies the location problem of charging piles, which is the problem of location selection. It is a typical problem in operations research, which began with the industrial layout problem proposed by Weber (1909) and has been widely applied, such as the selection of gas station location, express delivery center location, warehouse construction location, and commercial center location, all of which have been well applied. Location problems are constantly evolving based on dynamic variables and involve long- term decision-making. The location of public charging stations also directly affects user experience, various cost expenditures, and the profits of charging station operators. So, exploring and researching a high-quality charging station location plan can not only facilitate the charging of new energy vehicle owners, meet their needs, relieve their charging confusion, but also save costs, improve the profitability of related enterprises, and enhance the competitive advantage of charging station operators.

Due to the fact that the current construction of charging stations is generally led by the government, scholars often analyze the costs and benefits of building charging stations from the perspectives of the government and the public. For example, one type of research starts from cost and constructs a goal planning model with the minimum total cost by analyzing the construction investment cost, operation cost, maintenance cost, and network loss cost of charging piles (Liu et al., 2012); At the same time, based on the user's travel situation, determine the location and time of the parking lot, and construct a mixed integer programming model (T. Donna Chen, 2013). Of course, there is also the use of Markov chain traffic models and remote transmission methods to construct spatiotemporal models to predict the electricity demand for new energy vehicle charging in urban centers, and to explore the location planning of charging facilities (Mariz B. Arias, 2017). Another type is to explore in detail the location planning and main factors of new energy vehicle charging piles from the aspects of operational economy, transportation convenience, and grid safety, in order to adopt the most suitable method to solve the location problem of charging piles (Li, 201). The above are some studies on the optimization methods for the location of new energy vehicle charging stations. It can be seen that there are many algorithms that can be applied in the optimization of charging station location, and related charging station location optimization algorithms are also constantly developing, using fuzzy comprehensive evaluation method, immune algorithm, etc. Each optimization method has its advantages and advantages, and has certain reference significance.

2.2.3 Facility location problems based on particle swarm optimization

Particle Swarm Optimization (PSO), also known as Particle Swarm Optimization (PSO) or Bird Swarm Foraging Algorithm, is an iterative optimization algorithm; The PSO algorithm originates from the research on the behavior of birds' predation. It was initially inspired by the regularity of birds' flocking activities, and then a simplified model was established by using swarm intelligence; On the basis of observing the activity behavior of animal clusters, Particle Swarm Optimization (PSO) utilizes the sharing of information among individuals in the population to generate an evolutionary process from disorder to order in the problem solving space, thus obtaining the optimal solution. This algorithm has attracted attention from the academic community due to its advantages of easy implementation, high accuracy, and fast convergence, and has demonstrated its superiority in solving practical problems. In recent years, particle swarm optimization has been widely applied in solving location and layout problems in multiple industries such as fire stations, distribution and logistics centers, substations, commercial centers, and gas stations. Especially the integration of this algorithm and location layout problems has become increasingly active in academic research, with an increasing number of related research literature in recent years.

2.3 Overview of charging station development in different countries

The promotion and application of new energy vehicles are mainly concentrated in the four major automotive markets of China, Europe, the United States, and Japan. The promotion of this industry started relatively early abroad and has accumulated rich experience within the industry. In foreign markets, the promotion and development models of various countries have their own characteristics, and relevant models are worth learning from.

(1) United States. The United States actively promotes the development of charging stations and adopts the following positive measures to optimize the layout of charging stations: firstly, based on the overall deployment of smart grid development, combining the construction of charging facility networks with the interconnection technology of new energy vehicle networks; Secondly, implement the subsidy policy for charging facilities, advocate for enterprises and encourage

individuals to jointly participate in the construction of charging stations. If each charging station is built, individuals or businesses will receive different tax credits.

(2) Germany. Germany was the first to propose the technology of installing charging points on street lights, integrating charging devices into traditional street lights to reduce charging costs. This is one of the methods that countries around the world are trying to reduce the cost of public charging facilities for new energy vehicles.

(3) Norway. In order to promote the use of new energy vehicles, the Norwegian government has introduced a series of incentive measures in recent years. For example, new energy vehicles can use bus lanes at specific times on weekdays, and toll booths through specific roads, ferries, bridges, and tunnels are free. Car owners can also use parking spaces in public places for free. Most public charging stations can be used for free. In addition, the government has provided sufficient financial subsidies for the construction of charging stations.

(4) France. The French government has provided strong support for subsidies for purchasing new energy vehicles, while continuously improving the charging facilities of new energy vehicles. At present, the coverage of charging stations is among the top in the world. The French government and businesses adopt a dual approach. On the one hand, the government strongly supports and encourages enterprises to invest in the construction of charging piles through tax reduction measures; On the other hand, automotive companies are also continuing to make efforts in the field of new energy, accelerating the construction of charging stations, and continuously expanding the coverage of charging stations.

(5) Japan. In order to ensure the power supply of new energy vehicles, Japan has formulated policies to promote the construction of charging stations, and on the other hand, it has promoted automobile production enterprises to invest in the construction of charging facilities. Four well-known local automakers (Toyota, Nissan, Honda, and Mitsubishi) have partnered with the Japan Policy Investment Bank to establish a charging company that provides various services such as charging station installation and after-sales warranty. It is expected that by 2020, Japan will build 100 new energy vehicle charging stations on highways and optimize the layout of charging stations based on public land, including shopping venues,

attractions, amusement parks, hospitals, hotels, restaurants, parks, art galleries, golf courses, etc.

(6) Korea. In recent years, South Korea has actively promoted the development of new energy vehicles and vigorously promoted the construction of charging stations. To this end, South Korea has introduced a series of policies that are conducive to promoting the construction of charging stations: firstly, promoting the technological development of batteries and core components; The second is to revise relevant laws and regulations, such as providing more tax incentives to support the charging pile industry; Thirdly, promote pilot and demonstration projects in Seoul and Jeju Island; Fourthly, formulate plans to stimulate the development of new energy vehicles, such as supporting government agencies to adopt new energy vehicles and providing more preferential policies for consumers.

2.4 Analysis of Factors Influencing the Location of Public Charging Stations

The sales growth of new energy vehicles is stable and orderly, and has entered a new stage of development. It is urgent to further improve public charging facilities to meet users' travel electricity requirements. On the basis of studying a large amount of literature on the optimization of the layout of public charging piles for new energy vehicles, this article conducted interviews with relevant technical backbone and enterprise management personnel in industries such as new energy vehicles, charging piles, and power grids, conducted on-site research on public charging pile sites, new energy vehicle manufacturers, and new energy vehicle sales stores, and investigated and understood the current development status and main problems of new energy vehicles and public charging piles. By comprehensively organizing relevant literature and integrating industry experts' opinions, combined with the current survey results, in order to further optimize the layout of public charging stations, on the one hand, to facilitate and stabilize the provision of electricity for new energy vehicles, and on the other hand, to achieve the goal of maximizing profitability, the following influencing factors should be mainly considered:

(1) Cost expenses

In order to enhance the investment enthusiasm and enthusiasm of enterprises in the construction and operation of public charging stations, profit is a key factor.

Therefore, the layout of public charging stations should be controlled and cost reduced as much as possible, and the operational efficiency of public charging stations should be improved to ensure the profit of constructing and operating public charging stations. The cost of public charging stations mainly includes expenses for pile construction, daily operation and maintenance, losses, and parking expenses. In order to maximize efficiency and maximize profits, the layout of public charging stations should minimize costs and expenses, striving to minimize total costs.

(2) User Requirements

User demand generally refers to the need for users to charge a certain number of new energy vehicles at a specific time period and location. The charging demand is usually consistent with traffic density. The definition of traffic density is the number of cars driving on a unit length of road at a specific time. According to the definitions of the two, it can be seen that there is a positive correlation between traffic density and the number of vehicles in the region. That is to say, generally speaking, the larger the traffic volume, the more new energy vehicles there are. Therefore, the user's charging demand also increases, so the two have a positive correlation. In order to improve the utilization rate of public charging stations, it is necessary to consider the convenience needs of new energy vehicle users and set up charging stations in relatively concentrated places, such as choosing to layout them in urban commercial areas and densely populated areas to meet the needs of charging station users.

(3) Social factors

The construction of public charging stations requires the occupation of urban land, therefore, multiple related factors such as transportation network and compliance with urban planning should be comprehensively considered. Public charging stations can only play their social benefits and promote the development of new energy vehicles if they comply with the layout of the transportation network and urban planning.

(4) Grid factors

The normal operation of public charging stations requires the support of the power grid. In order to ensure the normal operation of public charging stations and the normal power supply of the power grid, the layout of charging stations should consider the reliability and safety of power supply to the power grid after installation, so as to meet the normal operation needs of charging stations.

2.5 Public Charging Station Layout Principles

Among many consumers, whether the number of charging stations is sufficient, whether they are convenient to use, whether costs can be reduced, and whether the location layout meets their expectations have become important decision-making considerations for whether to purchase new energy vehicles. Therefore, a complete supporting charging system can be said to be an important tool to help sell new energy vehicles. Given the above reasons, in the optimization of the layout of public charging stations, consideration should be given to the long-term planning and dynamic development of new energy vehicles, following the principles of easier promotion and application, in line with relevant urban development plans, and having foresight. Efforts should be made to make scientific and reasonable site selection better serve more new energy car owners, play a promoting, effective, and demonstration role, and dispel the anxiety of intended consumer groups, To continuously enhance their sense of identity and expand the word-of-mouth dissemination of new energy product vehicles, allowing more people to choose new energy vehicles as their means of transportation.

1. The principle of easy promotion and effective use
2. Conforming to the principles of urban planning
3. The principle of being forward-looking and able to cater to the development trend of new energy vehicles
4. Practical
5. Meeting actual needs

2.6 Summary

This chapter briefly introduces the concepts and types of new energy vehicles and public charging piles, summarizes representative literature from relevant scholars on the layout of new energy vehicle public charging piles, summarizes relevant theoretical achievements and development trends, and summarizes the application of particle swarm optimization algorithm in layout and location selection issues. After literature review and interviews with relevant experts, scholars, and industry technical backbone of charging piles, Explored the main influencing factors and layout principles of public charging stations, in order to facilitate quantitative research on optimizing the configuration of public charging stations in the following text.

CHAPTER 3
RESEARCH METHOD

Under the joint influence of rapid technological advancements and environmental protection, the application and promotion of new energy vehicles are being driven. The urgent issue to be addressed is the layout of public charging stations, which is closely related to the future development of new energy vehicles. The government optimizes the urban service environment by planning the spatial layout of charging stations, guiding the rational allocation and sustainable development of funds, related technologies, labor, and other factors; Starting from the goal of meeting the charging needs of users, the enterprise is committed to exploring and optimizing the layout of charging piles, reducing the cost of pile construction, and striving to achieve efficiency goals. Therefore, research on the layout of charging stations can provide theoretical guidance and technical support for governments and enterprises. As a new hot topic in facility location theory, the layout and location theory of charging piles is deeply influenced by traditional facility location theory. However, due to the characteristics of charging piles and new energy vehicles, the influencing factors, layout models, and methods of charging pile location are different from general facility location.

3.1 Model construction

The goal of the layout of public charging stations for new energy vehicles is to obtain the maximum benefits of the layout of charging stations for new energy vehicles at the lowest cost. That is to say, the layout problem of new energy vehicle charging stations is essentially an optimization problem, and the optimal planning model has good applicability in solving optimization problems. The optimization model is usually used to solve the problem of resource optimization allocation, that is, how to make the most effective use of various resources under established goals, or how to achieve the best results under limited resource conditions. The layout optimization model of the charging station constructed in this article mainly follows the following principles:

(1) Simplification principle

In order to save time and financial resources, when a simple model can be used to obtain a solution, complex models should not be established and the problem should be minimized as much as possible. Therefore, under the premise of meeting practical needs, if linear programming models can be used to solve problems, they should be used for analysis and calculation.

(2) Building models based on case studies

When constructing the optimal planning model, it is not advisable to directly copy and transport the models previously used, but to choose specific models and methods that are suitable for solving the problem. Therefore, based on reference to relevant literature, this article combines the objective programming model for optimizing the layout of charging stations with practice, and appropriately adjusts and adds relevant decision variables and parameters.

(3) Strict control of model inference

When the conclusion of the model does not match the actual situation, it is important to carefully determine the possible reasons, re-examine the original assumptions, and distinguish between external errors (generated by model construction) and logical internal errors (generated by model solving or operation) in the expression.

(4) Emphasize the accuracy of data input

The work of the model depends on the input information. Therefore, when solving the optimal planning model, attention should be paid to the accuracy of data input. Therefore, the relevant data and information related to the optimization of the layout of public charging stations must be accurate and scientific.

(5) Combining the influence of non quantitative factors

Models often only consider the influence of quantitative factors. When discussing the layout optimization of public charging stations, due to their different characteristics, some non quantitative factors should also be considered. Therefore, after using the optimal planning model to calculate the layout of public charging stations, it is also necessary to analyze some non quantitative factors in reality.

In addition, a particularly important aspect is that the construction of the model also involves the selection of key indicator elements. When constructing an optimization model for the layout of public charging stations, relevant indicators should be clearly classified, comprehensive in content, and logically clear. One is the combination of science and operability. Any indicator should be based on science, and under objective premise, it is required that the constructed project indicators are easy to measure, relatively simple, operable, and in line with actual needs during implementation; The second is the combination of comprehensiveness and hierarchy. Due to the complexity of optimizing the layout of charging piles, it is necessary to systematically reflect all aspects of the layout requirements when selecting a layout indicator system.

The determination of relevant factors should consider the characteristics of wide coverage, and different indicators should be adopted based on different levels. The main factors of charging pile layout should be included, and the weight of the indicators should be distinguished; The third is to emphasize flexibility. It is necessary to fully consider various situations that arise during the layout optimization process, especially when constructing an indicator system that is based on the actual case project, and establish a layout indicator system that is in line with the actual situation of the case itself. In a timely and appropriate manner, some indicators should be added, modified, or deleted according to the different situations of the project.

According to the analysis of the influencing factors and layout principles of new energy charging in Chapter 2, the planning and construction of public charging piles for new energy vehicles should not only consider the construction and operating costs of public charging piles, but also explore the social benefits after the completion of public charging piles. In this article, when optimizing the layout plan of public charging stations for new energy vehicles, the interests of charging station operators and users are considered, and the total social cost is minimized, including six factors such as enterprise cost and user cost (Table 3-1), as the objective function for scheme optimization. This article draws on the research results of previous scholars and references relevant literature. In addition to using five cost factors, it also introduces land use costs. Because the construction of public charging stations requires a certain amount of land resources, that is, the cost of land use, especially the scarcity and preciousness of urban land resources, land use prices are increasing year by year.

Therefore, it is included in one of the factors considered in this study. The mathematical description is as follows:

$$\min C = \sum_{i}^{n} (C_{1i} + C_{2i} + C_{3i} + C_{4i} + C_{5i} + C_{6i}) \quad (1)$$

In the formula : n is the number of public charging station stations.

Table 3.1 Main Cost Composition

Serial number	Character	Mean
1	C1i	Represents the construction cost of public charging station i
2	C2i	Represents the annual operation and maintenance cost of public charging station i
3	C3i	Represents the average annual network loss cost of public charging station i
4	C4i	Represents the annual charging cost of users within the service area of public charging station i
5	C5i	Indicates the average annual loss cost incurred by the user during charging
6	C6i	Represents the land use cost of public charging station stations

Construction cost of public charging station i:

$$C_{1i} = (e_i a + m_i b + C_i)\left(\frac{T_0(1 + T_0)^Z}{(1 + T_0)^Z - 1}\right) \quad (2)$$

In the formula :

e_i is the number of transformers

a is the unit price of the transformer

mi is the number of charging stations

b is the unit price of the charging station

Ci is the construction cost of public charging station i

T0 is the discount rate

Z is the service life

Annual operation and maintenance costs for public charging station i:

$$C2i = (eia + mib + Ci)\mu \tag{3}$$

In the formula : μ is the discount rate

The operation and maintenance costs of public charging station stations mainly consist of daily maintenance and repair of charging stations, depreciation costs, and labor expenses. Usually, the cost value of various expenses is not very clear. Generally speaking, the annual operation and maintenance costs of public charging station stations are calculated as a

percentage of the initial input cost (i.e. considered as a discount rate).

Average annual network loss cost of public charging station i:

$$C3i = ei\,(CFe + CCu) \cdot Tv \cdot 365 \cdot pC + mi\,(CL + CD) \cdot ki \cdot Tv \cdot 365 \cdot pC \tag{4}$$

In the formula : CFe is the iron loss rate of the transformer

CCu is the copper loss rate of the transformer

Tv is the effective daily charging time of the charging station

pC is the electricity price paid by the charging station to the power company

CL is the loss value of each charging station in the charging station

CD is the charging loss of a single charging station

ki is the simultaneous rate of multiple charging stations in the charging station

The average annual charging cost of users within the service area of public charging station i:

$$C4i = pQi \cdot 365 \tag{5}$$

In the formula : Qi is the daily average charging demand of users within the service area of public charging station i

p is the charging cost for the user

The average annual loss cost incurred by users during the charging process mainly considers two types of loss costs, namely the cost $h1$ caused by the idle driving electricity generated by users during the charging process and the indirect loss cost $h2$.

$$\text{The function is: } C5i = h\,1 + h2 \qquad (6)$$

Annual idle power consumption cost:

$$h\,1 = \frac{\sum L_i}{g}\, p \cdot 365 \qquad (7)$$

In the formula : σ Li is the comprehensive distance from all charging demand points in the service area of public charging station i to the public charging station site; g is the unit electricity consumption of a new energy vehicle (calculated by dividing the range of the new energy vehicle by the vehicle's battery capacity, which is simplified as the distance that the vehicle can travel per kilowatt hour of electricity).

Annual indirect consumption expenses:

$$h2 = \frac{\sum L_i}{v}\, k \cdot 365 \qquad (8)$$

In the formula : k is the cost of driving time for users, which can be estimated by the average wage income of residents within the layout range;

v is the average speed of new energy vehicles.

The comprehensive distance from all charging demand points within the service area of public charging station i to the public charging station site is:

$$\sigma L_i = \sigma_{j=1}^{n_u} d_{ij} q_j \qquad (9)$$

In the formula : dij is the distance between charging demand point j and public charging station i;

qj is the average number of new energy vehicles that need to be charged per day at the charging demand point j;

n_{um} is the number of charging demand points within the service area of public charging station i.

Substituting (7) (8)(9) into equation (6), after sorting, it can be concluded that:

$$C5i = \sigma_{j=1}^{n_u} d_{ij} q_j \left(\frac{p}{g} + \frac{k}{v}\right) \cdot 365 \qquad (10)$$

In the formula : dij is the distance from the charging demand point j to the public charging station i;

qj is the daily average number of new energy vehicles that need to be charged at the charging demand point j;

n_{um} is the number of charging demand points in the service area of public charging station i;

p is the user's charging cost;

g is the unit electricity consumption of new energy vehicles;

k is the cost of driving time for users, which can be estimated by the average wage income of residents within the layout range;

v is the average speed of new energy vehicles.

Land use cost of public charging station sites:

$$c_{6i} = \sum_{i=1}^{m_i} S_i \cdot (C_t \cdot \lambda_i) \quad (11)$$

In the formula : s_i is the floor area of each public charging station,

c_t is the highest land use cost in the region,

λ_i is the comprehensive factor of each public charging station (including distance from the city center, location, etc.). Generally, the closer the geographical location is to the city center, the higher the cost of using the site.

3.2 Fixed volume calculation

The consideration of fixed capacity is mainly to determine the number of charging stations required within each public charging station. Because the traffic flow on any road segment is generally bidirectional and asymmetric, it is necessary to use the same flow direction to calculate the traffic flow density at each node of the road segment. In other words, the number of vehicle traffic flowing into or out of nodes should be uniformly used.

The charging demand for intersection node j during the T time period is:

$$q_j = \int_0^T p_t^j \cdot a \cdot \beta \cdot p_v \, d_t \quad (12)$$

In the formula : a is the proportion of new energy vehicles;

β is the proportion of new energy vehicles that need to be charged;

p_v is the average capacity of new energy vehicles.

If there are ni intersection nodes in the service area of public charging station i, the charging requirements that i should meet during the T period are:

$$Q_i = \sum_{j=1}^{n_i} q_j \quad (13)$$

Number of charging stations to be equipped for public charging station i:

mi = [ ]Qpikx（k）t + 1 (14)

In the formula：m^i is the number of charging stations to be equipped at public charging station i；

ρ is the charging capacity margin of the public charging station;

P is the charging power of a single charging station;

kx is the efficiency of the charging station;

Formula (13) The main consideration is to meet the daily maximum flow demand in the service area of public charging station i, in order to configure the number of charging stations at public charging station i.

3.3 Particle Swarm Optimization

(1) Particle Swarm Optimization

This article uses an improved particle swarm optimization algorithm to solve the objective function, and uses particle swarm optimization (PSO) to optimize the objective function. The introduction of particle swarm optimization algorithm is as follows:

The PSO algorithm is initialized as a group of random particles, and then the optimal solution is found through multiple iterations. During each iteration, the particle updates itself by finding its own optimal solution (referred to as individual extremum) and the current optimal solution found by the entire population (referred to as global extremum). It can also use the extremum of its own neighbor (referred to as local extremum) to update its own speed and new position.

In the group bird foraging model, each individual can be seen as a particle, while the bird flock is seen as a particle swarm.Set in a D-dimensional target space, consisting of a group of m particles, where the position of the i-th particle is represented as x_i , i.e. the position of the i-th particle in the D-dimensional search space is x_i . In other words, the position of each particle is a potential solution. By bringing x_i into the objective function, its fitness value can be calculated, and its pros and cons can be measured based on the size of the fitness value. The best position experienced by an individual particle is denoted as p_i , and the best position experienced by all particles in the entire population is denoted as pg . The velocity of particle i is denoted as v_i .

The particle swarm algorithm uses the following formula to continuously update the position of particles (unit time is 1):

$$v_i = w\, v_i + c_1\, r_1\, (p_i - x_i) + c_2\, r_2\, (p_g - x_i) \tag{15}$$

$$x_i = x_i + a \cdot v_i \tag{16}$$

w is a non negative number called the inertia factor

C_1 and c_2 are called acceleration constants.

C_1 is a constant that is determined based on the individual's own experience;

c_2 Based on the group's experience;

a is called a constraint factor, which aims to control the weight of speed.

The flying speed vi of particle i is limited by a maximum velocity v_{max} . If the particle's velocity v_i in a certain dimension exceeds the maximum flying speed v_{max} of that dimension at the current time, then that dimension is limited to v_{max} .

The iteration termination condition is set according to the specific problem, usually to reach the predetermined number of iterations or the minimum allowable error of the particle swarm searching to the most favorable position that satisfies the objective function so far.

(2) Parameter selection

Parameter 1: Number of particles

The number of particles is generally between 20 and 40, and experiments have shown that for most 30 particles, it is sufficient. The more particles there are, the larger the search range, and the easier it is to find the global optimal solution, but the longer the program runs.

Parameter 2: Inertia factor

The inertia factor w plays a significant role in the convergence of particle swarm optimization algorithms. The larger the value of w, the greater the flight amplitude of particles, and it is easy to miss out on local optimization ability, while the stronger the global search ability; On the contrary, the stronger the local capability, the weaker the global capability. The usual approach is to set the inertia factor higher at the beginning of the iteration and gradually reduce it during the iteration process.The value of w is [0 1]. If w is taken as a fixed value, it is recommended to take 0.6-0.75.

Parameter 3: Acceleration constants c_1 and c_2

In general, $c_1 = c_2 = 2.0$. At present, there is significant disagreement in the academic community regarding the exact values of the acceleration constants c_1 and c_2. Typically, c_1 is equal to c_2 and the range is between 0 and 4.

Among them, c_1 represents one's own experience; c_2 represents group experience.

Parameter 4: Maximum flying speed v_{max}

The particle swarm optimization algorithm is achieved by adjusting the distance each particle moves on each dimension during each iteration, with a random change in speed. It does not want uncontrolled particle search trajectories to be extended to increasingly wide distances in the problem space and reach infinity. If particles are to be effectively searched, the parameter v_{max} must be restricted. The parameter v_{max} helps to prevent meaningless divergence of the search range. The determination of v_{max} requires a certain prior knowledge. In order to pick out the local optimum, a larger optimization compensation is required, and it is better to use a smaller step size when approaching the optimal value. If v_{max} remains unchanged, it is usually set to 10% -20% of the variation range per dimension.

The above is the standard particle swarm optimization (PSO) algorithm. This article has made improvements to the standard algorithm. After updating for one generation, this article will select individuals who are worse than the average fitness set value for mutation, hoping to produce better solutions. The steps are as follows:

1. Initialize relevant parameters;

2. Evaluate the initial fitness value of each particle;

3. Take the initial fitness value as the current optimal value for each particle, and record the current position as the local optimal value Location;

4. Take the optimal initial fitness value as the current global optimal value and record the current position;

5. Calculate based on the calculation speed and position formulas mentioned earlier. Pay attention to the maximum speed limit here Handling;

6. Compare the current fitness value with the previous fitness value, and update if it is better;

7. Find the global optimum of the current particle swarm;

8. Select individuals who are worse than the average adaptive set point for mutation;

9. Repeat steps 5-7 until the minimum error or optimal number of iterations is reached;

10. Output.

The entire optimization process is shown in Figure 3- 1:

3.4 Summary of this chapter

This chapter focuses on considering the interests of both public charging station operators and new energy vehicle users. Combining relevant industry standards and regulations, six factors including construction cost, user use cost, and land use cost are constructed, and a layout optimization model based on minimizing total social cost is proposed. The layout of public charging station stations also considers conditions such as road network structure, traffic flow information, and user mileage loss, and uses an improved particle swarm optimization algorithm to solve the objective function.

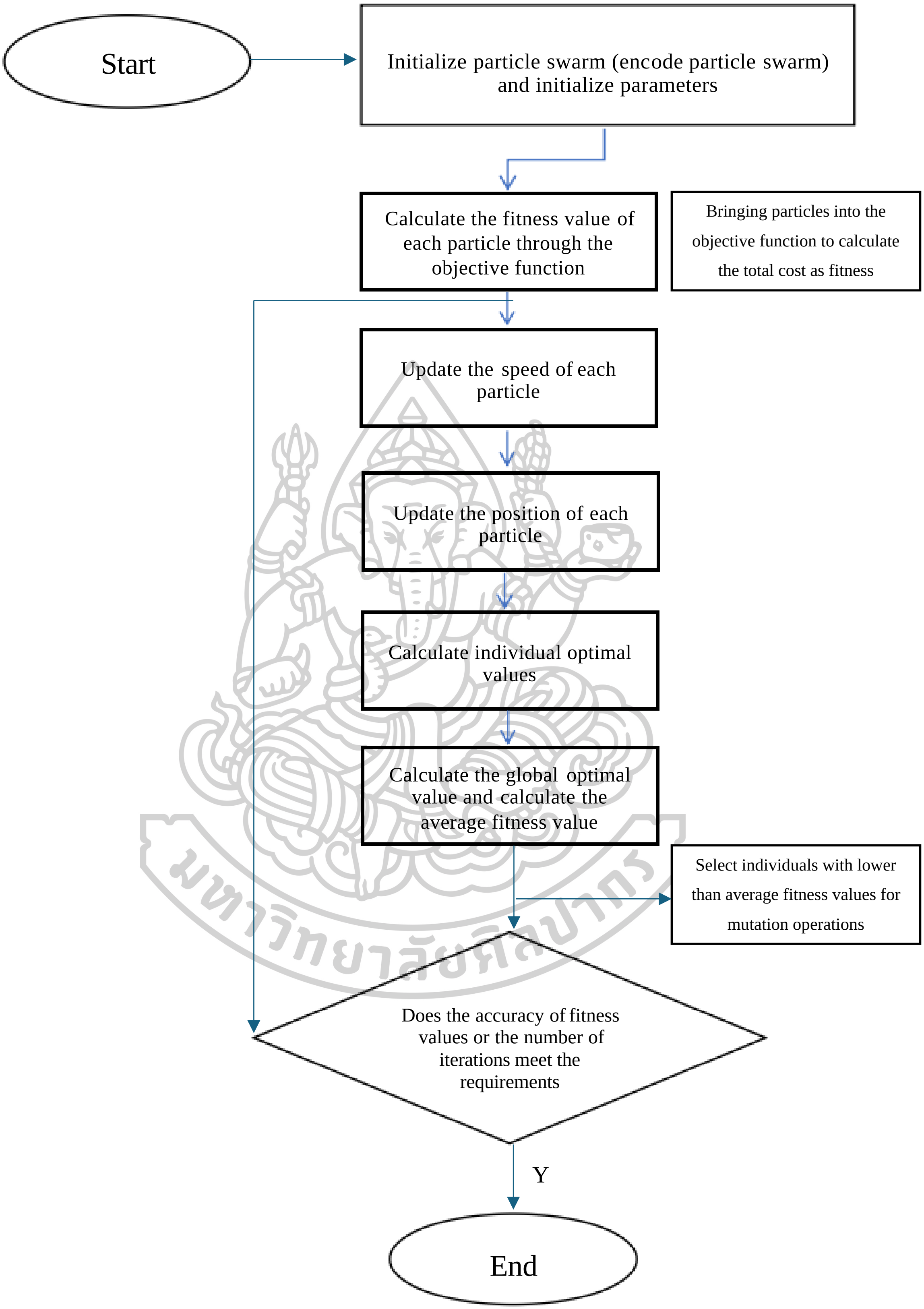

Figure 3.1 The process of solving optimization

CHAPTER 4
EXAMPLE ANALYSIS OF OPTIMIZING THE LAYOUT OF PUBLIC CHARGING STATIONS

4.1 Current situation investigation and analysis

4.1.1 Development Status of Public Charging Stations in Shizong County

(1) Basic situation of Shizong County

Shizong County, under the jurisdiction of Qujing City, Yunnan Province, is located in the southeast of Yunnan Province and is one of the revolutionary old area counties in Yunnan Province. It borders Luoping County to the east, Xilin County across the river to the southeast, Qiubei County to the south, Luxi County to the southwest, and Luliang County to the north. The land area is 2 725 square kilometers. As of October 2022, Shizong County has 3 streets, 4 towns, and 3 townships under its jurisdiction. In 2021, Shizong County will have 441 300 household registers and 371 800 permanent residents. (See Table 4.1).

The city has a relatively dense population and moderate economic development, which has brought very beneficial impetus to the demonstration and promotion of new energy vehicles.

Table 4.1 Basic Population Situation of Shizong County in 2022

	Administrative area (square kilometers)	End of year resident population (10000 people)	Registered residence population at the end of the year (10000 persons)	Permanent population density (person/square kilometer)	Registered residence density (person/km2)
County wide	2725	37.18	43.8	136	161
Danfeng Street	115.6	2.2	2.58	190	223

Table 4.1 Basic Population Situation of Shizong County in 2022 (Continued)

	Administrative area (square kilometers)	End of year resident population (10000 people)	Registered residence population at the end of the year (10000 persons)	Permanent population density (person/square kilometer)	Registered residence density (person/km2)
Yangyue Street	145.1	1.7	1.9	117	131
Datong Street	236.4	3.6	3.78	152	160
Xiongbi Town	225	2.38	2.48	106	110
Kuishan Town	129.12	5.4	5.5	418	426
Caiyun Town	190.6	5.2	5.56	273	292
Zhuji Town	226.9	6.5	6.7	286	295
Longqing Township	423.69	5.3	5.9	125	139
Gaoliang Township	561.57	3.8	4.3	68	77
Wulong Township	471.07	4.7	5.1	100	108

Source:The administrative area protectors are provided by Shizong County Civil Affairs Bureau, and the registered residence population is provided by Shizong County Public Security Bureau.

(2) Car purchase situation in Shizong County

Currently, Shizong County has become one of the top three cities in terms of car purchases in Qujing City (Qujing City, Luliang County, and Shizong County, respectively). Due to the fact that Shizong County is located at the border of Qujing City and Honghe Prefecture, linking economic exchanges between the two regions, it has a certain commercial foundation. The improvement of the living standards of citizens has also brought about continuous material satisfaction and updates, especially the increasing trend in the number and level of household car purchases.

Table 4.2 Purchase and Use of Automobiles in Shizong County in 2022

Index	2022
Car ownership	54326
Year-on-year growth	8.7%
Fuel powered vehicle ownership	49535
Growth in fuel vehicles	9.75%
New energy vehicle ownership	4791
Growth of new energy vehicles	54.3%

Source: Shizong County Traffic Police Detachment

In recent years, Shizong County has taken various measures to promote new energy vehicles, and the government has intensively introduced relevant policies, such as reducing the purchase tax of new energy vehicles, providing subsidies for consumers to purchase vehicles, establishing green new energy special license plates, exempting license plate auctions, and charging subsidies. Shizong County has made significant progress in the promotion of new energy vehicles, and the attention and purchasing power of consumers are also increasing. At the same time, The planning department and automobile transportation management department of Shizong County have also set up targeted distribution locations for public charging stations in the urban renovation process based on local conditions. As of December 2022, there are 7 registered charging construction and operation enterprises in Shizong County, and 12 public charging stations have been built, including 4 DC charging stations and 8 AC charging stations, which can generally meet the current charging needs of urban vehicles.

4.1.2 The layout and planning goals of public charging stations in Shizong County

According to the relevant planning guidance documents issued by the Shizong County Government, by the end of 2025, the planned number of Shizong new energy vehicles will exceed 30000. Among them, about 4000 vehicles are planned to be applied in the fields of public transportation, rental transportation, and environmental sanitation, and about 26000 vehicles will be promoted and applied in the private sector (such as individual consumers). The Shizong County Government actively encourages individuals to purchase and use new energy vehicles, guides the public to establish a green and low-carbon travel concept, continuously improves the subsidy policy and indicator management for related vehicle purchases, and further improves charging facilities to promote the orderly development of the industry.

In order to keep up with the rapid development pace of new energy vehicles, the original planning goal was to build 100 public charging stations by the end of 2020, and a special plan was formulated as guidance to improve supporting policies and encourage all sectors of society to actively participate in the construction of charging infrastructure. This goal has been fully implemented as scheduled; At present, the goal is to strive for the total number of charging stations in the county to exceed 1500 by the end of 2025; The charging service will be moderately advanced, achieving the goal of vehicle piles following each other, intelligent and efficient, and convenient use. Gradually, a comprehensive layout of four service sub centers, Xiongbi Town, Kuishan Town, Caiyun Town, and Zhuji Town, with the central urban area as the main service center, will be established to promote the healthy development of the new energy vehicle industry.

The Bureau of Industry, Trade, Science and Technology Information Technology of Shizong County pointed out that by 2025, the system and mechanism for charging facility construction will be further improved. Shizong County will add 20 new charging stations, and the charging service capacity of charging facilities in the public service areas of the county will reach 80000 kilowatts; Newly built residential areas must have 100% of their parking spaces equipped with charging stations for new energy vehicles, or must reserve space for installation; Urge the implementation of relevant national and provincial regulations on public parking lots, build new commercial buildings, tourist attractions, transportation hubs, public parking lots, etc., construct public charging facilities with fast charging as the main focus and slow charging as the auxiliary, create a good, safe, and convenient charging environment for new energy vehicles, and form an intelligent management and service system that combines the Internet and charging facilities.

4.1.3 Survey on Satisfaction with the Use of Public Charging Stations in Shizong County

The rationality of the layout of public charging stations also needs to be based on the actual usage needs of new energy vehicle users. Therefore, this article conducted a special survey on the owners of new energy vehicles in Shizong County using a questionnaire survey method, in order to explore charging station layout strategies that meet the actual needs of users from the perspective of users. This time, with the support of multiple new energy vehicle sales terminals (4S stores) located in Shizong County, new energy vehicle owners were randomly selected from multiple areas such as Shizong County, Xiongbi Town, Kuishan Town, Caiyun Town, and Zhuji Town. A post sale service interview survey was conducted on new energy vehicle owners, and a total of 250 effective survey questionnaires were completed from June 1 to July 30, 2023. The questionnaire survey content can be found in Appendix I.

(1) Main characteristics of respondents

Table 4.3 Main characteristics of respondents

Category	Option	Proportion
Respondent gender	male	65. 1%
	female	34.9%
Purchase type	Plug in hybrid vehicles	20.9%
	Pure electric vehicles	79. 1%

Table 4.4 Main characteristics of respondents

Category	Option	Proportion
Vehicle purchase time	Before 2022	16.5%
	2022.1- 12	36.8%
	January 2023 present	46.7%
Vehicle usage area	Shizong County, Xiongbi Town, Kuishan Town, Caiyun Town, Zhuji Town	78.3%
	Other villages and towns or surrounding areas	21.7%

(2) Car owner's charging time selection

By investigating the charging time that car owners generally choose, we can understand their daily use of new energy vehicles and have a certain degree of impact on the layout of charging stations. Based on this, we can consider the electricity consumption of public charging stations. In relatively concentrated charging times, the greater the charging demand. According to the survey, respondents generally choose to spot check their vehicles after 18pm, accounting for 52% of the time; 31% of people choose to use public charging stations for charging during the period from 12:00 to 18:00, while only 17% choose to use public charging stations during the morning period from 8:00 to 12:00. From this, it can be seen that car owners have a certain regularity in their choice of time for public charging. Therefore, when optimizing the charging layout, it is possible to study more reasonable time division service plans.

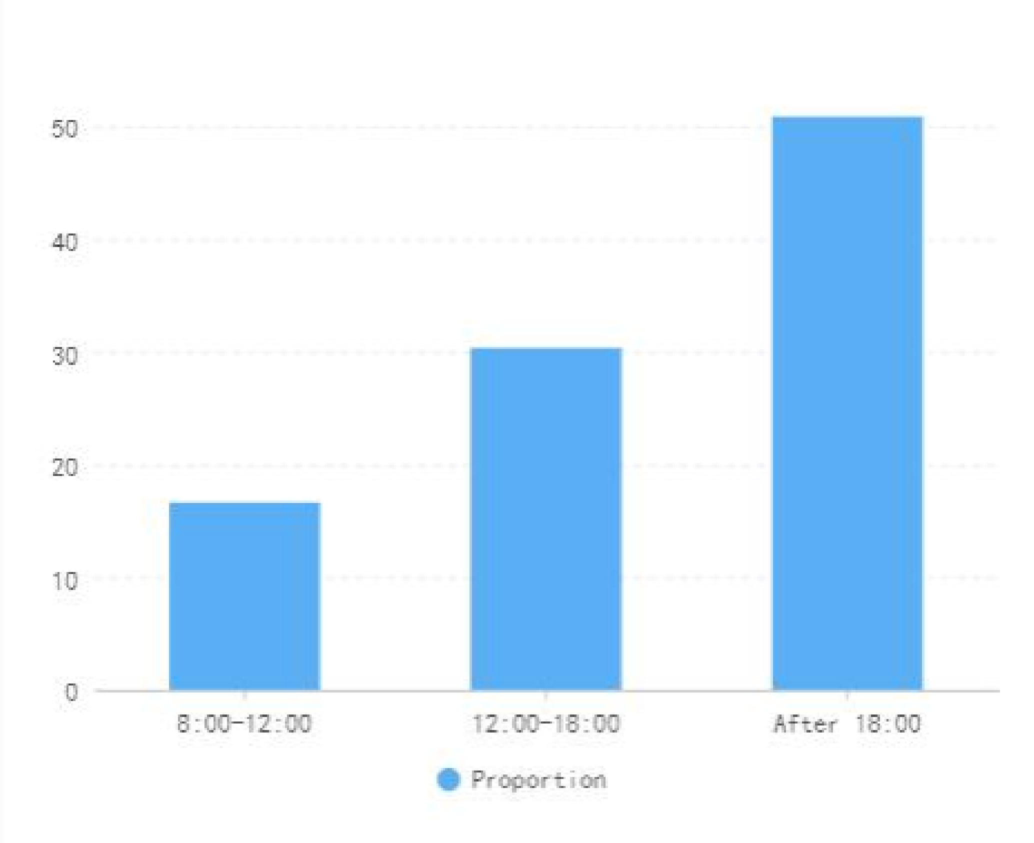

Figure 4.1 Car owner's charging time selection

(3) Vehicle owner's charging time consumption

The charging time typically consumed by car owners also reflects to some extent the user's habit of using public charging stations. A survey shows that 48.5% of new energy vehicles require charging time within 2 hours, 32% require charging time between 2 and 4 hours, 11.5% require charging time between 4 and 7 hours, and 8% require charging time of 7 hours or more. It can be seen that when using public charging stations, most car owners will choose fast charging stations to meet the problem of the lowest consumption time cost. Therefore, when laying out public charging stations, the selection of charging station equipment is important, Speed assurance should be the main focus.

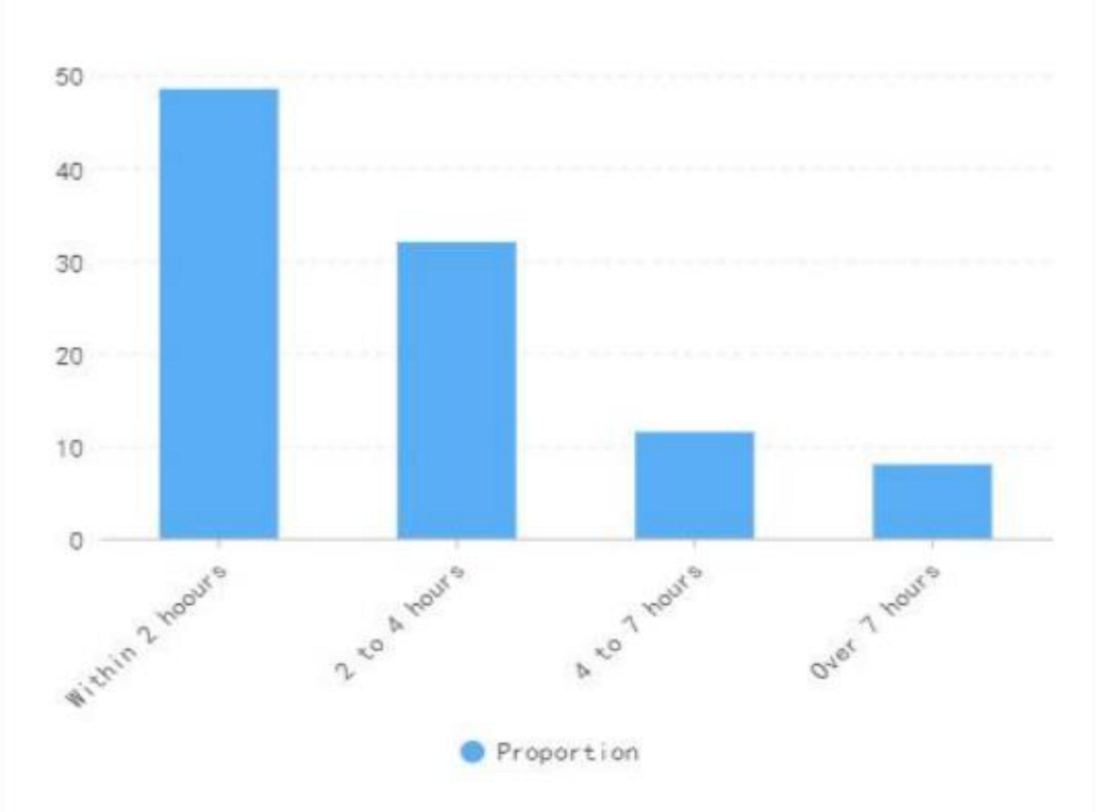

Figure 4.2 Car owner's charging time selection

(4) Selection of charging location

The tendency of car owners to choose which public charging station to use for charging services, that is, to choose the location of the charging station, directly affects the layout of the public charging station. The survey shows that 65% of respondents choose public charging stations around the community, followed by shopping malls and workplaces, with 14% and 20% respectively. From this, it can be concluded that the layout of public charging stations should be more inclined towards residential areas and unit areas, taking into account the flow of vehicles. This means that the commuting range of users should be fully considered, that is, the relevant road sections during the process of commuting from home to work, and should be arranged as much as possible in the vicinity of companies and communities, which will better meet the charging needs of car owners.

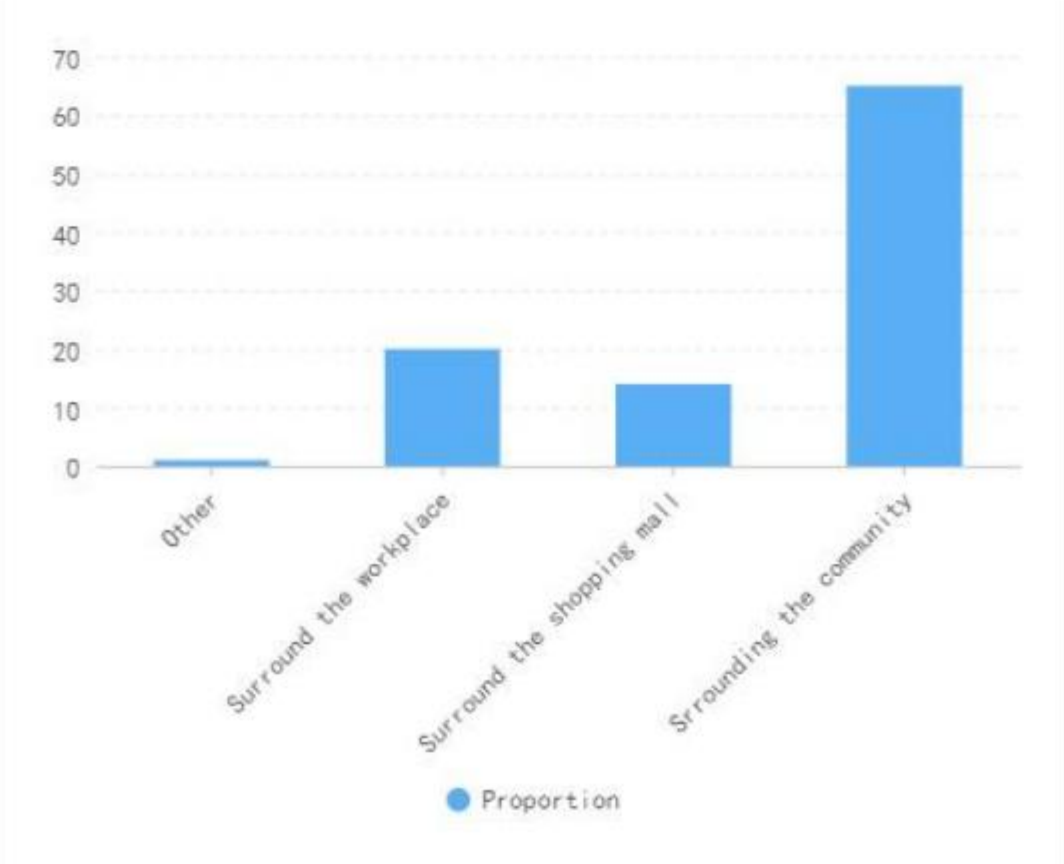

Figure 4.3 Charging location selection

(5) Charging fee price

The price issue of charging has always been an important factor affecting consumers when purchasing new energy vehicles, and it is a concern for the vast majority of car owners after purchasing, even playing a decisive role. The charging price of public charging stations is usually composed of three parts: charging electricity expenses, service expenses, and parking expenses. A survey shows that 49% of respondents believe that charging fees are reasonable, 32% of respondents believe that charging prices are average, and 19% of respondents believe that charging is unreasonable. Due to the current policy, the electricity and service fees of charging stations are generally stable within a certain range. It can be seen that the main influencing factor is the issue of parking fees.

Therefore, the layout of charging stations should fully consider the parking cost of the location where the station is built, and minimize the expenses required by the vehicle owner, thereby reducing the overall operating cost of the vehicle.

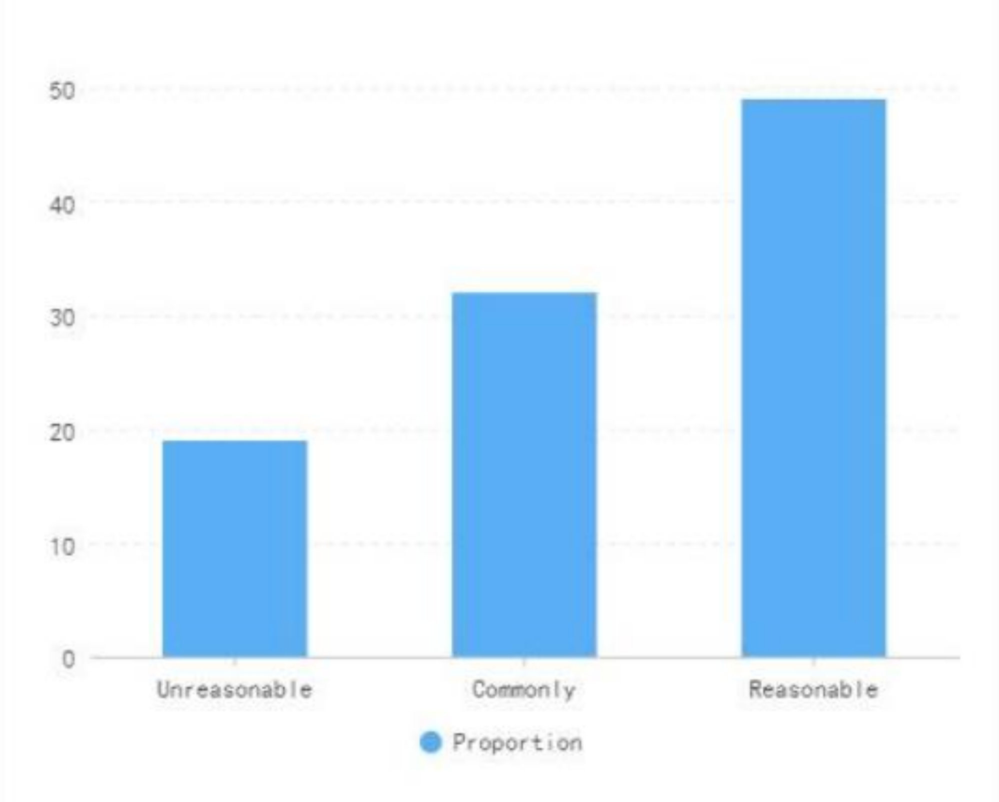

Figure 4.4 Satisfaction with charging prices

(6) Satisfaction with charging experience

The survey shows that the satisfaction rate of respondents with the experience of public charging stations is generally not high, with a satisfaction rate of only 22%. Those who think it is average and those who are dissatisfied are 45% and 33%, respectively. Therefore, there is still a lot of room for improvement in the satisfaction of car owners with their charging experience, especially in keeping up with the development of new energy vehicles, continuously optimizing and improving multiple aspects such as service, operation process, and charging, and improving user satisfaction is the key.

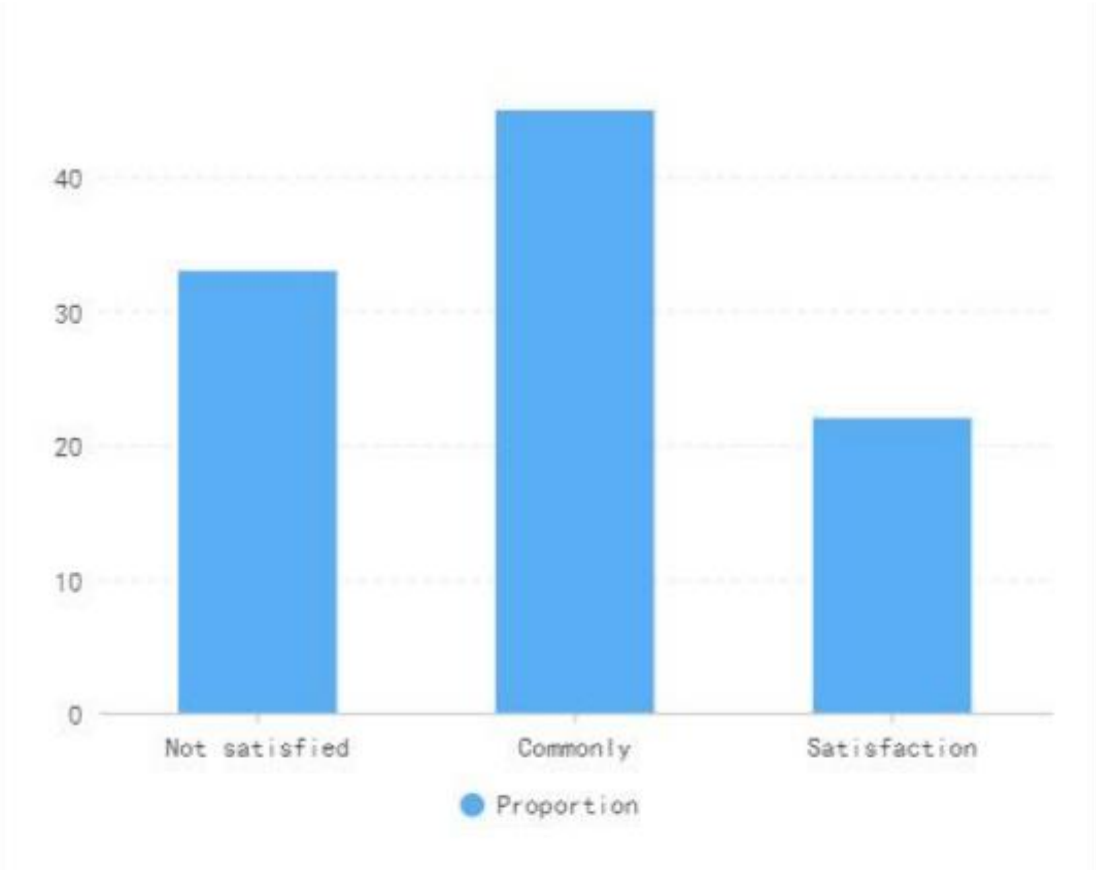

Figure 4.5 Satisfaction with charging experience

(7) Charging issues

The survey shows that the insufficient number of charging stations is the main problem that most respondents believe, accounting for up to 43%; Secondly, the layout of charging stations is unreasonable, accounting for 37.5%; In addition, respondents believe that there are certain issues with the occupation of charging spaces and the quality of charging station equipment, accounting for 11% and 7.5% respectively. Therefore, more attention should be paid to the impact of charging spaces being occupied by gasoline vehicles, including the negative issues that may arise in the normal use of new energy vehicle owners and the promotion of new energy vehicles. It can be seen that when considering the optimization of the layout of charging stations, appropriate parking space settings and strengthened supervision of daily parking space usage cannot be ignored.

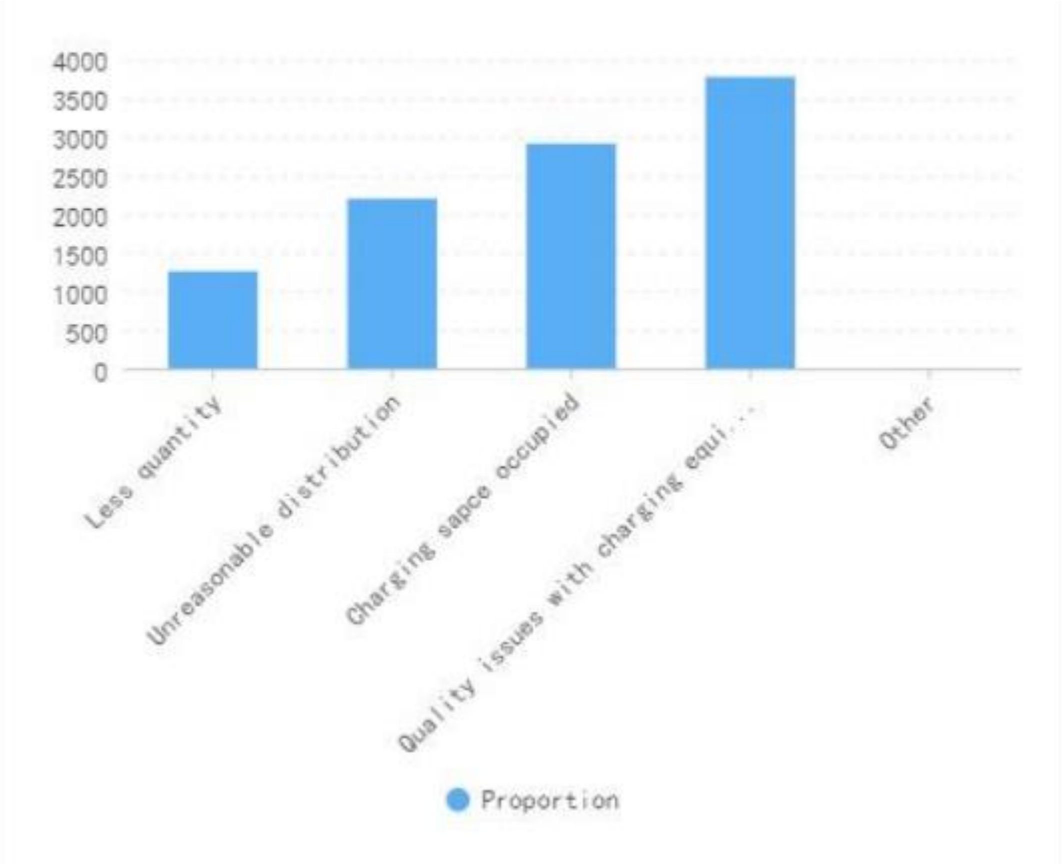

Figure 4.6 Charging issues

The above are several important indicator factors selected based on some literature and industry expert opinions, designed for energy vehicle owners in Shizong County. The main survey data on satisfaction with the use of public charging stations is collected with the support and cooperation of respondents. Based on the survey results, the real needs and satisfaction of users are understood and grasped, It is more conducive to identifying the problems in the development of public charging stations in the local area, so as to propose more targeted measures to solve the problems.

4.1.4 The main problems of public charging stations in Shizong County

The acceleration and efficiency enhancement of the layout and construction of charging stations is not only a strategic requirement for the government to develop the new energy vehicle industry, but also a useful measure to facilitate convenient transportation and promote the development of low-carbon economy. At present, there has been some progress in the construction of charging stations in Shizong County.

As of 2022, the scale of charging facilities in the county has reached nearly 200. But there is still a significant gap compared to projects in other fifth tier cities in Yunnan Province. With the increasingly enriched material and cultural life, the demand for new energy vehicles continues to accelerate, whether it is for personal use, public industries such as buses, taxi transportation, and logistics. Charging stations are crucial supporting equipment, and their supply-demand contradiction will become increasingly prominent.

Based on the satisfaction survey results of new energy vehicle owners using public charging piles in the previous section, combined with the relevant survey report released by the Shizong County Consumer Committee in December 2022, it is found that after the construction of charging piles, the profit model of the charging pile industry is unclear, the policy regulations for charging piles are unclear, the satisfaction with the use of charging piles is low, the number of charging piles is insufficient, and the distribution is unreasonable, The safety hazards of charging stations and the need for continuous improvement of charging technology remain prominent issues. Specifically, the problems faced by the layout of public charging stations in Shizong County mainly include:

(1) Uneven distribution of charging station construction

According to data from the intelligent management platform for charging facilities in Shizong County, as of October 2022, there are a total of 7 charging station operators, 12 charging stations, and 164 charging stations in the county. From the perspective of the whole county, there are currently no charging stations built in Caiyun Town, followed by Zhuji Town, with 16 charging stations already built. 32 charging stations have been built in Kuishan Town, 36 n Xiongbi Town, and 80 in the urban area of Shizong County. The public charging stations in Shizong County are mainly distributed in the commercial center of the city, a few newly built residential areas, suburban areas, and transportation service areas between towns; The charging stations in Xiongbi Town, Kuishan Town, and Zhuji Town are relatively densely distributed and concentrated in the central area of the town.

(2) Low utilization rate of charging stations

Shizong County and its affiliated villages and towns are vigorously promoting the construction of charging piles, but the arrangement of charging piles is either too centralized or too scattered, and the overall layout is unreasonable, resulting in some charging piles being idle. For example, the overall utilization rate of the six public charging piles located in the western suburbs of Shizong County is only 5.68%, which is low. Not only has the actual benefits of charging piles not been fully utilized, but it has also caused resource waste in the area, Moreover, due to the unclear profit model of the charging pile industry at present, some charging pile enterprises have unreasonable site selection for pile construction, coupled with inadequate maintenance work, ineffective charging piles have not been maintained in a timely manner, resulting in some charging piles being restricted and abandoned within a construction period of less than 2 years.

(3) High occupancy rate of charging parking spaces In the context of tight parking spaces in cities, there are cases where gasoline vehicles occupy charging spaces and parking spaces are not dedicated for charging, resulting in uncivilized occupation of parking spaces by car owners.

(4) The construction cost of charging stations is too high For charging station operators, firstly, the equipment cost of charging stations is high. Currently, the cost of building a regular specification slow charging station is about 30000 to 50000 yuan, and there is a significant investment in technology research and development costs and power supply capacity expansion; Secondly, the cost of land for pile construction is high, especially in the central area where the rent for land continues to increase every year, resulting in poor investment efficiency.

(5) The quality of charging stations varies greatly

In the early stage of charging station layout, due to the lack of unified industry standards in the market, some enterprises pursued cost reduction, and the selected materials had poor performance, resulting in incomplete product matching and uneven equipment quality and performance. Overall, there is still a lot of room for improvement in the operation of public charging stations in Shizong County in order to achieve more efficient and high-quality development. In this case, this article will consider and explore the reasonable layout and site selection of newly added charging stations in the local area based on the actual situation, bringing practical convenience to local car owners.

4.2 Instance solving

For example, a certain charging station construction and operation company plans to layout new energy vehicle public charging station stations within a designated area of Shizong County urban area. The area for planning and layout of charging station stations is 25k square meters. Within the intended construction area, there are a total of 18 road sections and 12 intersection nodes. The proportion of new energy vehicles is 8%, and the proportion of new energy vehicles that need to be charged is 20%; Based on the relevant regulations on new energy vehicles and charging piles issued by Shizong County, the values of relevant calculation parameters, coordinates of intersection points, and traffic flow are set in Table 4-5 and Appendix 3. According to the preset model in the previous chapter, an improved particle swarm optimization algorithm is used to calculate and analyze the example. The detailed solution process is shown in the Appendix.

Table 4.5 Relevant Calculation Parameter Values

Index	Value
The power of the charging station	96kW
The average capacity of energy vehicles	50kWh/unit
Minimum capacity configuration of charging stations within the site	5 unit
Maximum capacity configuration of charging stations within the site	20 unit
Unit price of charging station	¥72500
Effective charging time of public charging stations	16 h
Charging capacity margin	20%
Charging efficiency of charging stations	0.9
Discount rate	0.8
Loss rate	0.2
Iron loss rate	0.3

Table 4.5 Relevant Calculation Parameter Values (Continued)

Index	Value
Copper loss rate	0.3
Coefficient of simultaneous operation of charging stations	0.8
Operators pay electricity prices	1 yuan / (kW · h)
Unit electricity consumption of new energy vehicles	7 km / (kW · h)
User pays the charging price	1.8 yuan / (kW · h)
The average speed of the vehicle	32km / h
Value of user travel time	17 yuan / h
The service life of the charging station	10 years

(1) Location and traffic flow of 12 nodes

Table 4.6 Coordinates of 12 Node Positions

12 node position coordinates (X, Y)			
(1,1)	(2,1)	(3,1)	(4,1)
(1,2)	(2,2)	(3,2)	(4,2)
（1,3）	（2,3）	（3,3）	（4,3）

Table 4.7 Traffic Flow at 12 Node Positions

X-axis	Y-axis	Traffic volume	X-axis	Y-axis	Traffic volume	X-axis	Y-axis	Traffic volume
1	1	210	1	2	116	1	3	198
2	1	270	2	2	228	2	3	192
3	1	68	3	2	186	3	3	176
4	1	84	4	2	130	4	3	95

(2) Encoding particles：

1	2	3	4	1	5

4	3	3	5	1	2

As shown in the above figure, there are 12 nodes. Assuming there are 2 public charging station stations, randomly generate 1-5 values at these 1- 12 positions, and the number of each value is also random. There are 20 particles, c_1 =0.5, c_2 =1.49, and the maximum number of iterations is 20.

The final output result is: the location of each public charging station and the node location served by each public charging station, the number of service nodes, the cost of each part, and the total number of public charging station stations. The cost and total cost of each type of charging station:

Table 4.8 Cost and total cost of using POS algorithm to solve the number of charging station points

N/Number of charging stations	C1	C2	C3	C4	C5	C6	Total
1	39.37	28.71	1.43	19.32	3.13	26.45	118.41
2	38.65	21.92	1.69	19.62	3.06	25.72	110.66
3	38.61	24.82	1.85	19.18	3.08	26.03	113.57

Output the location of each public charging station and the corresponding service nodes of the public charging station, as shown in Table 4.9:

Table 4.9 Location of Public Charging Station Stations and Corresponding Service Nodes

	X	Y	X	Y
Charging station location	1.4	3.4	2.2	1.3
Service nodes	1	1	2	1
	1	2	3	1
	1	3	3	2
	2	2	4	1
	2	3	4	2
	3	3	4	3

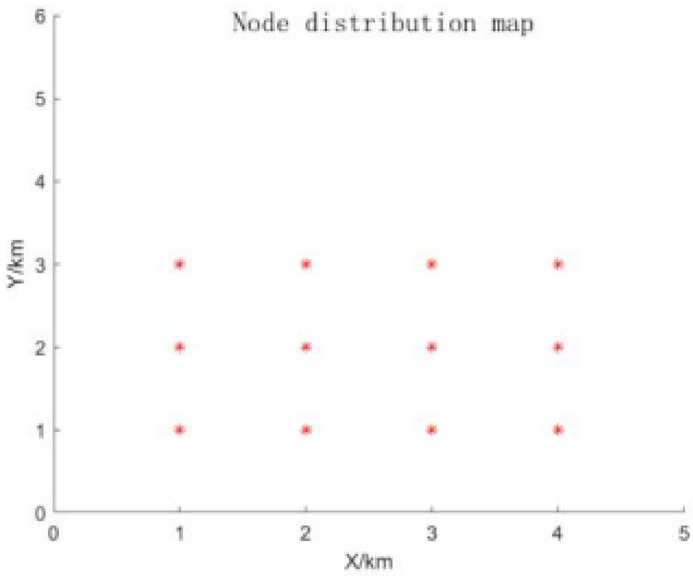

Figure 4.7 Node Distribution Map

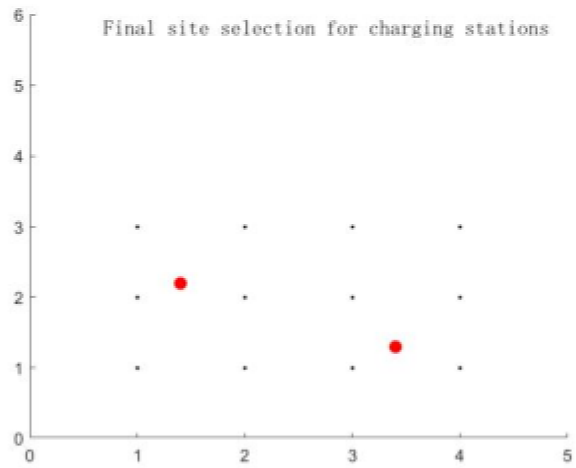

Figure 4.8 Final site selection for charging stations (The same color and shape represent the nodes served by the charging station)

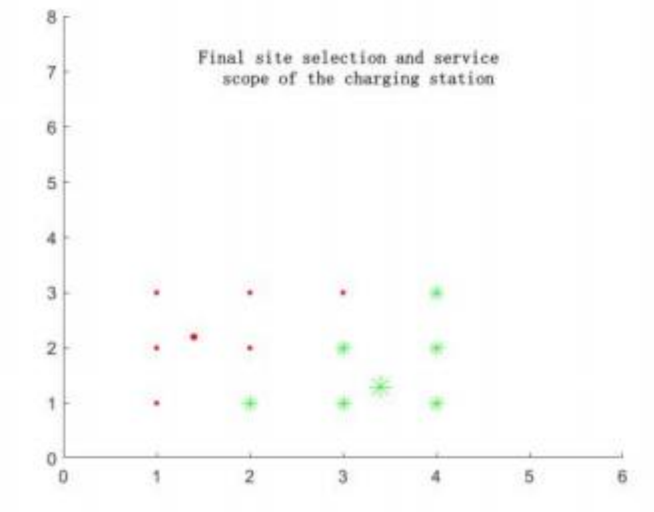

Figure 4.9 Distribution map of public charging station stations and corresponding service nodes

4.3 Suggestions for optimizing the layout of public charging stations

The example shows that the proposed method and model have certain feasibility and rationality in optimizing the layout of public charging stations. This provides decision-making references for optimizing the layout of charging station construction operators. Based on relevant industry standards for new energy vehicles and charging stations, and with the advancement of new energy vehicle technology, various factors such as construction investment costs, user demand for new energy vehicles, and consumption costs are fully considered to construct an optimal charging station layout model.For the optimization of the layout of the construction of new energy vehicle charging stations, on the one hand, efforts should be made to meet the various indicators of the above model. On the other hand, if we want to better improve the popularity of new energy vehicles, we also need to consider the status of the power supply network in the planning and layout area. Before implementing the planning and layout, we should actively coordinate with the power supply departments, fully utilize and play to the relevant government guidance policies, In order to continuously reduce the construction and operation costs of charging stations, and reduce the situation of unreasonable construction of charging stations, we should pursue the service quality of charging stations more finely, improve user experience and recognition, rather than pursuing the expansion of the number of charging stations, and bring tangible convenience to the travel of new energy vehicle users, better serving users.

At the same time, based on the analysis of population density in various regions of Shizong County, as well as the investigation of relevant new energy vehicle users, combined with the actual situation of charging piles and new energy vehicle ownership, the following strategies for optimizing the layout of public charging piles are proposed:

Table 4.10 Layout Strategy of Public Charging Stations in Various Regions of Shizong County

Region	Regional scope	Regionalism	Development strategy for the layout of public charging stations
Class I region	Datong street Longqing street Danfeng street	①High density of permanent population ②Large ownership of new energy vehicles ③Most of the residential areas have been built ④High demand for public charging ⑤High land use prices	①Comprehensive coverage ②Strengthen maintenance ③Service improvement
Class II region	Yangyue street Xiongbi Town Caiyun Town	① High density of permanent population ② Large number of new energy vehicles in stock ③ Both completed and newly built communities	① Strengthen encryption ② Accelerate layout ③ Reasonably set up points

Table 4.10 Layout Strategy of Public Charging Stations in Various Regions of Shizong County (Continued)

Region	Regional scope	Regionalism	Development strategy for the layout of public charging stations
		④ There is a high demand for public charging ⑤ Land use prices are relatively high	
lass III region	Zhuji Town Kuishan Town Gaoliang Town Wulong Town	① Low permanent population density ② The ownership of new energy vehicles is relatively small ③ Most newly built communities ④ Public charging demand is relatively small ⑤ Land use prices are relatively low	① Encourage and support ② Moderate increment ③ Improve publicity

4.4 Management inspiration

4.4.1 Research results

In the current global energy shortage crisis, environmental pollution is deteriorating and climate is warming. Vigorously promoting and developing environmentally friendly and energy-saving new energy vehicles is an important direction for the sustainable development of the automotive industry in the future, and it is also an inevitable trend for industry innovation and reform. With the strong support of the government and the promotion of technological progress, the progress of new energy vehicles has significantly improved, entering a stage of high-quality growth. As an indispensable part, charging stations can be said to be the key to the large-scale popularization of new energy vehicles. To some extent, it will also directly affect the daily operation of the car. After rapid development in recent years, China's charging station industry has grown from zero to gradually reaching a certain scale, and has now become the world's largest charging facility industry. However, as an emerging industry, there is still significant room for improvement in the development of charging piles in terms of product technology, quality, operational service level, as well as site selection and layout. This article analyzes the current situation, influencing factors, and operating results of charging piles both domestically and internationally, and provides specific policy recommendations for relevant government departments, providing a scientific and reliable theoretical basis for the operation of enterprises. On the other hand, linking theory with practice and proposing relevant strategies. On the basis of analyzing the current situation of public charging piles for new energy vehicles, combined with optimization planning models, explore relevant solutions for optimizing the layout of charging piles for new energy vehicles. The main achievements include:

(1) By studying the relevant literature on this industry, we can find that there are studies on both new energy vehicles and optimization of the layout of charging piles. From the literature, it can be seen that most of the research on new energy vehicles in China is focused on policies and industries. Research on specific infrastructure, such as charging stations, mainly focuses on optimizing the layout of charging stations and researching capacitance issues. Scholars choose indicator systems to construct layout models from the perspectives of economic operation and transportation convenience. These methods have reference value in layout optimization problems. This article also draws on the existing research of scholars and combines optimization models and particle swarm optimization algorithm to conduct research on the layout optimization of public charging stations, making the research results of this article more scientific and reliable.

(2) Investigate and analyze the current situation of the development and layout of charging stations. By integrating the opinions of relevant industry experts, this article believes that the planning and layout of new energy vehicles should follow the principles of easy promotion, comply with urban planning principles, have foresight, operability, and implementability, and meet practical needs. The factors affecting the layout of public charging stations include construction costs, user needs, social factors, and the influence of the power grid.

(3) Considering the relevant characteristics of new energy vehicle charging stations, various elements that need to be referred to when selecting a layout from a comprehensive and multi angle perspective. Based on questionnaire surveys and interviews, mathematical modeling methods are used to construct the optimal planning model for argumentation and analysis. Considering the benefits of both operators and new energy vehicle users, an objective function is established to minimize the total social cost. The layout problem of new energy vehicle public charging piles in Shizong County is selected as the main example, and the PSO algorithm is used to obtain the optimized layout of public charging piles in the area. The example shows that the plan is feasible for the layout of public charging stations. This study contributes to enriching the operational research theory of layout optimization and provides reference for future research. It has rich academic significance and helps provide practical reference value for the layout of charging stations.

4.4.2 Limitations of the study

(1) Industry limitations

The research object of this study is the layout of public charging piles for new energy vehicles, and the collection of research data is also based on the relevant indicator data of new energy vehicles. So the results of this research model are specific to the automotive industry, and its applicability to other industries is not within the scope of this study. The exploration of layout optimization problems is endless and requires further divergent thinking.

(2) Sample limitations

Due to time and personal limitations, this article only focuses on exploring six factors, including construction costs, land use costs, and user costs. However, there are various factors that affect the layout of charging stations; In addition, data collection mainly relies on online data collection and industry experts, as well as conducting interviews and surveys with the location of the case, relying on a large amount of qualitative analysis, which needs to be further supplemented, revised, and deepened in future research work.

4.4.3 Research Outlook

The main focus of this article is to study the layout optimization of new energy public charging piles, and to determine whether the results obtained are applicable to other enterprises with uncertainty. In future research, the research object can be extended to other types of enterprises. This research institute adopts the optimal planning model and particle swarm optimization algorithm, which can focus on the technological development dynamics of charging piles, combined with the actual needs of new energy vehicle users, and incorporate relevant factors such as the use of charging APP tools into the planning model, making the optimization model and method more closely related to practical problems.

4.5 Summary

This chapter obtains relevant data and information related to the layout of public charging piles for new energy vehicles through questionnaire surveys and field investigations; A satisfaction survey was conducted on the use of public charging stations among owners of new energy vehicles in Shizong County, and the survey results were analyzed; Through the establishment of a research model in Chapter 3, combined with an example in a planned area of Danfeng Town, Shizong County, the layout of new energy vehicle public charging piles is analyzed using an improved particle swarm optimization algorithm. The optimized layout scheme is obtained, and relevant layout optimization suggestions and strategies are proposed based on the actual situation

CHAPTER 5

CONCLUSION

The automotive industry is a typical intensive industry in terms of technology, talent, and capital. It is not only a traditional industry, but also an important force in achieving the upgrading and transformation of new industries. Today, the integration of new generation information networks, new energy and other technologies with the automotive industry has driven its industrial innovation. The automotive industry is developing towards electrification and intelligence. At present, the good development achievements of this industry are evident to all. At the national level, the government attaches great importance to and strongly supports the growth of this industry. With the continuous expansion of production and sales of new energy vehicles, the demand for charging is also increasing day by day. The lag of charging stations has become one of the important factors restricting the development of new energy vehicles. Therefore, it is urgent to study and analyze the problems faced by charging stations in China, explore paths to solve the problems, and propose corresponding solutions.

On the basis of organizing relevant literature and drawing on the research ideas and models of scholars, this article explores a series of problems related to the layout of charging piles derived from the current development of new energy vehicles. Starting from user satisfaction, the optimal planning model theory and particle swarm optimization algorithm are introduced, and a combination of quantitative and qualitative thinking is used to explore the layout optimization problem of charging piles. The main conclusions of this article are:

(1) The flourishing development of an industry relies on numerous related objects. The layout issue of the charging station is no exception. It involves many objects such as government, automobile manufacturers, dealers, charging station operators, users, and venue suppliers, and the factors that affect layout issues are also diverse. This article focuses on selecting the charging cost and idle driving cost of users, and the investment cost of building charging piles includes indicators such as electricity bills, equipment purchase fees, installation fees, and operation and maintenance fees. In the construction of the model, the important indicator of land

use cost is considered, and combined with industry standards and relevant goal planning, particle swarm optimization algorithm is used to solve the problem, proposing a new research and design idea. After practical examples, it is feasible.

(2) This article carefully summarizes the measures taken by countries that started earlier in foreign countries in the layout of charging stations as a foundation, hoping to trigger thinking on the promotion methods and model innovation of charging facilities, which has reference significance. In addition, this article conducted in-depth research on the status of the automotive related industry in Shizong county. Some positive innovative measures and development experiences in the region can provide a learning reference for other regions to promote common progress.

(3) This article will always adhere to the principles of easy promotion, operability, and practical needs throughout the entire paper, adhering to the principles of simplicity, speed, and efficiency, abandoning overly complex and cumbersome layout and calculation modes, and providing good solutions to practical problems, so that theoretical research can better serve practical needs.

(4) This article studies a large number of literature on the layout models and indicator construction of public charging piles. By using the optimal planning model for argumentation and analysis, a minimum social total cost target planning model is constructed. The layout of new energy vehicle public charging piles in Shizong County is selected as the main example, and the layout optimization plan is obtained through particle swarm optimization algorithm. Practice has shown that the methods and models proposed in this article are feasible and reasonable. This study is beneficial for enriching the operational research theory on layout optimization, providing reference for future research, and has rich academic significance and practical reference value

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APPENDIX

APPENDIX 1

User Satisfaction Survey Questionnaire for New Energy Public Charging Stations

Dear new energy vehicle owner：

Hello! We cordially invite you to fill out the following purely academic research questionnaire. This questionnaire is to be filled out anonymously. Please select the layout of new energy vehicle charging stations in Guangzhou based on your actual situation. The information you have provided is for academic research purposes only. Please rest assured to fill it out. Thank you sincerely for your assistance!

Your personal information

Your gender: □ Male □ Female

Your age: □ 18 years and below □ 19-25 □ 26-35

□ 36-45 □ 45-65 □ 65 years and above

Q1: Which area do you usually use your car in?

□ Yangyue Street, Datong Street, Longqing Street, Danfeng Street and other central urban areas

□ Xiongbi Town, Caiyun Town, Zhuji Town, Kuifan Town, Gaoliang Town, Wulong Town, etc.

□ Other

Q2: When do you usually charge?

□ 8:00-12:00 □ 12:00-18:00 □ After 18:00

Q3: When do you choose to charge your vehicle based on its mileage?

□ Below 100 kilometers □ 100-200 kilometers

□ 200-300 kilometers □ Above 300 kilometers

Q4: Where does your vehicle usually charge?

□ Community □ Unit 65

□ Shopping Mall Public Charging Station Station □ Other

Q5: Where would you like the public charging station to be installed?

□ Densely populated areas

□ office buildings and entertainment, commercial venues

□ Roadside near urban roads and highways

□ Other

Q6: What is the acceptable queue time for using public charging stations?

□ Within 15 minutes □ 15 minutes -30 minutes □ Over 30 minutes

Q7: Do you think the charging fee is reasonable?

□ Reasonable □ General □ Unreasonable

Q 8: Are you satisfied with the current construction of new energy vehicle charging stations in Shizong County?

□ Satisfied □ General □ Unsatisfied

Q 9: Do you think there are shortcomings in public charging stations? (Multiple options available)

□ Small quantity □ Low charging efficiency

□ cumbersome equipment operation □ Parking space occupied

□ Other

Appendix 2

Interview outline

Dear Madam/Sir

Hello! Thank you very much for taking the time out of your busy schedule to accept the interview. This is an interview survey on the optimization of the layout of public charging piles for new energy vehicles, aiming to understand the basic situation of the optimization of the layout of public charging piles for new energy vehicles, and better support the development of the new energy vehicle industry. This survey does not involve any confidential information of your organization, and the collected data is for academic research purposes only. Thank you sincerely for your assistance!

Interview time	
Interview location	
Interviewee	
Interview questions	Q1: How do you think the development prospects of the new energy vehicle industry are?
	Q2: What do you think are the opportunities and challenges facing the development of the new energy vehicle industry?
	Q3: What do you think are the main problems that need to be solved in the current development process of new energy vehicles?
	Q4: What do you think of the current construction of charging facilities for new energy vehicles? What are the main problems? Main solutions and suggestions?
	Q5: What do you think are the main factors that affect the layout of public charging stations? What is the order of importance of the relevant influencing factors (cost, user demand, power grid factors)?
	Q6: Regarding further optimizing the layout of public charging stations (from government, charging station operators, new energy vehicle production and sales enterprises, power supply enterprises, new energy vehicle users, etc.), what is your suggestion?
Sincerely thank you for your support and valuable feedback! Wishing you a happy life!	

VITA

NAME Wenchao ZHOU