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# Operation and Management Optimization on Data-Driven Intelligent Parking Reservation Platform

CHEN Rong

Doctor of Management

Supervisors:
PhD Pedro Sebastião, Full Professor,
ISCTE University Institute of Lisbon
PhD YAN Pengyu, Professor,
UESTC - University of Electronic Science and Technology of China

December, 2024

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BUSINESS SCHOOL

Marketing, Operations and General Management Department

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December, 2024

INSTITUTO UNIVERSITÁRIO DE LISBOA

**Operation and Management Optimization on Data-Driven Intelligent Parking Reservation Platform**

CHEN Rong

**Declaration**

I declare that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university and that to the best of my knowledge it does not contain any material previously published or written by another person except where due reference is made in the text.

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# Abstract

In China, there is a rapid development from rural areas to large cities, and the number of cars is also increasing rapidly. By 2021, the number of automobiles in China has reached 307 million, with 34 cities having over 2 million vehicles. However, the insufficient supply of parking spaces and the difficulty in parking have brought sharp problems to the city. This study uses real parking data from an underground parking lot in a shopping mall in Chengdu to analyze the parking patterns and periodicity of users. Based on this, a reservation process plan is designed, and a parking lot reservation process is formulated to improve the utilization rate of parking spaces. The specific research content is as follows:

Firstly, this study uses real parking data from shopping malls, and through data collection and analysis, obtains the peak parking periods and user parking patterns; Secondly, dynamic decision models were constructed for three types of parking reservation scenarios: advance reservation, temporary arrival, and random supply and demand, and deep reinforcement algorithms were designed for solution; Thirdly, based on the data analysis and model mentioned earlier, the parking process optimization design was carried out for three types of reservation situations; Finally, the effectiveness of the deep reinforcement algorithm and the operation and management process of the smart parking platform were verified through numerical simulation experiments.

To sum up, this thesis provides new ideas and inspiration for the reservation parking platform in the business scenario in terms of the parking reservation operation management mode, solution algorithm, pricing rules, etc., which can improve the profit of the management and make full use of parking space resources, and can help alleviate the current parking problem in China.

**Keywords:** urban parking, parking space utilization rate, parking data cloud platform, reserved parking, parking duration, data-driven, operation management

**JEL:** M1, M2

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# Resumo

Na China, há um rápido desenvolvimento de áreas rurais para grandes cidades, e o número de carros também está a aumentar rapidamente. Em 2021, o número de automóveis na China atingiu 307 milhões, com 34 cidades com mais de 2 milhões de veículos. No entanto, a oferta insuficiente de vagas de estacionamento e a dificuldade no estacionamento trouxeram graves problemas para à cidade. Este estudo utiliza dados reais de um estacionamento subterrâneo localizado num shopping center em Chengdu e permitiu analisar os padrões de estacionamento e periodicidade dos utilizadores. Com base nisso, um plano de processo de reserva é projetado e um processo de reserva de estacionamento é formulado para melhorar a taxa de utilização dos lugares de estacionamento. O conteúdo específico da investigação é o seguinte:

Inicialmente, este estudo utiliza dados reais de estacionamento de shopping centers e, por meio de coleta e análise de dados, obtém os períodos de pico de estacionamento e padrões de estacionamento dos utilizadores; De seguida, foram construídos modelos dinâmicos de decisão para três tipos de cenários de reserva de estacionamento: reserva antecipada, chegada temporária, e oferta e necessidade aleatórias, e algoritmos de reforço profundo foram projetados para solução; Com base na análise de dados e do modelo citado anteriormente, foi realizado o projeto de otimização do processo de estacionamento para três tipos de situações de reserva; Finalmente, foi verificado (através de simulação numérica) a eficácia do algoritmo de reforço profundo e o processo de operação e gestão da plataforma de estacionamento inteligente.

Em suma, esta Tese apresenta novas ideias e inspiração para plataforma de reserva de estacionamento em cenários reais que considera modelo de gestão de operação de reserva de estacionamento, algoritmos para solução inteligentes, regras de preços, etc., contribuindo essencialmente para a melhoria da gestão no geral, da receita e utilização dos recursos de espaços de estacionamento, e essencialmente na mitigação do problema atual de estacionamento na China.

**Palavras-chave:** estacionamento urbano, taxa de utilização de vagas de estacionamento, plataforma de estacionamento com dados na nuvem, estacionamento reservado, duração do estacionamento, orientado por dados, gestão de operação

**JEL:** M1, M2

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# 摘要

在中国，正在由农村向大城市急剧发展，汽车的数量也急剧增加。截止2021年，中国汽车保有量已经到达3.07亿，汽车保有量超过200万辆城市就有34个。而停车位供给不足，停车难给城市带来了尖锐的问题。本文利用成都市某商场地下停车场的真实停车数据，分析用户的停车规律和周期性，在此基础上，设计预约流程方案、制定停车场预约流程，来提升车位使用率。具体研究内容如下：

首先，本文利用真实的商场停车数据，通过数据收集与分析，得出了停车的高峰期时段以及用户停车规律；其次，分别构建了提前预约、临时到达和提前预约以及随机供给和随机需求三类停车预约情形下的动态决策模型，并设计了深度强化算法进行求解；第三，基于前文的数据分析和模型，分别针对三种预约情形进行了停车流程优化设计；最后，通过数值仿真实验，分别验证了深度强化算法和智慧停车平台运营管理流程的有效性。

综上所述，本文从停车预约运营管理模式、求解算法、定价规则等方面为商业场景中的预约停车平台提供了新的思路和启示，可以提高管理收入，充分利用停车位资源，有助于缓解当前中国的停车问题。



**关键词：**城市停车，车位使用率，停车数据云平台，预约停车，停车时长，数据驱动，运营管理

**JEL:** M1, M2

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# Chapter 1: Introduction

## 1.1 Research background

Urban traffic phenomenon is composed of dynamic traffic and static traffic. Static traffic is a general concept composed of short-term parking of various vehicles in traffic travel and long-term parking in parking lots. With the accelerating process of urban motorization, the problem of road traffic congestion has also become a common problem faced by major cities. The imbalance between the supply and demand of parking spaces has led to road parking and more and more illegal parking, which has further exacerbated the road traffic congestion and also led to frequent road traffic accidents. In recent years, major cities have successively implemented congestion mitigation plans, and achieved certain results in dynamic traffic problems through road reconstruction and expansion, vehicle lottery, and traffic restriction at the end of the number. However, there is no direct policy to intervene the parking problems caused by static traffic, and the governance of static traffic problems lags behind dynamic traffic.

At present, the problem of static traffic in China has become increasingly prominent. By 2021, the car ownership base has reached 307 million, and there are 31 cities with more than 2million cars, compared with 24 in 2017. The car ownership has increased rapidly. However, the gap of parking spaces in China's first tier cities is about 60% to 70%. In Beijing, for example, there are 6.08 million cars but only 1.89 million parking spaces. The parking problem caused by such a large parking gap has seriously affected urban development, especially in old residential areas, major business districts, hospitals and other areas with strong parking demand. On the one hand, the problem of parking difficulty is that the driver cannot find a parking lot or keeps searching for a parking lot when traveling. On the other hand, drivers can't find the best parking space in large-scale parking lots and can't successfully reach the designated parking space. From the perspective of urban traffic development, the number of motor vehicles in China's cities will continue to grow, which is bound to bring about the growth of urban motor vehicle travel in a certain period of time and greater parking demand.

In response to the problem of parking difficulty, the China Development and Reform Commission, the Ministry of housing and urban rural development and the Ministry of land and resources issued the guiding opinions on strengthening the construction of urban parking facilities and the notice on further improving the planning and construction of urban parking lots and land use policies and other relevant documents. The document requires that "parking facilities should be planned and constructed scientifically and reasonably, and the problem of parking difficulty and traffic congestion in cities should be alleviated by increasing the effective supply of parking spaces". In recent years, the level of Internet use, big data analysis and intelligence in China has been significantly improved. Many domestic parking technology companies have developed parking WeChat public accounts. For example, the public number platforms such as agile parking, fast parking, e-parking and intercity parking are mainly used to electronically pay parking fees and receive parking invoices for car owners and users. Many parking technology companies have developed parking space guidance systems to guide car owners to park and find cars in the parking lot. Some parking technology companies have also developed smart parking data platforms to effectively analyze the data, and then calculate the parking vacancy rate, turnover rate, utilization rate, etc. C-end tools, intelligent systems and big data are more and more widely used in the parking industry, which to some extent alleviates the problems of car owners' difficulty in parking and finding parking spaces.

At present, a large number of documents have proposed reservation modes and operation management methods to optimize parking problems, which can be divided into real-time reservation modes and shared reservation modes (W. Q. Huang, 2018). However, the real-time reservation mode is designed based on a simple first come, first served approach (FCFS) to obtain parking spaces, without considering the revenue management of the parking lot and the real-time resource supply. The shared reservation mode is a private release of empty parking spaces, and the release time and number of private parking spaces are random, which does not match the vacancy of parking spaces in the parking lot. Therefore, there are some drawbacks in the planning of these two reservation modes. It is urgent to use intelligent equipment and data analysis to further solve the real-time and profitability of the reservation parking process, so as to improve the parking turnover rate and solve the problem of car owners looking for parking spaces and parking quickly.

Based on the above parking status and literature review of relevant reservation modes, this thesis uses the real parking data of shopping malls to analyze the parking turnover rate of shopping malls and the occupancy rate of parking spaces in shopping malls, and obtains the parking behavior of users, the length of parking time of users and the operation status of parking lots in shopping malls. Secondly, the research points out that the existing reservation platform and mode have the problems of resource supply mismatch and unreasonable planning. On this basis, this study designed a better reservation management process of intelligent parking platform, hoping to effectively improve the parking utilization rate of parking managers and relieve the current urban parking pressure.

## 1.2 Research problem

As a developing country, China's automobile industry started relatively late, and the emergence of parking problems is also relatively late, so the studies related parking problems started relatively late. In the practice of parking management, in addition to the scarcity of parking space resources, the single mode of operation and management and the lack of scientific operation and management methods are also important reasons that can't be ignored. As an effective means to realize the pre management, in-process monitoring and post feedback of parking demand, reservation parking has been highly concerned and preliminarily explored and implemented by the parking management departments in various cities at home and abroad. However, the existing reservation parking mode can't effectively solve the problem of user parking randomness and heterogeneity.

Scholars have proposed reservation models and operational management methods to optimize parking issues, which can mainly be categorized into real-time reservation models and shared reservation models (W. Q. Huang, 2018). However, the real-time reservation model is designed based on a simple first-come-first-served (FCFS) approach to secure parking spaces, without considering the revenue management of parking facilities and the real-time supply of resources to match demand. The shared reservation model involves private individuals posting available parking spaces, but the timing and quantity of these postings are random, which does not align with the actual vacancy of parking spaces in the facility. Both reservation models have certain drawbacks, and there is an urgent need to optimize the operational management of parking reservation platforms based on real-time data, thereby improving the turnover rate of parking facilities and solving the problems of drivers finding parking spaces and parking quickly.

This thesis uses the real parking data of shopping malls to obtain the information of users' parking behavior and parking time through data analysis. On this basis, a better intelligent parking reservation management process is designed. The research work of this thesis will provide a new idea for domestic cities to solve the related problems such as the difficulty of users' parking and the difficulty of finding parking spaces.

In addition, the design of intelligent parking reservation management process in this study can find a more effective way to use parking resources. For car owners and users, the information-based booking service allows car owners to know the empty parking space in advance before going to the destination. After booking, they can find the parking space immediately after arriving at the destination, to solve the parking problem of car owners. In addition, in the intelligent parking lot, through the parking space guidance service, the reserved car owners can be guided to the reserved parking space, which not only allows the car owners to find the parking space, but also effectively saves the car owners' parking time and improves the car owners' experience. For parking managers, the information-based reservation service can make use of the time analysis of entering and leaving the parking lot to divert, extract the turnover rate of the parking lot, mine the vacancy rate under the data analysis, and then publish it through the intelligent reservation platform, so as to improve the efficiency of the parking lot and reduce the vacancy rate of the parking lot. For the government, intelligent reservation service can reduce vehicle parking time, reduce carbon emissions and vehicle exhaust, and reduce environmental pollution. The government can use the intelligent reservation system to release the vacant parking spaces, let the owners park, solve some parking problems, and effectively solve the parking difficulties. In addition, car owners can park accurately by using the reserved parking platform, which can promote the improvement of congestion around the parking lot and effectively reduce traffic accidents.

## 1.3 Research questions

Due to the uncertainty of parking time and exit time, the on-site vehicles are unbalanced, and the use rate of parking spaces is uneven due to the different car ownership and economic activities in various regions.

The problem studied in this thesis is how to use the data accumulated in the parking lot to analyze the characteristics of parking demand under the premise of considering the punctuality and randomness of car owners. On this basis, using data-driven and operation management related theories and methods, this thesis studies and puts forward the parking reservation management method and specific process of the intelligent reservation parking platform, so as to improve the utilization rate of parking space resources in the parking lot and the convenience of drivers' parking. Specifically, it includes the following four aspects:

(1) How to use mathematical and statistical analysis to uncover periodic patterns and characteristics of parking behavior?

(2) How to provide parking reservation services for busy periods (high parking turnover rate) and idle periods (low parking turnover rate)?

(3) How should the parking reservation platform make decisions under conditions of random supply and demand?

(4) How to design and validate the effectiveness of parking reservation algorithms and processes?

Through the previous literature research, there are many ways to find parking spaces. For example, looking at the signs on the road information board, or driving to the underground parking lot to look for it, or consulting the staff at the entrance of the parking lot to see if there is any parking space, these methods will more or less delay time, causing certain congestion or environmental pollution caused by vehicle exhaust, but the most direct and effective way to find a parking space is to make an appointment before going to the destination to ensure that the owner has a place to park after arriving at the parking lot. There are two types of parking reservation research in academia. One is the reservation information platform, which mainly uses information technology, algorithm and model knowledge to develop the reservation platform. The other is to take the reservation management process as the research type, which is more about the operation service direction, mainly for the parking management service. This thesis mainly studies the second appointment management process to find parking spaces for car owners and improve the parking utilization rate of parking managers.

## 1.4 Research objective

Based on the parking data collected from a large commercial underground parking lot in Chengdu, this thesis analyzes the characteristics of users' parking behavior and the dynamic change of parking space resources, and studies the reservation process and pricing rules of urban parking lot. The research objective on the operation and management of smart reservation parking platform mainly includes the following four parts:

(1) The current situation and demand of urban parking were investigated in the early stage. The government has built a new parking lot as the main solution to the parking problem. With the effective use of the parking space guidance system, the convenient payment of the parking charge system, and the various functions of the parking C-end tools (WeChat public accounts, Applets, Apps) online, intelligent parking has developed rapidly in China, but how to quickly find parking spaces and park them has always been the focus of the government and parking management.

(2) Field survey of a large commercial underground parking lot in Chengdu. Although parking is heterogeneous in China, the intelligent and platform-based parking has become very

popular in the first and second tier cities. The license plate can be captured by the camera entering the parking lot, and the data of the license plate can be stored by the parking management software. Based on this, this thesis collects the real parking data of the underground parking lot of the shopping mall, and uses the statistical analysis method to obtain the characteristics of users' parking behavior and the dynamic change law of parking space resources through monthly change analysis, weekly change analysis and daily change analysis.

(3) Model building. In this study, the car owner's reservation parking situation is divided into three cases: only advance booking, temporary arrival and advance booking, random supply and random demand. The optimization modeling of the above three cases is carried out, and the depth enhancement algorithm is designed to solve them. On this basis, the intelligent parking process optimization design is carried out for the above three cases.

(4) Numerical experiments and simulations. In this thesis, numerical experiments and simulations verify the effectiveness of the depth enhancement algorithm and the effectiveness of the operation and management process of the smart parking reservation platform.

## 1.5 Research method

(1) Literature research method. Literature method is mainly through the collection, identification, sorting out of literature, through the review and analysis of existing literature, we can understand the latest progress and research status in a certain field, which is a non-intrusive investigation method. By consulting the databases of CNKI, OKWF, VIP and other journals, combined with offline book resources, this thesis summarizes and analyzes the relevant theoretical literature on the optimization of reservation service operation, the operation and management of parking platform, and the process design of intelligent parking platform. On this basis, through literature reference and data analysis, this thesis formulates the reservation management process of parking lot to improve the utilization rate of parking space.

(2) Field research. The field survey method is a direct survey method. The investigators collect the relevant research data in person. Its advantage is that it can quickly and accurately obtain the required research data. This study collected the real parking data of a large-scale commercial underground parking lot in Chengdu. On this basis, the statistical analysis method is used to obtain the characteristics of users' parking behavior and the dynamic change law of parking space resources, which lays the foundation for the later research.

(3) Mathematical modeling. Mathematical modeling is to establish a mathematical model based on the actual problems studied and the relevant data collected, and solve the established

model, and solve the research problems according to the final solution results. In the fourth chapter, this thesis establishes the relevant mathematical model, and explores the decision-making problems of users' reservation of parking space and parking platform.

(4) Data simulation. Data simulation is a descriptive technology and quantitative analysis method, which is mainly used in scientific research, product development and other related fields. It describes the process or system through numerical calculation and simulation by computer. In the fourth chapter, through the data simulation experiment, compared with the approximation algorithm designed in the traditional literature, it is found that the effectiveness of the deep reinforcement learning algorithm is always significantly better than that of the approximation algorithm in terms of the predetermined cycle and the predetermined price.

## 1.6 Thesis structure

According to the above research contents and methods, the full text of this study is conceived as follows:

Chapter I: Introduction. This part mainly analyzes the current situation of urban parking, explains the significance of this study from the perspective of theory and practice, and expounds the research content of this thesis. On this basis, the research method of this thesis and the contribution and innovation of this study are proposed.

Chapter II: Literature review. This part mainly analyzes the domestic and foreign parking status, reservation service operation optimization research, parking platform operation management research, intelligent parking platform scheme design research and other related literature, laying a theoretical foundation for subsequent research.

Chapter III: Research data collection and analysis. This part introduces the data source, data collection and analysis process in detail. The monthly, weekly and daily changes of vehicle access on weekdays and weekends are analyzed by using relevant statistical analysis methods. In addition, this thesis makes a detailed analysis on the parking turnover rate and parking space occupancy rate of the underground parking lot of shopping malls within one week.

Chapter IV: Operation management optimization modeling and process design of smart parking reservation platform. In this part, the model is mainly established under three parking situations, i.e. only considering advance booking, considering temporary arrival and advance booking, and considering random supply and random demand, and the depth enhancement algorithm is designed to solve the model. On this basis, the operation and management process of the smart parking reservation platform in these three cases is optimized.

Chapter V: Numerical experiments and simulations. This part verifies the effectiveness of the deep enhancement algorithm and the operation and management process of the smart parking reservation platform through simulation experiments.

Chapter VI: Conclusion. It mainly presents the main conclusions of thesis. At the same time, it further discusses the main contributions and research significance of this thesis, and points out some shortcomings of the current research and the direction worthy of further exploration.

Figure 1.1 presents the roadmap of this thesis.

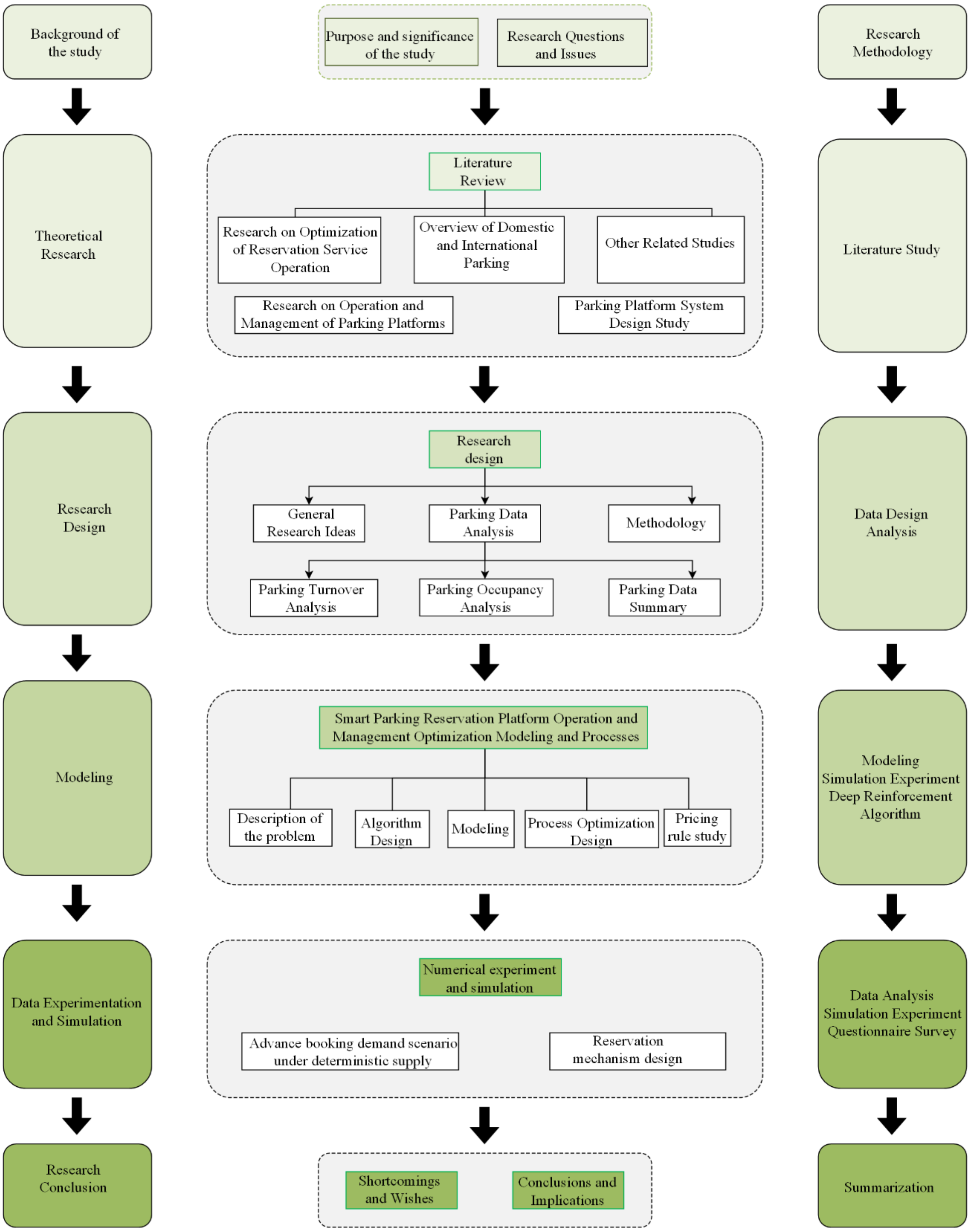


Figure 1.1 Research roadmap

## 1.7 Contribution

(1) This study uses the real underground parking data of shopping malls and obtains the characteristics of users' parking behavior and the dynamic change law of parking space resources through statistical analysis. At the same time, through literature and theoretical analysis, this thesis has a more profound understanding of the parking problem in various urban

environments. The research results of this thesis can provide some reference for subsequent research.

(2) At present, scholars at home and abroad have proposed a large number of reservation modes and operation management methods to optimize parking problems. However, these operation management methods do not consider the revenue management and real-time resource supply of the parking lot. The intelligent parking reservation process designed in this thesis can effectively solve the randomness and heterogeneity of users' parking, which is innovative and challenging, and makes up for the deficiency of current research to a certain extent.

(3) At present, there is little research on the number of parking spaces and price setting. This thesis divides the reservation parking in shopping malls into two cases, namely, free time reservation and busy time sharing. By studying the parking space setting range and price setting range of the two cases of free time sharing and busy time reservation in commercial parking lots, we can make better use of the limited parking space resources and help maximize the interests of the platform side. The research has a certain degree of innovation, which makes up for the deficiency of the current research to a certain extent.

(4) In the data simulation experiment, the deep enhancement algorithm designed in this study shows that the effectiveness of the predetermined period and the predetermined price is always significantly better than the effectiveness of the traditional approximation algorithm, which can provide new methods and ideas for future related research.

# Chapter 2: Literature Review

According to the research roadmap, this chapter will review the literature related to smart parking. This includes parking-related issues, operation optimization of reservation services, operation of parking platforms, and parking platform system design. By analyzing the existing literature, the shortcomings of current research will be identified to guide the smooth progression of this study.

## 2.1 Parking-related issues

### 2.1.1 International parking

The shortage of parking resources in foreign countries has brought sharp problems to cities: The first is the lack of parking resources, which leads to traffic congestion when car owners are looking for parking spaces. The second is that car owners waste time when looking for parking spaces. For example, in large cities such as New York and Paris, it takes an average of 7.8 minutes to find parking spaces (Arnott et al., 2005). Then, fuel is also consumed in the process of searching for parking spaces, which indirectly increases the economic cost. The fuel wasted by travelers in searching for parking spaces can reach 30% of the total amount of fuel used every year, and the wasted journey cost per traveler per year is about 4000 yuan (L. Zhang, 2016). Finally, the waste emitted by vehicles in the process of finding parking spaces will directly cause environmental pollution. For example, the 15 blocks of Los Angeles will produce 730 tons of carbon dioxide a year on average due to the search for parking spaces (Shoup, 2006).

Some foreign countries and regions started early in the research and application of intelligent parking lot management system. Its technology should be relatively mature and its functions should be relatively perfect (Z. Y. Zhou et al., 2006). In 1973, the earliest parking guidance system in Japan was established in Boshi, Japan. The specific location, number of parking spaces, number of empty parking spaces and specific occupation of parking lots are reflected in the parking guidance system (Z. H. Wang et al., 2006). As early as 1995, Japan has used intelligent parking guidance system for urban traffic management in more than 40 cities. Japan's first mature case Shinjuku District of Tokyo also combines monitoring safety, road network control, traffic control and other linkage factors. In terms of the function of parking space reservation, "ParkMe" in the United States and "JustPark" in the United Kingdom all use first come, first served (FCFS) reservation. Using mobile Internet, radio frequency identification (RFID) and other technologies, this kind of parking reservation platform can collect the specific location, occupancy status, available parking time and other information of parking spaces in real time. At the same time, these information can also be sent to travelers with parking needs in real time, and travelers can quickly find free parking spaces in the destination area through advance booking or real-time distribution, so as to improve the parking experience of travelers, improve the utilization rate of parking spaces, and then improve traffic congestion, reduce exhaust pollution and traffic accidents (W. Liu et al., 2014).

This kind of operation management means is single, that is, the parking manager puts all available parking spaces on the website platform at one time, and meets the parking demand in turn according to the time sequence of travelers arriving at the parking lot or sending parking space reservations. However, through the analysis of parking data, it is found that the parking time of demanders is quite different, and the arrival time of demand is uncertain. It is difficult to ensure the effective utilization of parking space resources and the maximization of platform revenue by using FCFS rules. Therefore, how to use information technology and operation management theory to establish the intelligent parking real-time reservation management process, and put forward a more scientific and reasonable parking reservation management strategy for the randomness and heterogeneity of parking demand, so as to improve the utilization rate of parking space and maximize the revenue of parking platform is an urgent problem to be solved for the parking reservation management platform (Z. X. Zhang, 2020).

### 2.1.2 Domestic parking

In China, parking is mainly divided into two categories, namely, urban parking is divided into roadside parking and closed parking. Local governments actively build urban parking. The construction ideas are as follows: First, master the data of parking resources and the utilization of parking facilities in the city, and deeply analyze the "where, how and why" of parking through big data. Second, public parking revenue is used to support the development of public transport and the planning, construction and management of parking facilities. Third, release relevant standards and specifications for parking management to promote service and long-term service. At the same time, establish a parking operation company to ensure long-term investment of the project through operation. Fourth, the intelligent transformation of public resources and the construction of urban parking networking, realize the interconnection of parking information, and revitalize the stock of parking resources through the construction of smart parking. Fifth, based on resource integration, open parking information to the public, and improve citizens' parking experience through parking information query, parking guidance and convenient payment.

According to international experience, the total demand for parking spaces is 1.1-1.3 times that of car ownership. China's large and medium-sized cities are generally faced with insufficient parking spaces and fewer cars. In recent years, the parking problem has become prominent (L. X. Yang, 2017). By 2018, the supply of parking spaces in China was 110 million, while the number of car ownership was 230 million and the demand for parking spaces was 300 million, as shown in Figure 2.1.

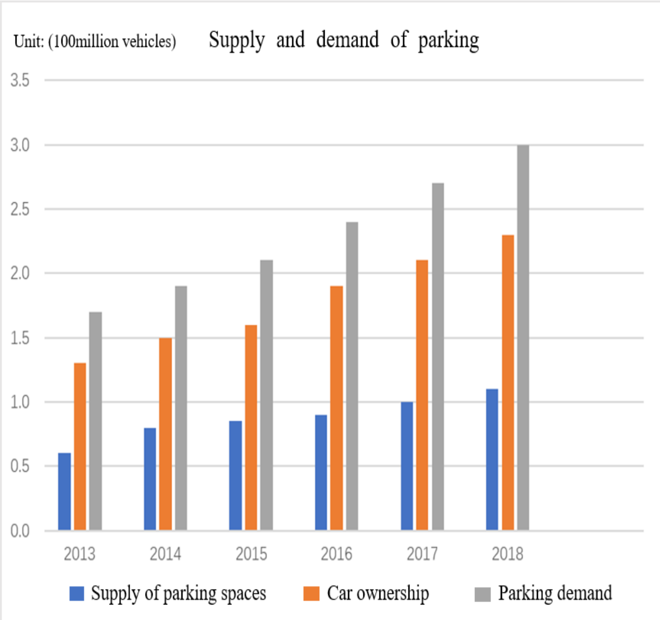


Figure 2.1 Parking space supply and demand

Source: Statistical data from Forward Industry Research Institute

The imbalance between supply and demand of parking facilities is a common problem in many cities, and the parking problem has brought great trouble to urban development planning. It is no longer possible to simply increase the supply of parking facilities to meet the parking demand, so the parking supply planning must be regulated from the perspective of supply and demand control. From the idea of "demand guidance and full satisfaction" to "differential supply and demand regulation", reasonable formulation of berth supply strategy is the key link of parking planning. This imbalance between supply and demand leads to the public side: parking is difficult, travel is blocked, and fees are charged indiscriminately; government side: no norms, no standards, difficult to manage; Business side: high cost, low efficiency and many loopholes.

Parking management has attracted great attention and interest from scholars in the fields of government policy, traffic planning, operation management and computer science. Relevant research mainly focuses on the following three aspects:

The first aspect is the government policy. China's urbanization process is fast. The government has successively launched the following policies in terms of parking. In 2015, China's seven national ministries and commissions jointly issued the guidance on strengthening the construction of urban parking facilities. Then, in terms of parking planning, the goal of "guidelines for urban parking facilities planning" was introduced; In terms of parking construction, the requirements of the guide for the construction of urban parking facilities were introduced; On the parking land, the notice on further improving the planning and construction of urban parking lots and land use policies was given; In terms of parking investment and construction, the guidelines for the issuance of special bonds for the construction of urban parking lots were issued; In terms of parking charge management, the guidance on further improving the parking service charge policy for motor vehicles was given. The publication of the above policies and documents shows that the Chinese government attaches great importance to the parking industry.

The second aspect is to study the planning of parking lots in large and medium-sized cities from the perspective of increasing the supply of parking resources, participate in the overall design of urban parking, and alleviate the problem of parking difficulty by building new parking lots to increase parking spaces, parking garages and three-dimensional parking facilities (L. Wang, 2014).

The third aspect is to propose the framework design and functional modules of the intelligent parking platform, and put forward the logical architecture, platform composition and technical methods of function realization of the urban parking platform (Y. W. Li et al., 2014).

The goal of smart parking technology companies in China to build urban parking intelligent system is to build a unified parking lot management system in the city around the core functions of "smart parking integration" of parking management, parking service, payment service, big data analysis and data operation. At the same time, through the formulation of technical standards, the establishment of service quality evaluation system and supporting management and operation system, the unified access of the city's parking lots and the centralized, integrated and professional management of parking resources are realized, providing regulatory support for the traffic police, price, quality supervision, market supervision, urban management and other departments, effectively alleviating the parking problem, promoting the standardized operation and management of berth operators, and improving the management and service level of parking lots.

From the perspective of operation management, through demand forecasting, parking lot management strategies and related management models, a dynamic pricing strategy using price to control demand is proposed. In terms of parking demand management, Chinese scholars have done relatively little research. In terms of hospital parking demand management, there is no more systematic research data. Although domestic research on parking demand prediction started relatively late, it also has a certain research foundation. The main research results are as follows: Bao et al. (2006), scholars from the school of transportation in Southeast University, based on the analysis of the current situation of urban static traffic, made specific assumptions for the development and management of urban static traffic in the future from five perspectives of parking supply, community parking, park and ride, parking intelligence, and parking fees. Lv and Hong (2010) made a detailed data analysis on the empty characteristics of parking demand and the influencing factors of parking demand, what's more introduced the concept of demand management to establish a parking demand management framework. C. Pan et al. (2012), scholars from the school of transportation in Dalian University of Technology, divided the parking behaviors into commuting, non-commuting and residential parking according to the different travel purposes of drivers. Based on the research results of parking behaviors with different land properties in Dalian, they summarized the characteristics and differences of parking demand of each parking behavior and proposed the demand management method based on these three parking behaviors.

## 2.2 Operation optimization of reservation service

### 2.2.1 Reservation scheduling and capacity allocation optimization

An effective reservation scheduling system can solve the problem of resource matching in various industries, which is very important to improve customer satisfaction in various service industries.

At present, there are many research on reservation scheduling system in China, mainly focusing on the medical treatment and transportation industry. For example, X. W. Pan and Geng (2016) conducted a field study on the Mir inspection in a class III a hospital. On this basis, a time-division magnetic resonance imaging (MRI) inspection appointment model was established based on discrete event simulation method, and a new appointment scheduling rule was designed. C. J. Yan et al. (2014) studied the reservation scheduling problem with fairness constraints and patient selection based on the exponential distribution of service time, and proposed an innovative sequential algorithm, which can be used to obtain the optimal number of patients and the maximum revenue of the hospital every day. Wu et al. (2022) established a matching appointment scheduling model based on Markov Decision Process (MDP) and compared it with the traditional First Come First Serve (FCFS) according to the real-time appointment and scheduling problem of medical treatment, considering the differences of doctors' qualifications and patients' diseases, and aiming at maximizing hospital profits. The results show that the MDP appointment strategy is a threshold strategy related to the number of patients remaining to be served by doctors. The revenue of this strategy is higher than that of the FCFS reservation strategy, which is conducive to ensuring the stable operation of the hospital. S. M. Yang and Guo (2008) proposed a reservation scheduling based MAC protocol for wireless sensor networks SSMAC. Zhu et al. (2014) established a finite time domain Markov decision support model to explore the optimal scheduling strategy for patients' appointments.

Klassen and Yoogalingam (2009) used simulation optimization method to determine the optimal rules of stochastic reservation scheduling problem. Cruz et al. (2005) analyzed the problem of service and capacity allocation in state dependent M/G/c/c queue networks and developed an algorithm to calculate the optimal allocation C. The model is applied to the modeling of pedestrian circulation system, and the basic series, merge and split topologies are studied. The results show that the optimal capacity model is surprisingly repeated on different topologies, and it also depends heavily on the arrival rate. Additional computational simulation results show the accuracy of the method in all test configurations. D. Gupta and Denton (2008) described the most common types of healthcare delivery systems and paid special attention to the factors that make appointment arrangements challenging. For each environment, it describes the relevant decisions from a set of rules guiding the scheduler to the real-time response to the deviation from the plan. The roadmap of the latest technology in the design of reservation management system is provided, and the future opportunities for the new application of IE/OR model are determined. Vanden Bosch and Dietz (2000) established an appointment strategy for a specific outpatient system with the goal of reducing the expected waiting time of patients and the expected overtime of doctors. Compared with the traditional scheduling practice, it can greatly reduce the waiting time, and once the optimal strategy is established, the process is easy to be implemented by naive scheduling program.

In terms of capacity allocation, foreign scholars have proposed a variety of models, which are mainly used in the service industry to improve the fairness of the industry and maximize revenue. For example, T. L. Chen and Wang (2016) discussed the allocation of medical resources in the case of long-term overcrowding in the emergency department of the hospital through multi-objective simulation and optimization. Deglise-Hawkinson et al. (2018) researched and developed a capacity allocation optimization method to ensure that services are provided to various types of patients in a complex comprehensive nursing environment. Habibi et al. (2017) introduced a multi-objective optimization model of urban domestic waste management system composed of customers, transfer stations, landfills, recycling plants and waste transport vehicles. The model can help decision makers determine the optimal location of municipal solid waste recycling and disposal facilities, optimize the capacity allocation of landfill to transfer stations and population centers, optimize the capacity allocation of transfer stations and recycling plants to population centers, determine the most suitable technology for each operation, and find the appropriate number and type of transport vehicles according to the above objectives. Dance and Gaivoronski (2012) studied the problem of repeated allocation of limited renewable service resources in distributed service centers. Hall (1999) proposed a method to allocate airport capacity to users of the National Airspace System (NAS) when resource demand exceeds capacity. One metric to evaluate the proposed method is the value that users of the network autonomous system can achieve through allocation. Simulation results show that this method can significantly improve the main indicators of user value. In addition, the method also brings some side benefits, such as reducing fuel consumption, reducing harmful emissions to the environment, and improving the service reliability of the flying public.

In addition, capacity allocation has also been widely explored in industrial activities. Roumeliotis et al. (2020) studied the optimal allocation of various performance indicators in multi beam high throughput smart satellite systems operating at extremely high frequencies. The goal of minimizing the total system capacity loss and matching the ratio is achieved, and the system satisfaction is maximized. Korilis et al. (1997) studied capacity allocation in non-cooperative user sharing networks. Shu and Niu (2003) studied the problem of random received signal interference caused by power control error and proposed a closed capacity quasi optimal power allocation scheme. Xie et al. (2019) studied the capacity allocation of energy storage equipment shared by multiple households in smart grid. L. P. Zhou et al. (2018) proposed a multi-objective stochastic programming model with the goal of maximizing revenue and fairness in order to maximize hospital revenue and fairness among different types of patients at the same time. White et al. (2011) developed an experience based discrete event simulation to examine the interaction between patient appointment policies and capacity allocation policies, and how they affect various performance indicators together. Aein and Kosovych (1977) studied several allocation strategies for sharing satellite capacity among user groups requiring circuit switching or store and forward (message switching) communication services and obtained the comparative analysis results of allocation strategies by using traffic model and queuing model.

The results show that the ability to provide a specific level of service depends largely on the specific allocation strategy selected. K. B. Chen and Xiao (2015) established a supply chain game model with multiple uncertainties and studied the impact of channel power on supply chain efficiency. The study found that when the disruption risk is low enough and the production capacity is large enough, the manufacturer has no incentive to outsource. When the disruption risk is high enough, the manufacturer will completely outsource production without considering the production capacity. Hsieh and Wu (2008) studied the coordination decision problem in a decentralized supply chain composed of an Original Equipment Manufacturer (OEM), a manufacturer and a distributor. The supply chain has uncertainty on both the demand side and the supply side. The research shows that the coordination with OEM improves the probability of manufacturers' meeting downstream demand and manufacturers' expected profits, but in the absence of downstream coordination, the coordination with manufacturers is not necessarily conducive to OEM.

### 2.2.2 Intelligent parking reservation service

Due to the limited urban space resources, high parking costs and parking spaces are often in short supply, the parking problem has become one of the main problems of urban traffic management. In order to balance the existing conflicts, parking fees and reservation mechanisms are usually used to improve the overall efficiency of parking spaces (Mei et al., 2019). Based on this, many scholars have proposed a variety of parking reservation systems to alleviate the current parking problem.

For example, He et al. (2018) proposed a real-time parking reservation service to minimize the total travel cost of all users. Teodorović and Lučić (2006) studied the basic concepts of parking reservation system and parking revenue management system. An "intelligent" parking space inventory control system based on the combination of fuzzy logic and integer programming technology is proposed. The system can "online" decide whether to accept or reject the parking request of a new driver. Boudali and Ouada (2017) studied and proposed an intelligent parking system based on multi-agent method, which provides real-time decision-making assistance for drivers by processing drivers' preferences. The system ensures online space allocation based on real-time information by optimizing drivers' preferences in operational constraints. Lei and Ouyang (2017) used dynamic location related parking pricing and reservation to improve the system performance of intelligent parking system. Through this system, parking agencies can determine the temporal and spatial distribution of parking prices to achieve a variety of goals, while drivers from different destinations and destinations can compete for limited parking spaces through online booking.

Mei et al. (2020) provided operation suggestions for the parking management department by allocating a reasonable reserved proportion for each public parking lot in the urban area, optimizing social benefits and parking revenue. Kotb et al. (2016) introduced an intelligent parking system based on intelligent resource allocation, reservation and pricing. The system solves the current parking problem, provides guaranteed parking reservation for drivers with the lowest cost and search time, and provides the highest income and resource utilization for parking managers. Geng and Cassandras (2012) proposed a new urban environment "intelligent parking" system. The system allocates and retains the optimal parking space for drivers according to the needs of users, combined with the destination distance and parking cost, while ensuring the effective use of the overall parking capacity.

Ahad et al. (2016) proposed a web app system called "Park easy". The system is based on the sensor monitoring technology of smart phones and uses cameras as sensors to take photos to display the occupancy of parking lots. Through the implementation of this system, the utilization rate of parking spaces will be improved. Srikanth et al. (2009) described the overall system architecture of spark from the perspective of sensor networks and studied and implemented a complete parking management prototype system to achieve the above design functions and characteristics. The results show that the performance of the system based on WSN can effectively meet the needs and requirements of the existing parking problems, so as to minimize the time to find vacant parking lots, real-time information presentation, and intelligent reservation mechanism. Somani et al. (2018) introduced a user-friendly application to provide users with operations from searching for parking spaces to confirming the reservation of parking spaces. The circuit used in the whole operation is easy to build and cost-effective for the organization to implement it.

In addition, another reason for the prominent parking problem is that it is difficult for car owners to find parking lots. To solve this problem, many scholars have also proposed a variety of models to solve this problem by using the Internet of things technology.

For example, J. Y. Liu et al. (2020) used Internet of things technology to model the roads and main parking lots, and used adaptive genetic algorithm to conduct driver guidance simulation. The optimal path and the shortest time for the driver to reach each parking lot from the current position are obtained. Sana et al. (2014) proposed an agent network that can reduce the search time required to find parking spaces. The solution is based on the multi-agent model and is designed to help drivers find parking spaces anytime and anywhere. Shin and Jun (2014) proposed an intelligent parking guidance algorithm, which supports drivers to find the most appropriate parking facilities when considering the real-time status of urban parking facilities. In addition, the algorithm considers the driving distance of the guided parking facilities, the walking distance from the guided parking facilities to the destination, the expected parking cost and the traffic congestion caused by the parking guidance to recommend the most appropriate parking facilities. The simulation results show that the algorithm effectively controls the utilization of parking facilities, reduces the traffic congestion caused by parking space search, helps to maximize the use of urban space resources, and reduces the unnecessary energy consumption and carbon dioxide emissions of stray vehicles.

Said et al. (2021) proposed a green intelligent parking system solution based on the Internet of things. H. W. Wang and He (2011) designed and implemented a prototype of reservation based intelligent parking system (RSPS). In addition, the most advanced parking policies in intelligent parking system are studied and their performances are compared. The experimental results show that the proposed reservation based parking strategy has the potential to simplify the operation of the parking system, and can alleviate the traffic congestion caused by parking search. Fu et al. (2014) designed an optimal parking lot recommendation model based on reservation networking environment, which can effectively solve the problems encountered in the process of finding the optimal parking lot, save drivers' parking time and costs, improve the overall utilization of parking facilities, and alleviate traffic congestion caused by vehicle parking patrol. J. Yang et al. (2012) proposed the design and implementation of an intelligent parking service prototype system based on wireless sensor networks, enabling vehicle drivers to effectively find free parking spaces. The scheme consists of wireless sensor networks, embedded web servers, central web servers and mobile applications.

Kabir et al. (2021) aim to solve the problem of parking difficulty by providing an automatic parking system through the Internet of Things (IoT). The project realizes the functions of automatic parking service, location tracking, parking management, real-time invoice generation and payment system. The system can be implemented at a very low cost to help parking owners earn income by providing solutions for ordinary people who struggle every day due to insufficient parking spaces. Ajchariyavanich et al. (2019) introduced the development and prototype design of Park king, a cloud integrated intelligent parking system based on the Internet of things, which is used in intelligent campus. Park King includes: (1) IOT module, which can monitor the availability of each parking space and control the parking baffle. (2) A web-based application that allows users to book parking spaces in advance. Sun et al. (2020)

based on the relevant theories of the operation mode, from the perspective of the operation manager of the reservation platform, established an integer programming model for the rental and matching of shared parking spaces, considering the rental cost of parking spaces, the user benefits of providing services, the profits of the platform and other related factors.

Hans et al. (2015) introduced an intelligent parking system based on the Internet of things. Software solutions such as python, PHP Web Gateway with MySQL database, cloud storage and mobile applications are proposed to provide mobile users with a pleasant parking experience. In addition, the data generated by sensors, image detection cameras and mobile applications will be stored in the cloud OEM and analyzed using Hadoop application big data to gain insight.

### 2.2.3 Technical support for intelligent parking reservation service

According to the white thesis on China's parking industry, the utilization rate of parking spaces is low, exceeding 90% of cities, the utilization rate of parking spaces is less than half, and the utilization of resources is unscientific. In recent years, the rapid development of due technology in China has provided a favorable tool for smart parking, which is mainly reflected in the following sectors:

The first is that the parking space guidance and reverse search function generated by IOT technology can help car owners quickly find empty parking spaces in the parking lot and find their cars through mobile phones when they leave the parking lot. IOT studies and proposes the framework design and functional modules of the intelligent parking platform, and proposes the logical architecture, physical architecture, platform composition and technical methods for function realization of the platform IOT studies and proposes the framework design and functional modules of the intelligent parking platform, and proposes the logical architecture, physical architecture, platform composition and technical methods for function realization of the platform (Kizilkaya et al., 2019).

The second is the big data platform data analysis technology. Some researchers use advanced technology to establish an intelligent parking platform. Travelers can more effectively find satisfactory parking spaces through intelligent parking services (Zou et al., 2015). At present, the license plate number of each entry vehicle is collected from the hardware machine through the license plate recognition technology. When the vehicle leaves the parking lot, there is also a capture camera at the exit of the parking lot. The software can record the time of the vehicle leaving the parking lot, and the parking time can be calculated. Through the platform statistics, the parking space allocation in various areas of urban parking. It can also count the vehicle flow data at the entrance of the parking lot to find out the peak parking time. According to the entry and exit time of vehicles, analyze the parking time rule of vehicle owners; Through the data of on-site vehicles, analyze the use and vacancy of berths at the same time. Based on the basic data, we can also do a lot of other analysis, which will be carried out in the later stage of the thesis, such as parking fees, parking space utilization, etc. the following is the data analysis big data platform display of Shenzhen intercity parking.

The third is mobile Internet technology: the role of smart parking in the operation of public account users in the Internet is mainly for public service, release of empty parking spaces, parking space navigation, reservation of parking spaces, parking fee payment, message push, vehicle theft prevention, invoice collection, reservation of parking spaces, monthly rental renewal, online shopping mall and other functions, as can be shown in Figure 2.2.


Figure 2.2 Function display of public number at parking C end

Source: Screenshot of the software system

The fourth is driverless and new energy charging technology: At present, driverless is mainly used in self-service parking system in the parking industry. The Compact Automatic Parking system (CAP) is a fully automatic parking system, which can store cars densely. Such systems are mainly used in crowded cities around the world to provide fast parking lanes and safe vehicle storage. This is a prominent new technology with relatively low cost and rapid response. The system has a rotating ring, each layer is equipped with a shuttle, which is used for horizontal transportation, and two are used to lift in the middle of the CAP system for vertical transportation. It uses one elevator for storage, another elevator for retrieval, and it uses the elevator for storage and retrieval at the same time. Based on two different elevator operation strategies (dedicated and general operation strategies), the queuing network policies of single-layer and multi-layer systems are proposed. The analysis model is verified by simulation based on practical application. Through sensitivity analysis, the elevator speed and car rotation are changed. Then the analysis model is used to optimize the system layout by minimizing the retrieval time. In addition, a suitable system layout designer is found by combining time efficiency and system cost. Through a general method, the optimal number of elevators compact automatic parking system is found.

With the rise of new energy vehicles in the Chinese market, it reached a peak of 400000 in December 2019. In 2022, the sales volume of pure electric passenger vehicle terminals in China was 188000, an increase of 133.7% year on year. Please refer to Appendix Figure 1 for details.

In addition to foreign auto brands (such as Tesla in the United States), many domestic new energy auto brands in China have also risen, for example, WEILAI, Ideal, BYD's new energy vehicles also grow rapidly every year. BYD has won the championship for many times. Wuling and Tesla are firmly in the second and third places, and Chery's sudden rise has reached 27200 vehicles.

With the rise of electric vehicles, a large number of scholars have studied the charging problem of electric vehicles, and the total energy demand of electric vehicles has increased sharply. Alinia et al. (2019) studied the charging rate capacity of limited charging stations and the uncertain total demand and charging capacity of electric vehicles. With the rapid development of the automotive market, China is expected to become the largest market for plug-in hybrid electric vehicle (PHEV). Y. H. Zhang et al. (2010) studied the parking demand of PHEVs and traditional cars in cities and the impending PHEV charging demand. The construction of "charging parking" integrated hybrid parking lot has become a standard configuration. More reasonable charging facilities construction sites should be urban parking lots such as companies, shopping malls, schools and living areas. Customers' vehicles will generally stay in such parking lots for a long time, so charging facilities in the parking lots can achieve the effect of "charging parking" with one stone.

Although Internet of things technology, mobile Internet technology, driverless and charging technology are relatively mature in China, parking guidance systems are also used for many parking lot projects with high turnover rate, which provides convenience for car owners to find parking spaces in the parking lot. This still can't effectively solve the problem of finding parking spaces outside the parking lot. Just in time, reservation service is a way to solve the problem of finding parking spaces outside the parking lot.

### 2.2.4 Usage scenario of intelligent parking reservation service

Appointment is widely used in hospital scenes. In view of the current parking problem of large and medium-sized hospitals in many cities in China, the national health and Family Planning Commission also required in the action plan for further improving medical services (2018-2020) "that hospitals with conditions should gradually improve inpatient beds and daily surgery appointment services and explore the provision of extended services such as appointment parking".

At present, some urban traffic management departments, together with relevant hospitals and street communities, have begun to plan the parking space resources around the hospital. The pilot hospital has explored the "registration + reservation + sharing" mode, realizing registration before booking parking space, further realizing the sharing of surrounding resources, solving the problem of medical treatment and parking for citizens, and alleviating the traffic congestion around the hospital.

For example, in December 2019, Shenzhen took the lead in carrying out reservation parking service in three hospitals and surrounding areas, and Beijing Union Medical College Hospital also launched WeChat reservation parking service. From the perspective of implementation effect, reservation parking can realize fine management of parking space resources, guide vehicles to enter and leave the parking lot orderly, and alleviate the difficulty of parking in hospitals and the congestion of surrounding roads to a certain extent (H. Zhang, 2022). In Chengdu, Sichuan Province, the people's Hospital of Sichuan Province also uses an appointment parking system, which uses the smart parking system to connect with the hospital's his system. Patients can directly make an appointment after registering with the hospital's WeChat public account, which is very convenient.

Reservation is used in community scenes, many of which are carried out in the way of parking space sharing. Shanghai and Chengdu have issued a series of documents to promote shared parking. In shared parking, the government and the internal parking lots of state-owned enterprises are the focus, and the resources that the government can mobilize. Shanghai proposed to "take the lead in implementing the responsibility of parking at wrong time"; Xiaoshan District of Hangzhou requires these parking resources to be gradually incorporated into the parking guidance system of the whole district and opened to the public; Xuancheng, Anhui Province, requested that "the municipal government agency affairs administration be responsible for guiding the opening of qualified internal parking lots of government agencies and units". According to relevant statistics, as of September 2017, Qingdao has more than

10000 shared parking spaces, and Shanghai has more than 6000. Some technology enterprises have also started to get involved in shared parking related businesses, including electronic toll collection project (ETCP), simple parking, China good parking, Dingding parking, e parking, etc. enterprises' participation is mainly to collect parking users and build a shared parking C-end information platform.

Appointment can also be used in some school scenes with strong control over vehicles entering the school. For example, in Chengdu University of Electronic Science and technology in Sichuan, reservation parking is used. The university does not allow foreign vehicles to enter the school. Visitors or car owners report the license plate number and telephone number to the corresponding reception department. The Department sets it on the platform. The reserved car owner can bind the license plate to enter the school through the public number of the security office of the University of Electronic Science and technology, and then receive the message to push the appointment, which plays the function of visitors.

### 2.2.5 Restrictions of intelligent parking reservation service in use

In the use of intelligent reservation service, many scholars are based on the deterministic demand, which requires all users to send the demand information to the reservation system before parking. However, in actual use, even if there are reservation platforms and scenarios, the utilization rate of reserved parking users is low, and the experience is not high. The main reasons are as follows:

The first is that there are not enough reserved parking spaces in some parking lots. Compared with foreign developed countries, the ownership rate of private cars in China's cities is not high, but it is difficult to accommodate in terms of the city's own conditions. Parking spaces, especially the auxiliary parking spaces, are seriously insufficient. There are already a large number of non-standard parking, occupying a large number of roads, green spaces and other public spaces, affecting the normal traffic of vehicles and reducing the quality of life of urban residents, but also adding congestion to the increasingly severe urban traffic (Kang, 2012). Booking parking spaces may cause temporary vacancy of parking spaces. Therefore, in the parking lots where parking spaces are very scarce, the parking management does not use the booking method to maximize revenue.

The second is the uncertainty of the number of reserved users. The owner and user of intelligent parking reservation service start to reserve a parking space several days in advance, so the number of reserved users in each reservation cycle (days) is uncertain. The number and demand of reservation users vary with different types of parking lots, for example, there is a large demand for off-duty hours or weekends in commercial parking lots. The demand for hospital parking lots depends on the number of patients. The demand for office building parking lots depends on how early the working hours are. There is a demand for park parking lots in the rest time after work. Most of the community parking lots are self-owned parking lots or fixed parking lots by rental property companies. There is basically no reservation demand, so the demand for different projects is different, and the number of users is uncertain.

The third is that the parking time and parking time are uncertain. The arrival time and parking time of car owners are different in different types of parking lots. For example, most of the owners of commercial parking lots go shopping during off-duty hours or weekends, most of the owners of hospital parking lots are for medical treatment or visiting, most of the owners of office building parking lots come to work or visit the company from 9 a.m. to 5 p.m., most of the owners of Park parking lots rest and relax during weekends or after work, and most of the owners of community parking lots go home for the night after work at 6 p.m. Therefore, the length of the reserved parking time is often highly uncertain.

The fourth is that the reserved parking space cannot be found, or the search time is long. Due to the complex underground construction of some parking lots, the parking spaces are not numbered, or the signal in the basement is poor, which will also lead to the failure or difficulty of finding the reserved parking spaces.

Fifth, the car owner who has reserved the parking space does not park, or the parking time is longer than the reservation period. Because of the uncertainty of parking, the car owner may also adjust the plan on the premise of reserving the parking space in advance, resulting in the problem of not using the reserved parking space or overtime of the reserved parking space.

Therefore, in the actual use process, due to the uncertainty and randomness of parking, as well as the above objective factors, the use of reserved parking is difficult, so it is necessary to develop a scientific and effective reservation process to make the optimal use of parking space resources.

## 2.3 Operation Parking platform

### 2.3.1 Operation management of parking platform

Dynamic pricing is a management technology commonly used in revenue management (Bitran & Caldentey, 2003; Pak & Piersma, 2002), which refers to the strategy that enterprises timely sell the same product to different consumers or different segments of the market at different prices according to market demand and their own supply capacity, and realize the impact on customer demand by appropriately changing the pricing of products or services over time, so as to maximize revenue.

At present, many scholars have carried out research on dynamic pricing strategy. Among them, Xu et al. (2022) showed that dynamic pricing can well adapt to time-related system inputs, so that the platform can increase profits through better market segmentation. Fabusuyi and Hampshire (2018) improved this pricing mechanism by developing forward-looking policy tools. The tool uses a two-stage panel data regression and optimization model to change the parking rate by calculating the price elasticity of parking demand measures, thus affecting the demand for parking spaces.

Müller et al. (2023) developed a dynamic pricing method for profit maximization, which is based on the concept of customer focus. It is found that price optimization combines the customer's location and the decomposed choice behavior to accurately capture the impact of price and distance on the customer's choice probability. Aljohani et al. (2021) proposed that in a competitive market, price is used as a signal to distribute goods to those who value them most. The research focuses on market-oriented solutions, including pricing as a tool to shape traffic and stimulate driver behavior expected by society. Jedidi et al. (2003) established a model to capture the continuous heterogeneity in the joint allocation of product and bundle reservation prices. The results show that the product line pricing strategy depends on the degree of heterogeneity of the reserved prices of individual products and bundled products. When the heterogeneity is high, it is optimal to adopt a unified high price strategy for all products and bundles, otherwise, the hybrid strategy is optimal.

Jing (2011) analyzed the impact of social learning (SL) on the dynamic pricing and consumer adoption of durable goods under the two-stage monopoly. The results are as follows. First, the market conditions under which homogeneous consumers may choose to buy at different times in advance are determined. Second, equilibrium adoption may be inertia (all adopted later) or fanaticism (all adopted earlier). Especially, when the SL intensity is quite high, the inertia will appear, but when the SL intensity exceeds a certain threshold, the inertia will disappear. Third, corporate profits and social welfare first decline weakly under SL intensity and then may rise at one time above the threshold level of SL intensity. Finally, research shows that companies may benefit from informational advertising or investment to cultivate more social learning. Koenig and Meissner (2010) studied the risk of applying inventory pricing policy rather than dynamic pricing policy. Several numerical experiments are carried out, and the expected revenue, standard deviation and conditional value at risk between pricing policies are compared. The differences between policies show that when dynamic pricing is expensive or impractical, list pricing may be a useful strategy.

In addition, dynamic pricing plays an important role in solving congestion control, peak load reduction, travel management and other problems of traditional or electric vehicles in a cost-effective way. Promote the construction of social ecological environment by optimizing the route planning of vehicles. However, considering various constraints, building a dynamic pricing strategy for intelligent transportation has always been a challenging task. Invalid dynamic pricing technology may lead to poor vehicle management, resulting in the increase of vehicle waiting time, the increase of air and noise pollution, and the waste of electricity and other energy. On the contrary, an effective dynamic pricing strategy can satisfy all stakeholders, including service providers and service consumers (Saharan et al., 2020).

At present, some scholars have also proposed some dynamic pricing models for parking platforms. For example, Tian et al. (2018) proposed a dynamic pricing model for parking space reservation, aiming to maximize the expected revenue of parking space managers. The research shows that dynamic pricing scheme can significantly improve revenue and make full use of parking resources in peak hours. Qian and Rajagopal (2015) proposed a method to maximize the benefits of parking management through optimal parking dynamic pricing and a general parking model for a group of sequential parking areas.

In addition, the optimal parking price relative to the average occupancy rate is derived. Mei et al. (2020) introduced an agent-based simulation system to describe parking and traffic conditions. Through agent-based simulation, various effectiveness measures under different parking charging strategies can be obtained. Then combined with the average cost and failure rate to build comprehensive benefits. Menelaou et al. (2020) combined route booking with pricing mechanism to assess the impact of congestion charges on drivers' choice of departure time. Jioudi et al. (2020) proposed some new parking fee schemes.

This thesis studies how to minimize his expected travel cost by selecting the optimal strategy. Garbarino and Lee (2003) used the concept of two-dimensional trust based on goodwill trust and ability trust to investigate how the experience of dynamic pricing events and the direction of pricing discrimination (i.e., whether to provide higher or lower prices) affect the average level of trust and give the weight of individual trust dimensions in the formation of overall trust. The results show that the mean value of benevolent trust decreases significantly (leading to the decline of the overall trust margin), the weight of benevolent trust in the formation of overall trust increases significantly, and the price oriented discrimination effect is usually not supported. Low (1974) proved that there is an optimal stationary strategy, and each strategy has monotonicity: the optimal advertising price is a non-decreasing function of the number of customers in the system. In addition, an efficient algorithm is developed to generate the optimal stationary strategy in limited steps.

Den and Arnoud (2015) studied dynamic pricing and learning under the changing market environment. Their study introduces a method to enable price managers to hedge against changes in the market, and provides a clear upper limit of regret, which is a measure of the performance of the company's pricing decisions. In addition, the method also guides the selection of the best method to evaluate the market process. The study provides a numerical example of the actual situation to illustrate the method. Q. Liu and Zhang (2013) studied the dynamic pricing competition between the two companies. These companies provide vertically differentiated products for strategic customers with maximum intertemporal utility. The results emphasize the asymmetric effect of strategic customer behavior on quality differentiated enterprises. Although the profits of any company will decrease as customers become more strategic, low-quality companies suffer much more than high-quality companies. In addition, the research shows that any one company's unilateral commitment to static pricing will usually improve the profits of the two companies.

### 2.3.2 Parking platform reservation strategy

The research on parking space sharing platform started early. The studies on parking platform reservation strategy mainly focused on the formulation of reservation rules, the construction of prediction model, and the design of optimization algorithm.

Among them, Song et al. (2023) proposed a TOPSIS-SA algorithm (based on similarity sorting preference technology and simulated annealing algorithm) to solve the model. Numerical experiments show that the model is superior to the baseline model in all performance indicators such as total operating profit, average walking distance of users, acceptance rate and parking space utilization. L. F. Zhang et al. (2023) proposed a reservation control strategy for two types of customers' shared parking system, and allocated capacity among customers.

Firstly, a dynamic programming model with dynamic characteristics of demand information is proposed, and the boundary conditions of the model are proved to be difficult.

Secondly, a decomposition model based on cycle and product is proposed to approximate DP model. In addition, three approximate algorithms are proposed to obtain the retention policy based on the decomposition model.

Finally, numerical experiments verify the effectiveness of the proposed model and algorithm.

Mei et al. (2023) discussed the impact of parking space reservation mechanism on Park and ride system. A park and ride network model based on multi-mode agent is established, and different parking reservation strategies are evaluated and optimized to minimize carbon emissions. Jioudi et al. (2019) defined the concept of intelligent parking, made a historical analysis of the evolution of the intelligent parking framework, and used the orbit database to statistically analyze the patent applications published worldwide in this field. On this basis, a new intelligent parking architecture based on multi-agent features is proposed. Finally, the electronic parking system platform is introduced, which provides real-time parking prices, and provides reservation and guidance services. S. J. Shao et al. (2020) studied an auction-based parking reservation problem and proposed an effective Multi-Level Vickrey-Clarke-Groves (MS-VCG) auction mechanism. In addition to disruptors, MS-VCG auction can achieve configuration efficiency, incentive compatibility and individual rationality. The calculation results show that without reference effect, the penalty and compensation fees increase with the increase of the number of bidders.

S. F. Wang et al. (2022) proposed an opportunity constrained optimization model to solve the reservation and allocation problem of shared parking platforms. The model aims to maximize parking utilization and make the service failure rate below the threshold. A rule-based mixed integer linear programming is also proposed to find the satisfactory solution of the model. Numerical experiments show that the model is superior to the baseline model in terms of parking utilization and service failure rate.

W. Liu et al. (2021) established a joint equilibrium model of urban destination selection and parking selection under the mixed supply of roadside parking and shared parking. In addition, the study also analyzes the pricing strategies of private and public shared parking operators, and how these strategies are related to travelers' destinations and parking choices, in which private operators maximize their profits (monopoly or oligopoly), and public operators maximize social benefits. H. H. Xiao et al. (2024) proposed three auction-based parking mechanisms (ABPM) modes: no exit right, no cost exit right and no free exit right. In addition, the study describes the withdrawal behavior of parking demanders in ABPM. It is found that the introduction of exit right will stimulate the demanders to increase the bid price, and under certain conditions, ABPM with non-free exit right will generate the highest profit.

In addition, X. T. Wang and Wang (2019) proposed a new flexible reservation mechanism, which is no longer limited to a specific place at a specific time, but tolerates the space-time flexibility of reservation. The continuum approximation framework is used to analyze the parking system in large cities, which is easy to handle. It can successfully provide accurate system management decision support and limited optimality gap and analysis opinions. Y. S. Jiang et al. (2023) discussed the regulation of dynamic hybrid parking reservation strategy based on One-way Station Vehicle sharing System (OSVS). Firstly, a dynamic hybrid parking reservation strategy is proposed. Based on the O2DES (object-oriented discrete event simulation) framework, a discrete event simulation model is established to compare the Dynamic Hybrid Parking Reservation (DHPR) strategy with No Reservation (NR), Static Hybrid Parking Reservation (SHPR) and Complete Parking Reservation (CPR) strategies. On this basis, a simulation optimization model and a genetic algorithm for calculating the optimal budget allocation are proposed to determine the fleet size, station capacity and dynamic reserve distance threshold.

Mei et al. (2019) analyzed and compared the benefits of parking fees and reservation mechanisms. The research introduces the agent simulation system and constructs the simulation framework of parking charge and reservation. The results show that parking fees and reservations can significantly improve the comprehensive benefits, and the comprehensive benefits are the largest when the fees are high. Tasseron and Martens (2017) studied the impact of street parking reservation system. The performance of the system is studied by a very detailed simulation based on space agent. The simulation results show that in almost all simulation cases, users who book the system benefit from reducing search time and walking distance. T. X. Yan et al. (2011) proposed CrowdPark, a crowdsourcing platform. Crowdpark gets information about when parking resources are available through the crowd, and uses the available information to help other users find parking spaces. Through the combination of simulation and experiment, it is found that Crowdpark can effectively encourage users to participate and detect malicious users, with an accuracy rate of more than 95%. In addition, it can handle more than 95% of the spatial uncertainty and achieve more than 90% of the parking space reservation success within a few minutes of waiting time.

Alho et al. (2022) proposed an agent-based simulation method, which integrates a data-driven parking selection model and a demand/supply simulation model. Research shows that the demand management strategies (DMS) can improve travel time, parking costs, emission levels and reduce queuing. Roca-Riu and Menendez (2019) proposed a reservation scheme to manage the rental reservation of the car sharing system based on two-way stations. It allows operators to better plan the vehicles required at each station, and encourages drivers to make better use of existing vehicles by showing the flexibility of starting lease time. The results show that when drivers show flexibility in the start time of leasing, operators can reduce the number of fleets, and have little or no impact on the overall rental income. For a certain level of demand price elasticity, we can even expect the positive impact on the overall rental income. In addition, the reservation fee has been proved to partially compensate for the reduction of rental income provided to auction users.

Dahi and Jemili (2021) proposed collision avoidance scheme for smart parking (CAS-SP), an intelligent parking collision avoidance scheme, which aims to help drivers shorten the search time in the parking lot, reduce costs by consuming less fuel, and reduce pressure in daily tasks. The results show that the scheme effectively solves the problem of contention, reduces about 88% of vehicle collisions, shortens the time of finding vacant space in the parking lot, and saves about 450s for multi-store parking lots with multiple entrances.

### 2.3.3 Revenue management of parking platform

Revenue management is an important concept of management discipline and a relatively new management mode. It was proposed by American airlines around 1960. In the past few decades, it has developed into a general and indispensable method framework, including the technology of actively managing the demand and further improving the profits of Companies in many different industries (Klein et al., 2020; Van Ryzin & Talluri, 2005). The object of income management is limited resources, and the purpose is to maximize the use of resources, to get more economic benefits. It mainly establishes the optimal price or capacity allocation strategy by building a real-time prediction model and studying the demand behavior under market segmentation (A. Gupta et al., 2017).

At present, revenue management is applied to the research of various fields. Strauss et al. (2018) stated the issue of choice based network revenue management by developing a potential dynamic plan, and organized the review according to its components and the inherent challenges arising therefrom. X. L. Wang et al. (2015) evaluated the main development of revenue management in the past decade, and discussed the challenges and research prospects of revenue management. Bertsimas and Popescu (2003) studied the dynamic strategy of allocating scarce inventory to the random demand of multiple fare categories in the network environment to maximize the total expected revenue.

Chiang et al. (2007) comprehensively reviewed the latest development of revenue management in different industries. We discussed different revenue management strategies, including pricing, auction, capacity control, overbooking and forecasting. Lan et al. (2008) used the method of competition analysis to study the classic multi ticket price single resource problem in revenue management with limited demand information. Netessine and Shumsky (2005) studied seat inventory control under horizontal competition (two airlines compete for passengers in the same segment) and vertical competition (different airlines fly different segments in a multi segment journey). The analysis results and numerical examples show that under horizontal competition, passengers with higher ticket prices get more seat protection than single airline monopoly. However, under vertical competition, reservation restrictions may be higher or lower than the monopoly level, which depends on the demand for connecting flights at each fare level.

Harris and Pinder (1995) believed that revenue management is a process of accepting and rejecting orders. They studied the application of revenue management concepts and technologies to assemble-to-order (ATO) manufacturing environment, and proposed optimal pricing and capacity decision models. Wright et al. (2010) established a Markov game model, which can be used to analyze the impact of these mechanisms on the behavior of each partner. Research shows that there is no Markov transfer pricing mechanism to coordinate any alliance. In addition, three dynamic schemes and three forms of static schemes which are widely used in practice are studied, and the equilibrium acceptance strategy under each scheme is derived. The analysis technology and the numerical analysis of the sample alliance are used to generate the basic opinions on the partner behavior under each scheme.

Perakis and Roels (2010) established a robust formula for the capacity allocation problem in revenue management using the maxima and minimax regret criteria under the general polyhedral uncertainty set. Numerical analysis shows that the minimum maximum regret control performs very well on average and is superior to the traditional control. In particular, the minimax regret method is 2% higher than the traditional heuristic method on the real large-scale problem set. Maximum control is more conservative, but its advantage is associated with the minimum income guarantee. Queenan et al. (2007) reviewed the existing unconstrained methods and proposed a new method, which contains some attractive properties that are not available in the existing methods. This study evaluates the proposed method by testing several common unconstrained methods on intentionally constrained simulated data. The results show that the proposed method is superior to other methods in two of the three data sets. Cooper (2002) described the asymptotic behavior of the revenue management strategy derived from the solution of the deterministic optimization problem. The results show that in the random and dynamic framework, the solution generated by a single known linear programming can be used to generate the distribution strategy, in which the normalized income converges to the constant upper bound of the optimal value in the distribution. In addition, the study describes the counterintuitive behavior that may occur when updating the allocation during the booking process (updating the allocation may lead to lower expected revenue).

Phillips (2012) studied the problem of generating an effective boundary between two business objectives in pricing and revenue management. The research shows that under the standard condition of demand function, when pricing a single product, the effective boundary between revenue and profit will be a continuous, bounded, downward sloping concave boundary. In addition, for the single branch revenue management problem, it is proved that the effective boundary between any two linear load objectives (such as revenue, load factor and operational contribution) can be effectively generated using the weighted sum (or scalarization) method. B. C. Xiao and Yang (2010) studied the revenue management problem with two capacity characteristics and expressed it as a continuous time stochastic control model. The results show that if the rate of return is concave in capacity utilization, the expected value of marginal capacity is monotonous, and the control strategy is characterized by a series of thresholds, which show significant differences when the combination of residual capacity changes.

In addition, some scholars have also studied the revenue management of parking platforms. Among them, Mataruse and Gambe (2024) discussed the strategies that can be adopted in the management of urban parking spaces to improve the tax revenue. The results show that careful planning and implementation of parking management can improve the accessibility inside and outside the city center, and increase the municipal revenue from urban parking spaces. Rojas (2006) considered a parking facility network consisting of multiple parking lots, divided into two, three and four fare levels, and used revenue management technology as a means to maximize revenue and stimulate and diversify demand.

Lazov (2019) proposed a method for analyzing parking revenue. Roper and Triantis (2009) evaluated whether the implementation of parking Revenue Management (RM) system in dense urban parking areas has reduced the degree of urban congestion, and the results showed that the default rate of parking people was the main driving factor of the implementation value of parking RM. Roper and Triantis (2010) used hyperbolic Data Envelopment Analysis (DEA) model to measure the performance of urban parking system from the perspective of stakeholders under the framework of matrix DEA. The study found that when the Revenue Management (RM) policy was not implemented, the default rate and the tenacity of potential parking people were key considerations. Designers could effectively eliminate the impact of default rate and its negative impact on congestion by encouraging parking suppliers to implement revenue management parking strategies. Mouskos et al. (2000) built a parking space matching model for shared Parking Based on the consideration of booking time, booking duration and delay, with the dual optimization objectives of maximizing platform revenue and minimizing walking distance.

Yu et al. (2018) conducted research on parking space allocation with the goal of maximizing revenue from the perspective of operators. Among them, because the reservation requirements include basic requirements and delay requirements, corresponding allocation strategies for reservation parking requests are provided respectively. Y. H. Liu et al. (2022) proposed a temporary parking space allocation model with the minimum user cost as the goal and a reservation parking space allocation model with the maximum system revenue as the goal in view of the parking demand of shared parking lots in multiple residential areas.

## 2.4 Parking platform system design

Under the background of population explosion, the continuous expansion of community scale and the increasingly complex regional transportation network, the traditional parking system has been unable to meet the needs of society. On this basis, people began to explore the construction of intelligent parking platform combined with Internet technology. Intelligent parking is a typical Internet of things application, which can benefit from the progress of sensors, actuators and RFID technology, and provide many services for users and parking owners in smart cities (Bagula et al., 2015).

The main architecture of intelligent parking platform system includes three layers, namely user layer, server layer and data layer. Foreign research on the construction of intelligent parking platform started earlier, and a variety of intelligent parking systems have been designed. For example, Al-Kharusi and Al-Bahadly (2014) proposed an intelligent parking space detection system based on image processing technology. The system captures and processes the fillet image drawn by the parking lot to generate parking space information. P. P. Liu and Zhu (2021) analyzed the influencing factors of time-consuming and laborious parking, and designed an intelligent parking device. It can reduce the space area of parking spaces, realize the automatic retrieval of empty parking spaces and automatic parking of vehicles, and provide a feasible solution for the industrialization of parking equipment in residential areas.

Ai and Wang (2018) described the overall design of the intelligent parking system. Its architecture includes PXA270 master control platform, ZigBee network, remote communication part and Android Software. In addition, the liquid crystal display (LCD) interface circuit is introduced, and the design idea of analog camera circuit is described. C. W. Yang et al. (2021) proposed a multi technology intelligent parking system to manage and guide vehicles in large communities and avoid confusion. Fraifer and Fernström (2016) designed and developed a new parking system based on (USP CCTV camera) to provide simple parking services for drivers. X. W. Ma and Xue (2020) based on open network big data, using spatial syntax theory and technical methods, and taking the current layout of urban parking facilities in Shinan District as an example, studied the lack and unreasonable layout of parking facilities. Through the quantitative analysis of the distribution of traffic network and parking facilities on the urban scale and block scale in Shinan District of Qingdao, we find that Baidu's heat density is closely related to the spatial syntactic parameters of the urban area on the large scale and local scale. The research has solved a series of problems such as the unreasonable allocation of parking facilities around scenic spots in tourist cities and can also provide reference for the layout optimization of parking facilities in similar cities.

L. Yang et al. (2009) proposed an active integration mode of parking guidance information system composed of parking lots, vehicles, parking information service centers and traffic management centers. The multi-stage navigation method based on double-layer traffic map is used for parking route negotiation and guidance. Based on the extended foundation for intelligent physical agents (FIPA) architecture, the system is implemented by using mobile agent, message queue, agent container and agent execution environment, making full use of the interoperability of FIPA standards and the flexibility of mobile agents.

Mohammadi et al. (2019) proposed a safe and reliable smart city cloud intelligent parking system based on Internet of things technology. To dynamically check the availability of parking spaces in different parking areas, wireless sensors are used to integrate on-site data collection and real-time and streaming data analysis of Internet of Thins (IoT) data.

J. C. Li et al. (2018) proposed a deep learning parking prediction system architecture based on cloud platform, which uses long short-term memory (LSTM) network to predict the availability of parking spaces and has good time series prediction effect. In addition, the research also proposes an economic workflow based on Elastic Computing Service (ECS) provided by cloud platform. In the optimized workflow, the training and updating process of the model does not need to be running all the time, which can significantly reduce the avoidable calculation and cost.

In addition, Karunamoorthy et al. (2015) proposed a parking lot occupancy detection and parking control algorithm for automatic valet parking system. Fang et al. (2016) developed on the Android platform, and conducted in-depth analysis and design of user positioning, parking lot pre selection, driving route planning, parking lot details, parking fees and other functions, and implemented an intelligent parking real-time query system based on Android, which helps car owners obtain parking information in real time and solve the problem of "parking difficulty". Chai et al. (2020) studied the design, test and verification of a control scheme based on deep neural network (DNN), which can predict the optimal motion command of automatic ground vehicles (AGVS) during parking maneuvers.

Lyu and Fan (2022) designed a parking lot management system with IoT device management function. The system has three subsystems corresponding to IoT device information management, vehicle information management and management personnel information management. Bangare et al. (2023) used license plate recognition and Android applications to automatically Book parking spaces in various places and notify users of the availability of parking spaces. J. L. Wang et al. (2021) designed a self-service intelligent parking management system based on wireless sensor network (WSN). J. L. Zhou et al. (2021) analyzed the main shortcuts of the current parking lot, and proposed a design scheme of driverless intelligent parking lot based on Xinghai Internet of things (IOT) Xstar-T platform, which integrates 5g and artificial intelligence (AI) technology.

Balfaqih et al. (2021) proposed an intelligent parking system based on the IoT, which provides drivers and parking administrators with useful information about available parking spaces and parking space navigation, reservation, availability estimation and other related services. The intelligent Parking Management System (SPMS) proposed by Melnyk et al. (2019) can help drivers solve several problems related to parking. SPMS provides a sensing platform supported by mobile applications, enabling drivers to interact with the parking infrastructure in real time, thus minimizing the time for drivers to find empty parking spaces in large multi-storey parking lots and promoting the positioning of parked vehicles. In addition, in order to verify the efficiency of SPMS, a small-scale test platform is developed as a proof of concept, and tested in five different scenarios. The results highlight the effectiveness of the method.

Kadusic et al. (2022) proposed a new method of intelligent parking solution using the advantages of the NarrowBand Internet of things (NB-IoT) technology. The research integrates NB-IoT into the core platform of the Internet of things, navigates the sensor data directly to the Internet of things radio station for processing, and then forwards it to the user Application Programming Interface (API). Experiments show that NB-IoT technology can support geographic positioning and navigation services, as well as vehicle parking payment and reservation services, making intelligent parking solutions more intelligent.

Sehdehi et al. (2018) proposed an intelligent parking solution to guide users to free parking while booking parking lots. The proposed solution not only helps to significantly reduce the traffic of looking for parking spaces, but also increases the occupancy rate through the convenient management of parking spaces, a valuable resource of the subway city. By reducing the carbon footprint, this greatly reduces the impact of environmental problems. Annirudh et al. (2021) provide users with real-time idle time slot information with the help of GSM short message service, and realize the automation of parking lot management and tariff calculation through optical character recognition and time axis, which greatly reduces the waiting time of customers and the manpower required for parking places.

## 2.5 Other studies related parking operation management

Parking operation and management is to set up parking lot management and production posts, allocate staff and parking lot facilities and equipment according to factors such as the scale and functional positioning of the project parking lot. According to the distribution of parking lots, site management personnel and local agencies shall be reasonably allocated. Without changing the nature of the use of the parking lot and engaging in activities unrelated to parking, establish and improve relevant supporting systems such as parking lot operation management, safety management, fire management, emergency management, and orderly organize the implementation and supervision of the management of the parking lot. Parking management services should be carried out in accordance with the system for the appearance, professionalism and attitude of parking management personnel. The management of the parking lot should also have an energy-saving and emission reduction management mode for the water and electricity of the facilities, and do a good job in the process of energy consumption control during the operation of the parking lot.

From the perspective of research, the early research on the operation and management of parking spaces mainly focused on how to improve the utilization rate of urban land and improve the planning of parking facilities. Many research on traditional parking operation and management are from the perspective of public management, which studies how to effectively allocate public parking spaces in cities and improve the utilization rate of parking spaces. In terms of the supply of public parking spaces, many scholars use the parking reservation mechanism and the relevant theory of operation optimization to build relevant optimization models with the optimization goal of minimizing the travel distance or travel time of all travelers. In addition to booking, parking operation management also includes demand and supply, allocation and assignment, private parking space sharing and other aspects:

The first is demand and supply. At present, in the research on the parking space supply strategy, most scholars mainly based on the revenue management theory, and took the profitable parking lot as the object for discussion. Ji et al. (2010) proposed the corresponding real-time decision-making model of parking space reservation based on the theory of revenue management and used fuzzy logic to judge whether to accept the reservation application. In addition, Sun et al. (2020) based on the relevant theories of the operation mode, from the perspective of the operation manager of the reservation platform, established an integer programming model for the rental and matching of shared parking spaces, taking into account the rental cost of parking spaces, the user benefits of providing services, the profits of the platform and other related factors. J. Wang et al. (2018) discussed the optimization of parking space supply in the parking allocation strategy and proposed a dual objective model to minimize the total travel cost and traffic emission cost.

The second is distribution and assignment. S. C. Zhang et al. (2020) have studied the parking space allocation problem from the perspective of operators with the goal of maximizing revenue. Among them, because the reservation requirements include basic requirements and delay requirements, corresponding allocation strategies for reservation parking requests are provided respectively. Y. H. Liu et al. (2022) proposed a temporary parking space allocation model with the minimum user cost as the goal and a reservation parking space allocation model with the maximum system revenue as the goal in view of the parking demand of shared parking lots in multiple residential areas. Teodorović and Lučić (2006) started from the perspective of revenue management and divided parking users into different priorities according to the charging situation. By predicting the admission rate and departure rate of various priority users, the revenue maximization goal of the operation management party is achieved, so as to complete the effective allocation of parking spaces. Mouskos et al. (2000) proposed a parking space allocation model with the goal of minimizing the system parking cost under matching constraints and parking capacity constraints.

The third is parking space sharing. Lin et al. (2018) described the reservation and sharing of private parking spaces. In some studies, on the management of shared parking in residential areas, they explored the allocation of parking spaces from the perspective of users and with the goal of minimizing the cost. For example, S. C. Zhang et al. (2020) established a parking space matching model for shared Parking Based on the consideration of booking time, booking duration and delay, with the dual optimization objectives of maximizing platform revenue and minimizing walking distance. Xue et al. (2022) proposed to reserve a certain buffer time to deal with the early or late arrival of reserved orders, so as to enhance the robustness of parking space allocation, and built a parking space allocation model with the dual objectives of maximizing platform revenue and robustness. X. Huang et al. (2020) proposed a parking space sharing strategy to effectively use the idle parking spaces in residential areas to meet the parking needs of people working nearby or participating in other activities. This thesis analyzes the distribution of the number of vehicles arriving and the parking time, considers the overtime parking behavior of parking users, and establishes a shared parking allocation model aiming at maximizing the parking benefit. The relationship between parking benefits and the proportion of reserved parking spaces, the number of parking demands, the acceptance rate of parking demands and the utilization rate of shared parking spaces is analyzed by simulation method. Then, according to the principle of maximizing parking benefits, the optimal proportion of reserved parking spaces and the number of shared parking spaces that should be purchased from residents are determined. Taking the utilization rate of shared parking space as an index, the effectiveness of the static allocation principle is verified. The parking demand allocation rules are proposed to ensure the maximization of parking revenue and the minimization of the impact on residents.

## 2.6 Summary

This chapter mainly reviews the literature in related fields such as reservation service, parking platform operation management, parking platform scheme design and other studies on parking operation management.

In terms of reservation service research, this chapter mainly conducts literature research from two aspects: Reservation scheduling and capacity allocation and intelligent parking reservation service operation optimization. At present, there are many research on reservation scheduling system in China, mainly focusing on the medical treatment and transportation industry. Many scholars have established various reservation scheduling models to pursue the maximization of benefits and resource utilization. There are many research on capacity allocation in foreign countries, which are mainly used in the service industry and industrial activities, and through the construction of various allocation models to achieve industry fairness and maximize revenue. In addition, in terms of operation optimization of intelligent parking reservation service, domestic and foreign scholars have proposed a variety of parking reservation systems to optimize the utilization rate of parking spaces and parking revenue by configuring a reasonable reservation ratio for each public parking lot in the urban area, to alleviate the current parking problem.

Regarding the operation and management of parking platforms, this chapter mainly conducts literature research from three aspects: the dynamic pricing strategy of parking platforms, the reservation strategy of parking platforms, and the revenue management of parking platforms. When studying the dynamic pricing strategy of parking platform, firstly, the application of dynamic pricing strategy in various industries is summarized. Then, the application of dynamic pricing in intelligent transportation is studied. Many scholars have put forward the dynamic pricing model of parking space reservation to improve revenue and make full use of parking resources in peak hours. As for the parking platform reservation strategy, scholars' research mainly focused on the formulation of reservation rules, the construction of prediction models, and the design of optimization algorithms. By proposing a variety of flexible reservation mechanisms, different parking reservation strategies were evaluated and optimized. Regarding the revenue management of parking platforms, the thesis first summarizes the application of revenue management in various industries. Then, the revenue management research of parking platform is reviewed.

In terms of parking platform scheme design, because the current parking system can no longer meet the needs of society, scholars at home and abroad began to explore the construction of intelligent parking platform in combination with the Internet of things, and improved the utilization efficiency of parking space by designing various parking lot management systems with Internet of things equipment management function, and ensured the maximization of the revenue of parking lot managers.

In addition, other research on parking operation management mainly focus on three aspects: demand and supply, allocation and assignment, and private parking space sharing. Among them, in terms of demand and supply, most scholars mainly based on the revenue management theory and took the profitable parking lot as the object to carry out relevant discussions; In terms of allocation and assignment, scholars mainly study the parking space allocation with the goal of maximizing revenue; In terms of parking space sharing, scholars explore parking space allocation methods from the perspective of users, with the goal of minimizing the cost.

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# Chapter 3: Methodology

Based on the summary of the literature review, this chapter will design research strategies to address the shortcomings of existing studies and optimize parking lot operation management. The main content includes research strategies, methods, and data. These elements lay the methodological and data foundation for the subsequent optimization of parking reservation platform operation management.

## 3.1 Research strategy

According to different research questions, this thesis adopts different research methods to answer these questions.

For the research question (1): how should the shared parking platform make decisions based on different parking reservations. To answer this question, this thesis divides the car owners' parking reservation into three situations based on the diversity of actual parking needs, namely, advance reservation, temporary arrival, random supply and random demand. On this basis, in this thesis, the parking optimization models are built for these three cases, considering the dynamic and uncertain matching of parking space supply and demand, and the reinforcement learning algorithm is designed to solve the model. Finally, the research conclusion is formed, which answers the research question 1 of this thesis.

For the research question (2): how to design the parking reservation process of intelligent parking reservation platform. In order to answer this question, this thesis first analyzes the feasibility of parking reservation and discusses the mode of car owners' parking reservation. Secondly, based on the previous model construction and solution, this thesis carries out the optimization design of the parking reservation process for the three cases of advance reservation, temporary arrival and advance reservation, as well as random supply and random demand. Finally, this thesis designs the parking reservation business process, including the busy parking reservation process design and the idle parking reservation drainage process design. Thus, answering the second question 2 of this thesis.

For the research question (3): how to verify the effectiveness of the depth enhancement algorithm and the smart parking reservation platform. In this thesis, numerical simulation experiments are used to compare the revenue changes of the depth enhancement algorithm and the traditional approximation algorithm under different booking periods and prices. The results show that the effectiveness of the depth enhancement algorithm is always significantly better than that of the traditional approximation algorithm in terms of the booking period and the booking price. Secondly, using simulation experiments, this thesis verifies the effectiveness of the operation and management process of the intelligent parking reservation platform. Thus, answering the research question 3 of this thesis.

## 3.2 Parking data collection

### 3.2.1 Parking data source

(1) Parking lot operation data

The operation data of the parking lot truly reflects its operation and the characteristics of users' parking behavior. In order to optimize the use efficiency of parking lots and find the rules and differences of parking use, the data in this thesis comes from the 348556 parking operation data of THGJ shopping mall on the "intercity SPPS parking" data platform from January 1, 2023 to October 31, 2023 in a year.

The "intercity SPPS Parking" data platform is the parking fee management system adopted by the mall and is one of the typical cases of China's parking fee system. The system consists of hardware, software, and cloud platform, providing comprehensive management and operational support for parking lots. Its core function is to achieve automation and informatization of the parking process by integrating hardware devices, software algorithms, and cloud data management of the parking lot.

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The software part of the parking lot mainly includes license plate management module, parking rate management module, image recognition algorithm, and related calculation functions. Through the license plate management function, the system can effectively record and track the entry and exit of vehicles. The parking rate management module supports flexible adjustment of charging strategies to meet the operational needs of different time periods. The image recognition and algorithm module further improve the accuracy and processing speed of license plate recognition.

In addition, the data sources of the cloud platform are all on-site information recorded by the hardware devices in the parking lot, so every piece of data in the parking cloud platform is from the parking lot site, which is true and can't be modified.

(2) Questionnaire survey data

This thesis obtains data through questionnaire survey to analyze travelers' behavior choice, waiting willingness, price sensitivity and so on. The main methods of investigation are Revealed Preference (RP) and Stated Preference (SP) surveys. The main difference between the two is whether the investigation content has occurred. See Table 3.1 for details.

Table 3.1 Comparison of characteristics between RP and SP survey

| Survey method | advantage | shortcoming |
|---|---|---|
| RP Survey | True reflection, Constraint materialization, Strong reliability. | Cannot process virtual scheme, There are deficiencies in selecting limbs, attributes and attribute levels, Lack of change in attribute level. |
| SP Survey | Can handle virtual scenarios, the conversion relationship among attributes, horizontal values and attributes is uncertain and can be designed freely, Multiple survey data can be obtained from one survey object, and small sample statistical analysis can be realized. | Low consistency,<br>Lack of realistic constraints. |

According to the survey content of this thesis, the method of combining RP survey and SP survey is used to conduct a questionnaire survey on travelers. RP survey provides observational data on real behavior, which can characterize existing behavioral patterns. SP survey explores the potential selection tendencies of respondents through scenario simulation, providing a supplementary perspective for understanding the decision-making logic behind behavior. During the implementation process, we combined both paper-based and online survey methods to ensure that data collection was both extensive and accurate.

The site of this field survey is the DAYUAN Business District of Chengdu high tech Zone, as this area is a typical business district in Chengdu, the public parking lot and the open parking facilities are relatively complete, and the number of parking travelers in this area is large, which is conducive to the investigation.

This study adopts a questionnaire format to understand customer needs and specific parking issues. The content of the questionnaire is designed with reference to the research of W. L. Li et al. (2015) and J. Liu et al. (2016). The purpose of this survey is to delve into the characteristic patterns of parking reservation behaviors, aiming to provide detailed data support and scientific basis for setting reservation fee standards during peak and off-peak hours. The main content covers the following aspects:

(1) The socio-economic attributes of travelers, including gender, age, etc.;

(2) Travelers' parking traffic attributes mainly include whether they find it difficult to park in China, whether they often encounter it or not the situation of parking spaces, the purpose of commercial parking, and the time spent in finding parking spaces;

(3) The related attributes of travelers' parking reservation mainly include whether they are willing to use the Internet or mobile phone before going out. The terminal reserves parking space in advance, the selection method of reserved parking space, the willingness to pay the reservation fee, and the proportion of the reservation fee;

(4) The main factors that travelers pay attention to when choosing parking lots include the reliability of parking lot reservation, walking distance, parking safety, parking cost, driving time, etc.

The data sources for this study are divided into offline (on-site) survey data and online questionnaire data:

(1) The on-site survey (offline) was conducted from October 25 to 31, 2023, during which 300 questionnaires were distributed, and 212 valid responses were collected.

(2) To ensure a wider distribution of the data, this study also distributed online questionnaires. From October 25 to 31, 2023, a total of 800 online questionnaires (The online questionnaire has been incorrectly placed, and all are valid) were collected, with respondents widely distributed across various regions of China.

### 3.2.2 Data presentation

On this parking data platform, each data includes the vehicle license plate number, the type of access channel, the exact time of vehicle entrance or exit, whether the access status is normal, vehicle type, and data source. Appendix Table 1 illustrates 10 pieces of data from 14:00 to 15:00 on May 7, 2023.

The parking time data can be obtained by subtracting the entrance time from the exit time of the same license plate. Appendix Table 2 gives an example of 10 pieces of data that arrived at 12:00 on May 7, 2023. Appendix Table 3 example of parking time data. Eliminate the data of abnormal data parking time (less than 5 minutes or more than 120 hours), and use the relevant statistical analysis method to analyze the actual operation situation in the shopping mall scene.

## 3.3 Summary

This chapter develops the research methodology, which includes three parts: research strategy, specific methods, and data collection plan. According to the research strategy, this study will use questionnaires to collect primary data and obtain secondary data through parking platforms. Based on this, the data characteristics will be analyzed, models will be constructed, parking processes will be optimized, and simulation will be conducted to verify the effectiveness of the improvements.

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# Chapter 4: Operation Management Optimization Modeling and Process Design of Smart Parking Reservation Platform

This chapter first analyzes parking data, discovers customer parking characteristics, and based on this, models and designs processes.

## 4.1 Parking data analysis

### 4.1.1 Second-hand parking data in shopping mall

#### 4.1.1.1 Monthly variation analysis

The parking data of the parking lot from January 1 to October 31 were 34855. The data from January to October are shown in the Appendix Figure 2. As can be observed that the minimum traffic flow from January to February is less than 30000, because these two months are the Spring Festival in China, and the residential population of the city is less than usual. In July, the traffic volume increased sharply from 35000 to more than 40000. After checking with the staff of the shopping mall, it was because the shopping mall introduced a large supermarket in July, which caused the traffic volume to increase sharply. This also shows that the commercial parking lot is closely related to the population around the shopping mall and the business type in the shopping mall.

#### 4.1.1.2 Weekly variation analysis

There is a significant correlation between the number of vehicles per week from Monday to Sunday and the number of people per day in shopping malls. For example, as shown in Appendix Figure 3, the daily number of vehicles admitted in March 2023 is the largest on Saturday and Sunday, with more than 1200 vehicles. The number of vehicles admitted from Monday is reduced to about 800, which is balanced at about 800 from Monday to Thursday, and the number of vehicles on Friday has increased to about 1000.

#### 4.1.1.3 Daily variation analysis

**(1) Analysis of parking access records in shopping malls**

The access of vehicles in the commercial parking lot directly affects the use efficiency of the parking lot. In this section, based on the time-varying data of vehicles in and out of the parking lot in the second week of May, the daily, weekly and monthly changes of vehicles in and out of the parking lot on weekdays and weekends are analyzed respectively.

(a) Admission analysis on working days and non- working days

Select the same arrival data of vehicles entering the parking lot from Monday to Friday as the analysis object for data analysis. The situation of vehicles entering and leaving the parking lot on business weekdays is shown in Appendix Figure 4 distribution of vehicles entering the parking lot on business weekdays:

As shown in Appendix Figure 4 distribution of vehicle arrivals in shopping malls' parking lots on weekdays (Monday to Friday), the change trend of average daily vehicle arrivals during weekdays shows the trend of average daily vehicle arrivals respectively, from which it is obvious that the change trend of daily vehicle arrivals is relatively consistent. Among them, 9:00-10:00 a.m., 14:00 p.m., 17:00 p.m., and 19:00 p.m. reached the peak, all of which were higher than 60 vehicles. The number of admission per hour from Monday to Thursday was relatively close, and the number of admission per hour on Friday was increased compared with the previous four days.

It can be clearly seen from Appendix Figure 5 that the admission data of two different non-working days have similar regularity: According to the distribution of vehicles entering during the working day, there will be two peaks in a day, namely, 9:00-11:00 and 17:00-19:00, which reflects that the travel of car owners is mainly concentrated in this period. In addition, there will also be a small peak from 12:00 to 14:00, which is consistent with the data of lunch in the shopping mall. From the analysis of the distribution of vehicles' departure with time on weekdays, there will also be two peak hours in a day, which are 16:00-17:00 and 20:00-21:00, respectively, corresponding to 2-4 hours after the dinner peak. Therefore, it can be estimated that the car owners grow up in 2-4 hours when eating.

(b) Exit analysis on working days and non-working days

Appendix Figure 6 variation trend of the number of vehicles leaving the shopping mall parking lot on weekdays (Monday to Friday) respectively shows the trend of the number of vehicles leaving the parking lot on weekdays in a week, from which it can be clearly found that the variation trend of the number of vehicles leaving the parking lot on a daily basis is relatively consistent. Among them, 10:00-11:00 a.m., 17:00 p.m. and 20:00 p.m. reached the peak, which were higher than 60 vehicles. The number of vehicles per hour from Monday to Thursday was relatively close, and the number of vehicles per hour on Friday was increased compared with the previous four days.

On non-working days, Appendix Figure 7 shows the distribution of vehicle departures in the shopping mall parking lot on non-working days (Saturday and Sunday). It is very active from 9:00 a.m. to 21:00 p.m., reaching the peak at 12:00 a.m., 17:00 p.m. and 20:00 p.m., with more than 100 vehicles, compared with 40 vehicles on weekdays, which is related to more activities in shopping malls on weekends.

From Appendix Figure 4 and Appendix Figure 6, the time distribution of vehicles entering and leaving on weekends is similar to that on weekdays, but the number of vehicles entering and leaving on weekends is significantly higher than that on weekdays, and it can reach about twice that on weekdays during peak periods, which is related to more activities in shopping malls on weekends. From the analysis of the peak hours of entering and leaving, the peak hours of vehicles entering are 9:00-10:00 and 15:00-16:00, respectively. There is no change in the morning peak hours relative to the working day, and the peak hours of entering and leaving the vehicle in the evening are two hours ahead of schedule, which is related to the travel habits of weekend shoppers. The peak hours for vehicles to leave are 16:00-17:00 and 20:00-21:00, respectively, and the peak hours for vehicles to leave are relatively close to working days.

It is worth noting that the peak period for the first vehicle to exit is similar to that on weekdays. However, after the second peak period, the trend of vehicle exit tends to stabilize. This phenomenon indicates that the time distribution of weekend shopping activities is relatively concentrated, but has not formed an overly abrupt peak period, thus reflecting the dispersed nature of shoppers' activity time to a certain extent. These findings provide important references for us to gain a deeper understanding of weekend parking demand patterns and optimize parking management strategies in shopping malls.

(c) Parking Characteristics on Sundays

The above analyzes the entry and exit of vehicles on different working days in a week in the commercial parking lot, and analyzes the daily variation law of parking from a short time span. As Friday and Monday may be affected by the factors of rest and the first day of work, and Tuesday to Thursday show the same change rule, this section selects the phase in and out data for four consecutive weeks on Sunday for comparison. See Appendix Figure 8 for the entry of vehicles in shopping malls on the same working day in different weeks (Statistics of the number of vehicles entering the parking lot every Sunday in April).

From the change rule of vehicle entry on the same working day in different weeks, the change of vehicle entry with time is basically the same, and the two peaks of vehicle entry in a day are 9:00-10:00 and 15:00-16:00. From the perspective of the number of vehicles entering, the number of vehicles entering in the same period is basically stable at a fixed value between different weeks, and the fluctuation will not be large. Mastering this law can also provide data support for the opening hours of entrances and exits of commercial parking lots and other relevant management measures.

**(2) Analysis of parking time in shopping malls**

The parking time of vehicles refers to the total time from entering the parking lot to leaving the parking lot. The parking time of vehicles in the parking lot of public buildings has different characteristics with different land use properties. It can be observed in the previous section that there are different rules between working days and non-working days. In this section, the parking hours of vehicles in the parking lot on working days (Monday to Friday) and non-working days (Saturday and Sunday) in the second week of May (May 8, 2023 to May 14, 2023) are analyzed, and the general law of the characteristics of parking hours in commercial parking lots and the probability distribution of parking hours are found through the probability distribution. The parking time of vehicles directly affects the utilization rate and turnover rate of commercial parking lots. This section selects the data of all vehicles in and out of a week to analyze the parking time of each vehicle. Figure 4.1 shows the distribution probability of specific parking hours on weekdays (average from Monday to Friday) and Figure 4.2 on non-working days (average Saturday and Sunday).

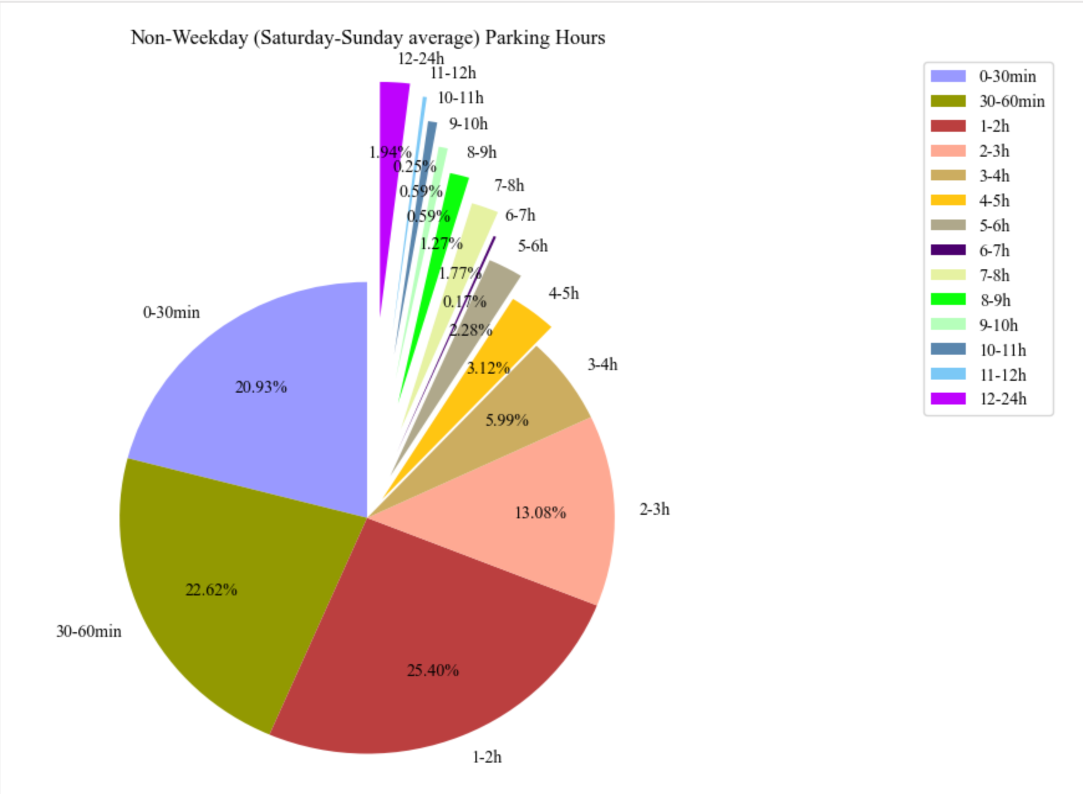


Figure 4.1 Analysis of parking time in working days (average Monday to Friday)

Source: Intercity SPPs parking data platform

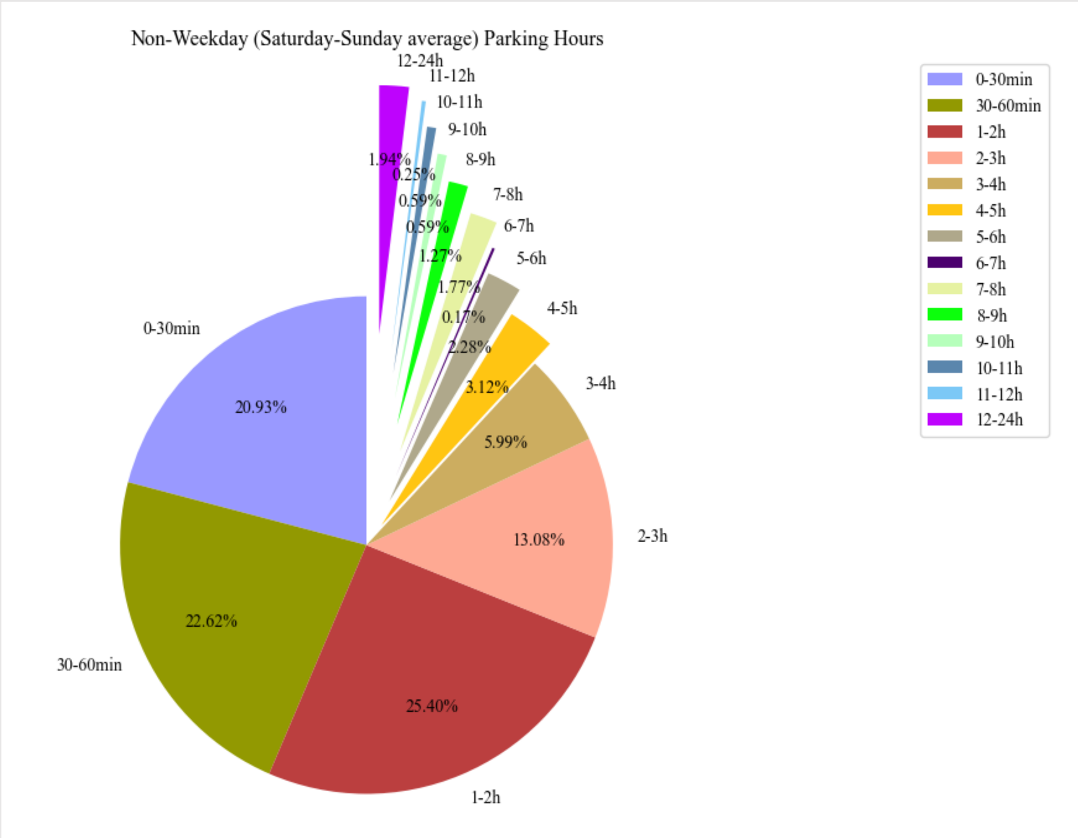


Figure 4.2 Parking time on non-working days (average Saturday and Sunday)

Source: Intercity SPPs parking data platform

It can be observed from the data that most of the vehicles parked in commercial areas are used for a short time, and their use time is basically within 4 hours. The proportion of vehicles parked for more than 6 hours is less than 4%, and the proportion of time between 1-2 hours is the largest. In order to obtain the distribution frequency of parking duration, we statistically analyzed the proportion of parking demand per unit of parking duration.

Figure 4.1 shows the length of parking hours on weekdays (average Monday to Friday). Most of the parking demands on weekdays are concentrated in parking hours of 0-30 minutes, 30-60 minutes, 60-120 minutes and 120-180 minutes, accounting for 22%, 18%, 25% and 13% respectively. Figure 4.2 shows the length of parking time on non-working days (average Saturday and Sunday). Most of the parking demand on non-working days is concentrated in the parking time of 0-30 minutes, 30-60 minutes, 60-120 minutes and 120-180 minutes, accounting for 21%, 22%, 25% and 13% respectively. The distribution of working days and non-working days is the same in other periods, and the non-working days in the 30-60 minutes period is higher than that in the working days by 4%. This shows that most of the vehicles parked in commercial parking lots on non-working days are mainly for shopping, and the number is more than that on working days.

### 4.1.2 Parking turnover rate in shopping malls analysis

The turnover rate of parking spaces in a parking lot changes over time, reflecting the ratio of the number of times parking spaces are used within each observation period relative to the total number of parking spaces available in the IoT. The larger the turnover rate, the more parking spaces are used by more users. This indicator can better reflect the number of parking service users in hospitals, government agencies and other places. Within the observation period *t*, the calculation formula of parking space turnover rate is as follows (H. Zhang, 2022):

$$Rt=St/C \tag{3.1}$$

Wherein, *R* represents the parking turnover rate of the parking lot, *S* represents the cumulative number of parking lots (vehicles) during the survey period, and *C* represents the capacity of the parking lot (units). Parking turnover rate is an indicator to measure the number of times each parking space in the parking lot was used during the survey period. It roughly represents the average number of vehicles repeatedly parked in a parking space during the observation period, reflecting the utilization of parking facilities. The following analyzes the change of turnover rate of commercial parking lots on working days, non-working days and seven days a week, to find its general rule. In this section, the data of all vehicles' entry and exit on working days, non-working days and seven days a week are selected for processing. The specific curve of parking space turnover rate with time is used to describe the change of commercial parking lot turnover rate.

(1) Changes in turnover rate of commercial parking lots for a continuous week (seven days)

In addition, the average daily turnover rate of the parking lot within a week is counted, as shown in Appendix Figure 9. The daily turnover rate of parking lot is directly affected by the number of vehicles entering the parking lot every day, and the characteristic law is similar. It can be observed from Appendix Figure 9 that the turnover rate on non-working days is the highest, and the average turnover rate of the parking lot exceeds 3. The turnover rate of non-working days is low, and the average turnover rate is less than 2.5.

(2) Changes in turnover rate of commercial parking lots on weekdays

It can be observed from the previous section that there is consistency between admission and exit on weekdays, so the turnover rate is most representative in the middle of the week (Thursday). Appendix Figure 10 depicts the parking turnover rate in hours on weekdays, reflecting the average utilization times of each parking space in the parking lot per hour in a day.

From the above figure, the change curve of parking turnover rate and the change curve of the number of parking lots arriving have a similar change law, respectively rising in a straight line from 9:00 to 20:00, with a maximum of 4.72, which indicates that the average number of parking spaces in commercial parking lots has increased during this period. The increase of the parking is directly related to the change of vehicles entering the parking lot, indicating that the number of vehicles entering the parking lot is the largest during this period.

(3) Changes in turnover rate of commercial parking lots on non-working days

Appendix Figure 11 shows the average daily hourly turnover rate of the depot within the time range of data collection. It is obvious from the figure that the change curve of parking turnover rate is similar to that of the number of parking lots. The turnover rate increases rapidly from 11:00 a.m. to 12:00 a.m. and from 17:00 p.m. to 18:00 p.m., and rises linearly from 9:00 a.m. to 20:00 p.m., respectively.

This shows that during this period, the average number of parking spaces in commercial parking lots has increased, which is directly related to the change of vehicles entering the parking lot, indicating that the number of vehicles entering the parking lot is the largest during this period. Compared with weekdays, the curve on Saturday rose faster, reaching a maximum of 7.25, while it was only 4.72 on Thursday, indicating that the utilization rate of parking spaces on Saturday was much higher than that on Thursday.

### 4.1.3 Parking space occupancy in shopping malls analysis

The occupancy rate of parking lots over time reflects the ratio of the total number of parking lots occupied to the total number of parking lots at each observation time. The higher the ratio, the higher the utilization rate of parking space resources, and the less free parking space resources. The occupancy rate often indirectly reflects the operating income of the parking lot. For the observation time *t*, the parking lot occupancy rate is calculated as follows:

$$Ot=Pt/C \tag{3.2}$$

The *O* is the occupancy rate of parking space in the parking lot at time *t*, *P* is the number of vehicles in the parking lot at time *t*, and *C* is the total number of vehicles in the parking lot. By observing the instantaneous parking space utilization rate of commercial parking lots at each time, and analyzing the data, we can find the time-varying law and understand the changing law of parking lot utilization at each time. The following three points respectively analyze the daily and weekly variations of the berth utilization rate for vehicle access on weekdays and weekends.

#### 4.1.3.1 Daily variation analysis

(1) Change of occupancy rate of commercial parking lot on weekdays

To fully understand the characteristics of the occupation of commercial parking lots on weekdays, this section selects the data of vehicles entering and leaving a commercial parking lot on a Thursday, analyzes and processes them, and obtains the change of the occupation of commercial parking lots on weekdays with time, as shown in Appendix Figure 12.

It can be observed from Appendix Figure 12 that the utilization rate of parking lots in daytime is above 40% on weekdays; The highest occupancy rate of parking lot is about 85%. The change rules of berth utilization curve are different. On weekdays, the occupancy rate of parking lots has two peaks at 16:00 p.m., and the growth of occupancy rate is obvious. For the growth of occupancy rate after 16:00 p.m., it is mainly because fewer people enter shopping malls in the morning of weekdays. Generally, they enter shopping malls or eat in the afternoon, which can also explain the reason why the occupancy rate of parking lots increases significantly in the afternoon.

(2) Changes in occupancy rate of commercial parking lots on Saturday.

By selecting the data of Saturday for analysis and calculation, the change of occupation ratio of commercial berths on Saturday with time is shown in Appendix Figure 13:

It can be observed from Appendix Figure 13 that in non-working days, the utilization rate of parking lots during peak hours (from 9 a.m. to 20:30 p.m.) is more than 60% during the day, mainly because the owners of non-working days are relatively free in the morning and afternoon, and can choose to enter shopping malls or other consumption, which can also explain the high and active occupancy rate of parking lots during the day. The utilization rate at night is relatively low (22:00-7:00), and the utilization rate of parking lot is basically kept at 20% or below, reaching a peak of 100% at 9:00-10:00, 12:00-13:00, and 15:00-18:00, 20:00 in the afternoon, which indicates that all parking spaces in the parking lot have been used, and other owners who drive to the mall can't enter the parking lot. This is related to the rich dining, watching movies and shopping activities of owners in the mall at that time.

#### 4.1.3.2 Workday analysis

In China, Monday to Friday are weekdays, and the occupancy of parking lots during this period can be directly seen from the analysis of the occupancy data of weekdays. Figure 4.3 shows the analysis of parking space occupancy on weekdays (Monday to Friday). It can be observed from the figure that the fluctuation of occupancy on weekdays is relatively gentle. Among them, the average hourly parking space occupancy rate on Friday is slightly higher than that from Monday to Thursday to a certain extent. This law is consistent with the change trend of the number of parking spaces in and out of the parking lot every day. The utilization rate of the parking lot is more than 40%, and the peak time of each day is basically the same. The specific time periods are in the afternoon, 17 p.m. and 19-20 p.m., and the maximum parking space occupancy rate is 98%.

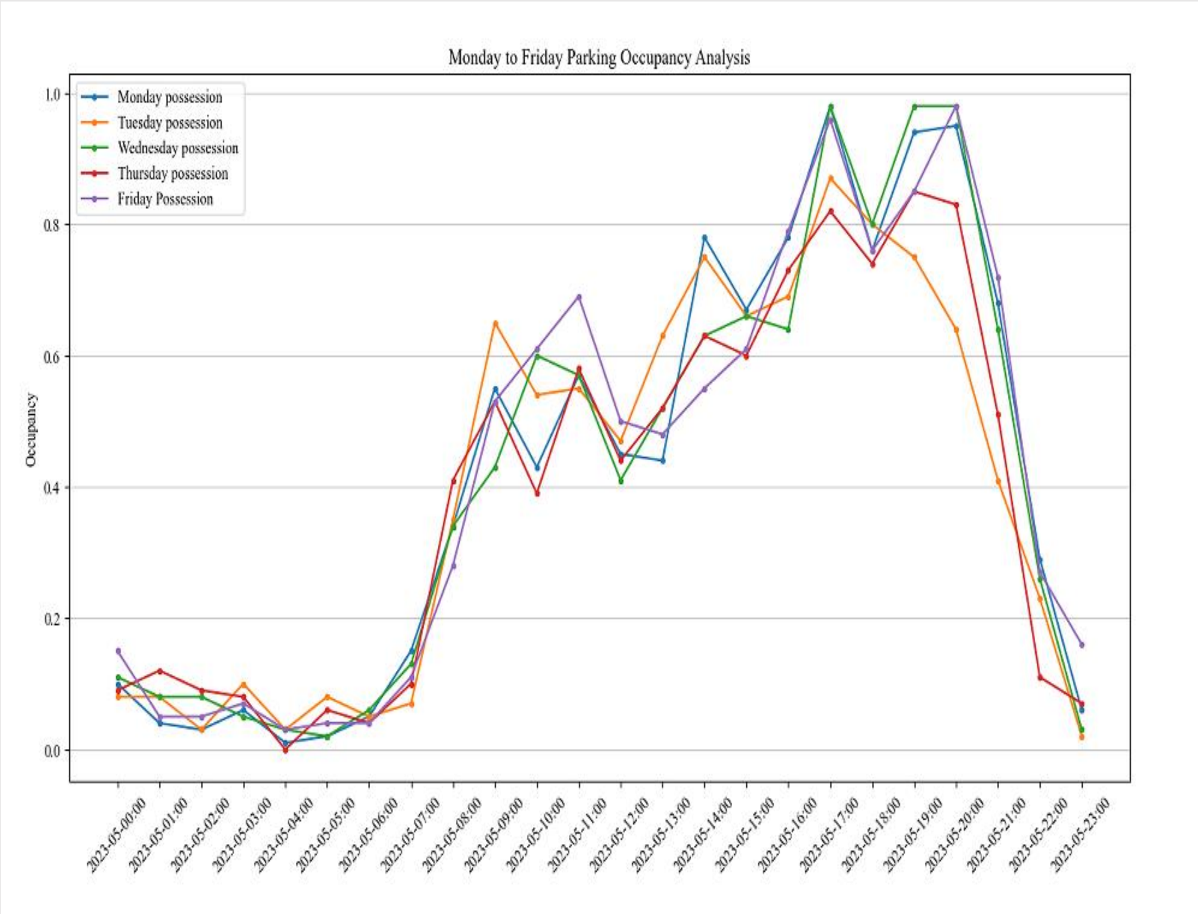


Figure 4.3 Parking space occupancy analysis on weekdays (Monday to Friday)

Source: Intercity SPPs parking data platform

#### 4.1.3.3 Non-working day analysis

In China, Saturday to Sunday are non-working days. The occupancy of parking lots during this period can be directly seen from the analysis of non-working day occupancy data. Figure 4.4 analysis of parking space occupancy on non-working days (Saturday to Sunday). It can be observed from the figure that the parking space occupancy on non-working days is very high. During peak periods, the utilization rate of parking lots is above 60%. The specific periods are 9-10 a.m. and 15-17 p.m., and the maximum value can reach 100%. This shows that all the parking spaces in the parking lot have been used, and the rest of the car owners who drive to the mall cannot enter the parking lot, which is related to the rich dining, watching movies and shopping activities of the car owners in the mall at that time.

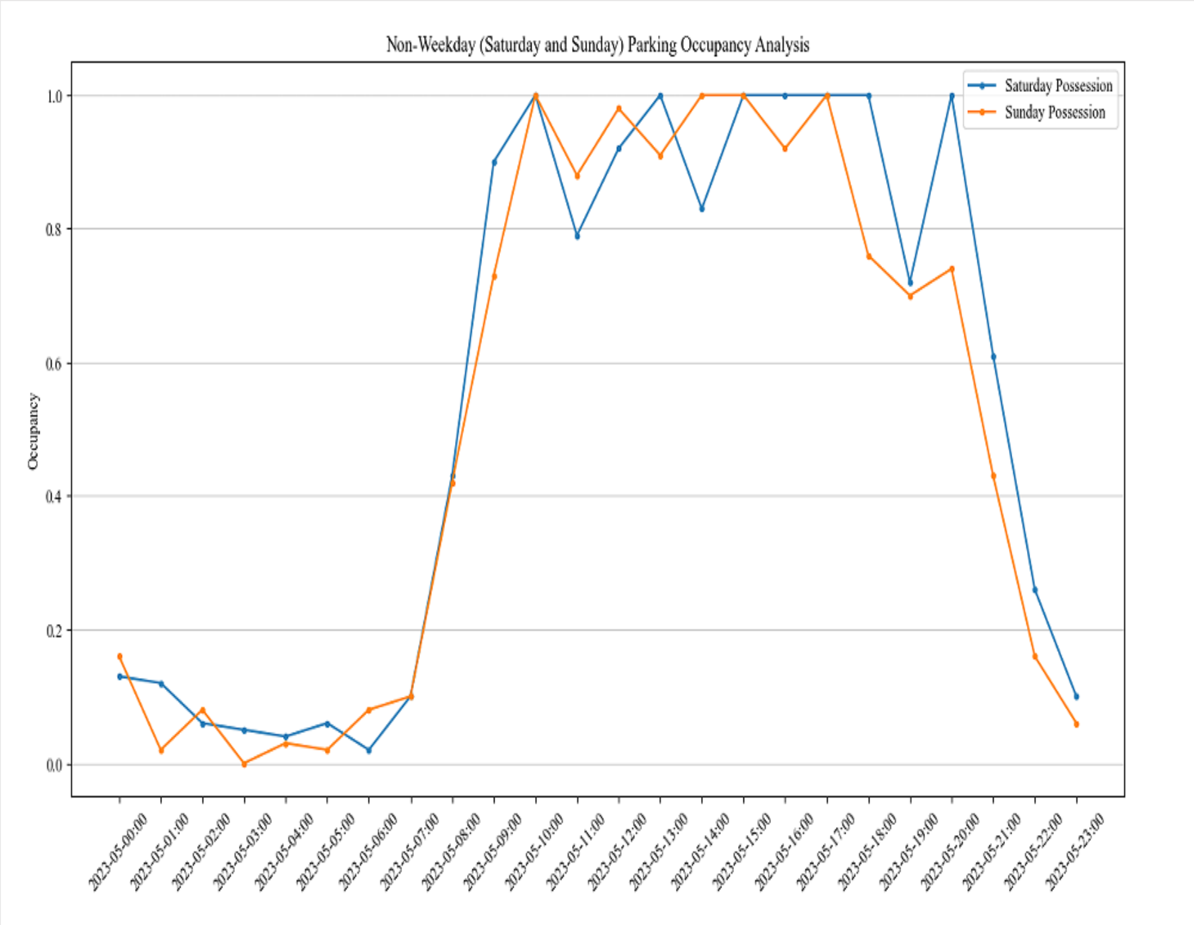


Figure 4.4 Parking space occupancy on non-working days (Saturday and Sunday)

Source: Intercity SPPs parking data platform

From the comparison of the two figures, there are certain differences between the occupation of parking lots on weekdays and on weekdays, mainly in the following four aspects:

(1) On weekdays, the utilization rate of general parking lots will have two peaks, which are relatively regular. On the weekend, the berth utilization rate curve has three obvious peaks at 10 a.m. and 15 and 17 p.m., both reaching more than 90% and changing significantly.

(2) The difference in the utilization rate of non-working days during peak periods is mainly due to the more shopping and consumption activities on weekends and the demand in the morning and afternoon, which can also explain the great changes in the utilization rate of berths during the day on Saturday and Sunday.

(3) There is no peak in the morning on weekdays, and there is a peak period at 10 a.m. on weekends. The peak time of non-working days in the afternoon (15:00) is about two hours ahead of the peak time of working days (17:00), which is related to the characteristics of the travel time of vehicle owners on non-working days.

(4) Finally, we also found that at 20:00 on non-working days, the occupancy rate on Saturday was 100%, which was very active, while the occupancy rate on Sunday at the same

time was 74%, which was related to the fact that car owners considered the characteristics of Monday working days.

### 4.1.4 Travelers' parking reservation behavior

According to the research design, this thesis uses questionnaire data to analyze travelers' parking reservation behavior. A total of 300 thesis questionnaires were distributed in this field survey, of which 212 were valid. After screening, 800 valid questionnaires were finally obtained from the online questionnaire survey. After analyzing and processing the survey results, the following relevant data and information were obtained.

#### 4.1.4.1 Travelers' socio-economic attributes

The survey obtained the socio-economic attributes of travelers in the survey area, which mainly showed the following characteristics:

(1) Gender distribution. As shown in Appendix Figure 14, the proportion of male travelers was 62.5%, which was significantly higher than that of female travelers.

(2) Age distribution. As shown in Appendix Figure 15, in this survey, the age of travelers is counted according to the five intervals 18-25, 26-35, 36-45, 46-55 and above 56. The results show that the proportion of travelers aged 36-45 is 50.32% of the total, so this part of the population is the main body of parking travel.

#### 4.1.4.2 Traveler parking traffic attribute score

(1) In order to investigate the properties of commercial parking lots, we also investigated the purpose of car owners to go to business. The research content is what is the purpose of driving to shopping malls frequently. Please refer to Appendix Figure 16 for details. Five options are set, namely shopping, eating or other catering, watching movies, office work, children's training, and others. The results showed that meals and catering accounted for 74.04%. This phenomenon reflects the important role that modern consumers play in their daily lives when it comes to catering needs in commercial activities. It is worth noting that because car owners may have multiple purposes when going to the mall, the survey has set up a checkbox that allows travelers to choose multiple purposes. This indicates that shopping malls are not only places for shopping, but more and more consumers are choosing to go to shopping malls for various activities such as dining and entertainment, which makes the parking demand in shopping malls diverse at different times and for different purposes.

(2) Do you think it is difficult to park in China. In this survey, the parking problems faced by travelers during travel are counted according to four levels: very difficult, relatively difficult, general and easy. As shown in Appendix Figure 17, The survey results show that the proportion

of travelers who think it is difficult or relatively difficult to park in China has reached 59.29%, which is consistent with the current phenomenon of difficult parking in China as a whole, and the status of parking spaces is unknown.

(3) Whether there is often no parking space. As shown in Appendix Figure 18, the survey results show that the proportion of travelers who often and sometimes encounter no available parking spaces is 43.91% and 51.6% respectively, that is, the proportion of travelers who encounter no available parking spaces is 95.51%, which also reflects the current overall parking difficulty in China.

(4) It takes a long time to find a parking space. As shown in Appendix Figure 19, the survey results show that it takes about 0-30 minutes for travelers in this area to find available parking spaces. Through statistics, it was found that the number of travelers who spent 6-10 minutes in searching for parking spaces reached 46.79%. The time spent by travelers to find parking spaces increases the travel burden of travelers, and also leads to more energy consumption.

#### 4.1.4.3 Attribute analysis of travelers' parking reservation

(1) Whether you are willing to reserve a parking space in advance through the network or mobile client before travel. As shown in Appendix Figure 20, the survey results show that 67.31% of travelers are willing to choose to reserve a parking space in advance before travel. Booking parking spaces in advance can make travelers' driving plans more organized, reduce the time wasted due to last-minute search for parking spaces, and also meet their expectations for on-time departure and convenient parking. Based on the above analysis results, we can further enhance the booking experience of travelers by optimizing the parking reservation service function, aiming to optimize the service process according to the changing needs of travelers and improve user satisfaction.

(2) Appointment selection method. As shown in Appendix Figure 21, It can be observed from the analysis that 91.03% of travelers choose to use mobile software for parking space reservation because it is more convenient and faster than other methods. Based on this survey result, we can further optimize the functions and services of its mobile application, such as providing real-time updated parking information, convenient payment systems, etc., aiming to improve reservation efficiency based on technological innovation and further promote the intelligent development of parking services in the future.

(3) Whether they are willing to pay the reservation fee. As shown in Appendix Figure 22, the survey results show that 81.33% of travelers are willing to pay the reservation fee to find a parking space when the parking space is tight. In the case of scarce parking spaces, most travelers hold a positive attitude towards paying reservation fees and are willing to pay

additional fees for a better travel experience and parking convenience. This preference is mainly attributed to the fact that paying reservation fees not only provides certainty and convenience for travelers, but also effectively reduces uncertainty and time costs in finding parking spaces. Based on this analysis result, we can design flexible reservation fee strategies aimed at maximizing parking space utilization while also reasonably adjusting demand and supply, providing more personalized and diversified charging options.

(4) When the parking space is tight, the proportion of the reservation fee that the owner is willing to pay in order to find the parking space is (according to the proportion of the local hourly parking fee, such as 5 yuan per hour parking fee). As shown in Appendix Figure 23, the survey results show that 86.86% of travelers are willing to pay the reservation fee below 50% of the parking fee per hour. Through statistical analysis, 11.86% are willing to pay 50% to 100% of the hourly parking fee, and less than 2% are willing to pay more than 100% of the hourly parking fee. The reservation fee is an important factor affecting whether travelers choose the parking reservation method. Therefore, the analysis results can provide reference for the formulation of the reservation fee scheme, to attract the most travelers to use the reservation metho.

(5) When the parking space is idle, in order to make it possible for the parking lot to book the parking space here in advance, the parking lot management can give parking concessions, and the proportion of the amount that the owner expects to give is (according to the proportion of the local hourly parking fee, such as 5 yuan per hour parking fee). As shown in Appendix Figure 24, the survey results show that travelers' expected preferential booking fees account for 55.13% in the range of less than 50% of parking fees per hour; Through statistical analysis, travelers' expectation of preferential fees in the range of 50% -100% of hourly parking fees is 35.58%, and the proportion of booking fees exceeding 100% of hourly parking fees is less than 10%; Preferential fee is an important influencing factor for travelers' choice of parking reservation and drainage mode. Therefore, the analysis results can provide reference for the formulation of leisure reservation and drainage fee, so as to attract the most travelers to use the reservation mode for parking choice.

#### 4.1.4.4 Factors of concern for travelers' parking lot selection

When travelers select parking lots, several key factors influence their decision-making process. These factors include the ability to reserve parking spaces, the reliability of the reservation system, the proximity of the parking lot to the destination, the safety of the parking facility, parking fees, reservation fees, and driving time, among others. Each of these elements plays a crucial role in shaping the travelers' overall parking experience, and understanding their relative importance is essential for designing effective parking policies and pricing strategies.

These factors meet the different needs of travelers in parking choices. For example, booking a parking space in advance provides certainty and psychological comfort, a reliable booking system ensures a smooth booking experience, the distance between the parking lot and the destination directly affects the convenience of travel, and parking safety responds to car owners' concerns about vehicle safety. Parking and booking fees are key cost factors for travelers to consider, while driving time and overall accessibility ensure that parking choices do not add unnecessary travel time. Therefore, how to balance these factors and design parking policies that meet the needs of travelers is the key to improving parking lot utilization and enhancing user experience.

Through the above questionnaire survey, as shown in Appendix Figure 25, we can see that it is reasonable to set the reservation fee for travelers to be less than 50% of the hourly parking fee in busy hours. During these high demand periods, travelers are typically more price sensitive due to scarce parking spaces and intense demand. Keeping the reservation fee below 50% of the hourly parking fee can effectively motivate more travelers to use reservation services while ensuring that the fees remain within a reasonable and attractive range.

It is reasonable to set the preferential reservation fee to be less than 100% of the hourly parking fee in idle hours. During these low demand periods, there are many vacant parking spaces in the parking lot, and many parking spaces are in an unused state. By offering discounted reservation fees lower than standard parking fees, parking lot operators can encourage more travelers to book parking spaces in advance, thereby improving the utilization rate of parking spaces.

### 4.1.5 Summary of parking data analysis results

This section uses the collected parking data of a large-scale commercial underground parking lot in Chengdu and uses statistical analysis method to analyze the current situation of parking lot operation from two aspects: the characteristics of users' parking behavior and the dynamic change law of parking space resources. The parking law of vehicles in commercial parking lots is analyzed from four aspects: the arrival and departure characteristics of owners' vehicles, the parking time characteristics, the parking turnover rate characteristics, and the parking occupancy characteristics, The main conclusions are as follows:

(1) The parking time of most users in the parking lot is less than 4 hours, accounting for more than 80%. The change trend of the number of vehicles in and out of the parking lot on weekdays is relatively consistent, and there is a certain increase in non-weekdays. This shows

that most of the vehicles parked in commercial parking lots are shopping and other consumption vehicles parked for a short time. According to the analysis of the characteristics of users' parking behavior, considering the distribution of parking time and the frequency of vehicle in and out, through the data analysis, it is found that the centralized travel time of users entering the shopping mall coincides with the travel time, and coincides with the peak arrival time of vehicles in the commercial parking lot.

(2) On weekdays, the average hourly parking space occupancy rate on Friday is slightly higher than that from Monday to Thursday, and the peak time is basically the same every day. The specific time is in the afternoon, from 17 to 22 p.m., and the parking space occupancy rate is higher than 80% and the maximum is 98%. The change trend of the number of parking spaces in and out of the parking lot every day is consistent. The utilization rate of the parking lot is below 40% from 22:00 to 9:00, and the occupancy rate is less than 70% every morning on weekdays. Before 17:00 p.m., the occupancy rate is less than 80%, indicating that there are a large number of idle periods for parking in shopping malls on weekdays, and the parking resources are not effectively utilized.

(3) On non-working days, the maximum value can reach 100% at 9-10 a.m. and 15-17 p.m.; The peak time of the share on Saturday and Sunday morning is basically the same, but at 20:00, the share on Saturday and Sunday is very different. The share on Saturday is 100%, very active, while the share on Sunday at the same time is 74%, with a difference of more than 25%, which is related to the owner's consideration of the characteristics of Sunday night activities and Monday working days.

(4) On weekdays and weekends, the arrival of commercial vehicles reflects different rules. There are only two peak arrival periods in the afternoon on weekdays, and peak arrival periods in the morning and afternoon on non-weekdays. There are also differences in the number of arrivals. On Saturdays and Sundays, the number of vehicles arriving in shopping malls is large, the turnover rate is large, the occupancy rate is high, and it is more active than on weekdays. This shows that all the parking spaces in the parking lot have been occupied, and the rest of the owners who drive to the mall cannot enter the parking lot. It is very difficult for the mall parking lot to park on non-working days, and the mall management should solve it.

## 4.2 Shared parking platform operation logic

The shared parking platform is a bilateral platform. On the one hand, it accepts the supply of parking spaces, and on the other hand, it leases the received supply of parking spaces to the user groups in need. The decision-making of this kind of bilateral parking sharing platform enterprise is more complex than that of traditional parking operation enterprises. As long as the parking space of the traditional parking operation enterprise is not used, the time period for customers to park is the same, while the bilateral characteristics of the shared parking platform make the time period of unused parking space different. The logic of the shared parking platform operation is shown in Appendix Figure 26. In addition, there are two main links in the daily operation process: Booking and service. Decide whether to accept the customer's reservation in the reservation process. In the service sector, the shared parking platform meets the needs of scheduled customers. Some of the platform providers (parking space providers) have fixed parking space supply time. For example, for people who need to go to work every weekday, when these people go to work, the parking space in the residence is free, or the parking sharing platform directly rents part of the parking space. This part of the supply group can provide the parking space information to the parking sharing platform in advance. In view of the characteristics described above, this part of the supply can be referred to as determining the supplier.

Although it is determined that the supplier can provide the parking sharing platform with more specified rental time. However, compared with traditional parking spaces, the time for sharing parking spaces is different. For example, if the total parking time is three hours, the time for parking space A may be from 8:30 to 11:30, while the time for parking space B is from 9:30 to 12:30. When the customer's demand for parking is from 8:30 to 11:30, if the parking spaces in this time period have been reserved, the parking sharing platform should decide whether to refuse the reservation or use the parking spaces from 8:30 to 12:30 to meet the reservation demand. When a long-term available parking space is used to meet a short-term parking demand, it may fail to meet the demand when it arrives at a reservation demand that happens to be a long-term demand, thus losing part of the revenue. In summary, when the parking sharing platform is faced with reservation, it is necessary to decide whether to accept the reservation demand. If there are no parking spaces in the scheduled time period, it is necessary to further decide which longer time period to meet the demand.

## 4.3 Parking reservation mode analysis and algorithm design

### 4.3.1 Parking reservation mode analysis

At present, there are two kinds of parking reservation methods. Method:

(1) is to make an appointment to a specific parking lot and a specific parking space;

(2) is to make an appointment only to a specific parking lot without making an appointment to a specific parking space.

Method 1: In this reservation mode, travelers choose specific parking spaces to make an appointment according to the available parking spaces at the time of query, and users tend to select a parking space from the perspective of their own convenience. Because the system will accept many users' appointments, this method is simple and clear. The system releases the empty parking space information, and the car owner can make an appointment. Without other equipment and technology, it is the most convenient way to make an appointment. The disadvantage is that the car owner does not know his parking position before entering the parking lot.

Method 2: Make an appointment for the only parking space in a specific parking lot. In this reservation mode, the user will get a confirmation number information (in the form of digital number, two-dimensional code, barcode, etc.) after successfully making an appointment. After entering the parking lot, the user will find the parking space number of his own appointment according to the parking lot guidance system or the parking lot map and parking lot number. This method has strong real-time performance, which is conducive to the system arranging reasonable parking options for users from the overall perspective, and is conducive to improving the utilization efficiency of parking resources. When the user arrives at the parking lot, the system can select the best parking space for him according to the specific situation, and provide the best parking service to the user through dynamic selection. The disadvantage is that it takes time for owners who are not familiar with the parking lot to enter the parking lot to find a specific parking space. The reserved parking lot must also have a perfect parking space number, communication network and map.

The comparative analysis of these two reservation modes is presented in Appendix Table 3.

### 4.3.2 Algorithm design

Reinforcement Learning (RL) (Kaelbling et al., 1996), as a sub domain of Machine Learning (ML) (Jordan & Mitchell, 2015), has been successfully applied to solve complex sequential decision problems. Reinforcement Learning focuses on how the agent chooses an action to maximize the rewards accumulated. Reinforcement Learning is a popular tool in robust control, game theory and other fields. Reinforcement learning considers the interaction between an agent and the environment. At each time step $t$, the agent (such as the parking space management platform) observes the current system state $s_t \in S$ （$S$ is a collection of feasible States）, selects an action $a_t \in A(s_t)$ （$A(s_t)$ is a collection of feasible actions when the system state is $S_t$ ）and gets a reward $r_t \in$ R, and then the system state is randomly transferred to the state $s_{t+1} \in S$, as shown in Figure 4.5.

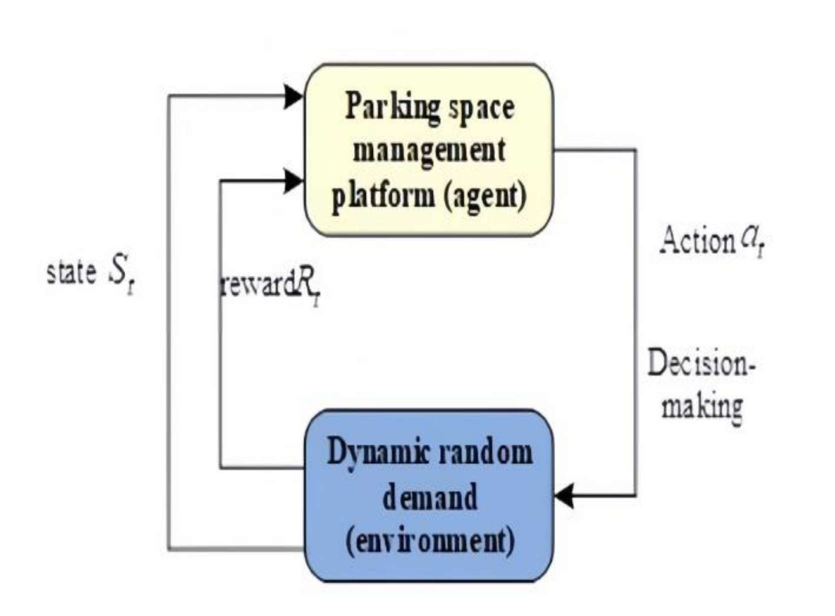


Figure 4.5 Markov decision process of parking space reservation control and pricing

Source: drawn by the author based on Boucherie and Van Dijk (2017) and Kaelbling et al. (1996)

This decision-making process is also a Markov Decision-making Process (MDP) (Boucherie & Van Dijk, 2017), reinforcement Learning algorithm can be applied to solve complex Markov process problems. Let $P_a(s,s')$ be the state transition matrix, that is, the probability of state transition to $s'$ when state $s$ selects action $a$, that is, $P_a(s,s') = \Pr(s_{t+1} = s' | s_t = s, a_t = a)$. Similarly, $R_a(s,s')$ stands for the corresponding reward matrix. In each cycle $t$,the decision maker (parking space management platform) takes action $a_t = \pi_t(s_t)$ according to a given strategy $\pi_t$. The goal of reinforcement learning is to maximize the expected discount total reward $r_t$ ,that is to find a strategy $\pi : S \to A$, maximize

$$\mathrm{E}\left[\sum_{t=0}^{\infty} \gamma^t R_{a_t}(s_t, s_{t+1})\right] \tag{4.1}$$

And $0 \le \gamma \le 1$ is the discount factor.

Given $P_a(s,s')$ and $R_a(s,s')$, the optimal strategy can be solved by dynamic programming or linear programming. However, for large-scale Markov decision-making process, the traditional dynamic programming algorithm is not solvable. Currently, reinforcement learning algorithm provides a way to find the approximate solution.

Specifically, the Markov decision-making process of parking space reservation control and pricing described in the above model, It is described by array $\langle S,R,R,P,\gamma\rangle$ and strategy $\pi$, where $S$ is the state space, $A$ is the action space, $R$ is the reward (reporting) function, $P$ is the state transition probability, and $\gamma$ is the discount factor. The details are as follows:

(1) State space: State $s_t$ in phase $t$, parking space $s_t \in S$ available for rent in the current and future periods observed by the shared parking platform in cycle $t$.

(2) Action space: In the case of exogenous (endogenous) price, the action space is the collection of the number of accepted parking space reservations (pricing and accepted reservation quantity, replacement quantity). First, we study the price exogenous situation. In phase $t$, the agent takes action $a_t$, which is the number of reserved parking spaces and the number of substitutions accepted by the shared parking platform operator in cycle $t$.

(3) Reward function: Take action $a_t$ when the status of stage $t$ is $s_t$, and the immediate reward of the environment for the action obtained after interacting with the reservation quantity control environment $r_{t+1}$,This thesis uses most of the methods of deep reinforcement learning in the literature to deal with dynamic problems, Reward $r_{t+1}$ is expressed by the rental income of parking spaces on the shared parking platform in time period $[t,t+1)$.The number of customers who book parking spaces in cycle $t$ and choose to park in cycle $l$ is $\beta_l d_t$. Suppose the parking revenue per cycle is $p_t$, so the revenue of customers who book parking spaces in cycle $t$ and choose to park for cycle $l$ is $p_t l \beta_l d_t$. Then the revenue of the parking platform in cycle $t$, $r_{t+1}$ is the sum of the revenue from all customers who book parking spaces in the current period (regardless of the number of parking cycles).

$$r_{t+1} = \sum_{t=1}^{N} p_t l \beta_l d_t \tag{4.2}$$

(1) State transition probability: $P_t(s_{t+1} | s_t, a_t)$ represents the probability of transferring to the next state $s_{t+1}$ when the state is $s_t$ and the reservation action $a_t$ is taken. The source of the uncertainty of the state transfer mainly lies in the change of customer arrival rate caused by the dynamic change of the influencing factors of the observed state under the current inventory

state and the demand response strength of the market environment to the reservation action $a_t$, Therefore, it is difficult to describe the state transition probability. To solve this problem, this thesis uses reinforcement learning method, which does not need to predict the state transition probability of the model in advance.

(2) Discount factor: Also known as discount factor, it measures the discount rate of future earnings for the selected action at the current stage, and is used to measure the relative importance of current immediate return and delayed reward, $\gamma \in [0,1]$ ,If $\gamma = 0$ indicates that the agent has no vision and only focuses on the current reward; If $\gamma = 1$ indicates that there is no discount for future rewards, the agent pays attention to long-term benefits, and the future rewards are equal to the current rewards.

(3) Strategy $\pi$ : decide what action to take when in a certain state $s$, represented by probability $\pi(a|s)$, thus, by the definition, we have $\pi(a|s) = \Pr(a_t = a | s_t = s)$.

Deep Q Network (DQN）is a typical Deep Reinforcement Learning (DRL) algorithm. The following design of Q-network structure comprehensively considers the state and observation information as well as the sequence feedback information to evaluate the cumulative discount return value of different actions under the current state. Therefore, the observation status, inventory status and sequence feedback information modules are designed for the underlying feature extraction. In cycle $t$, the current inventory status of parking spaces is $s_t$, , the action taken by the shared parking platform is $a_t$, and the future will follow the optimal strategy. Finally, the total revenue that the parking platform can obtain is $Q(s_t, a_t)$, which is called the $Q$-value function, i.e.,

$$\begin{aligned} Q(s_t, a_t) = E_\pi[r_t(s_t, a_t) + \gamma r_{t=1}(s_{t+1}, a_{t+1}) + \gamma^2 r_{t+2}(s_{t+2}, a_{t+2}) + \cdots \\ + \gamma^{T-t} r_T(s_T, a_T)] = \sum_{k=0}^{T-t} \gamma^k r_{t+k+1} | s_t = s, a_t = a \end{aligned} \tag{4.3}$$

For the dynamic pricing problem in this study, the state of each pricing time step belongs to high-dimensional feature space sampling, and it is not feasible to use Q-learning algorithm to estimate the $Q(s,a)$ value of each state action pair $(s,a)$. To solve this problem, a function approximator with $\theta$ parameter can be used to estimate $Q(s,a) \approx Q(s,a|\theta)$.

The solution of deep Q network is as follows: In phase $t$, the shared parking platform first observes the inventory status of each parking product and generates a targeted parking space reservation control scheme $a_t = \arg\max_a Q(s_t, a_t; \theta)$ and according to the current Q network parameters; and then simulate customer feedback through customer arrival modeling, i.e. reward return $r_t$ in the current period. Finally, the new reservation record is updated to the product inventory status to obtain the status $s_{t+1}$ of phase $t+1$, and the decision-making process of phase $t$ is completed. Then, store $(s_t, a_t, r_t, s_{t+1})$ as a parking space reservation control experience into the sample pool, and start the parking space reservation decision of phase $t+1$ until the end of the whole decision cycle. In the iteration process, the shared parking platform needs to continuously optimize and update the Q-network parameters according to the current sample pool until the parameters converge to the stable value $\tilde{\theta}$. The structure of deep Q network is composed of convolutional neural network and dueling DQN (Yamashita et al., 2018). The convolutional neural network is composed of four convolution layers. Dueling DQN evenly divides the output of convolutional neural network into two vectors and connects the full connection layers to construct the action advantage function and environmental value function. The input of Q network is the state variable, and the output is the Q value of all feasible parking space reservation control schemes in the current state. The training algorithm of Q network is shown in Table 4.1.

Table 4.1 Training algorithm of Q network

| Training algorithm |
|---|
| 1: Initialize storage sample pool D to capacity N. |
| Initialize the main value function $Q_{main}$ with parameter $\theta$. |
| Initialize target value function $Q_{target}$parameter $\theta^- = \theta$. |
| 2: Number of rounds=1, M do |
| Initialize state $s_1$ and preprocess$\Phi_1 = \Phi_1(s_1)$ |
| For t=1, T do, |
| Step 1: Select action $a_t$ randomly with probability $\varepsilon$ |
| Otherwise select $a_t = argmax_a\, Q_{main}\,(\Phi(s_t), a; \theta)$. |
| Step 2: Execute $a_t$ in the simulator and observe the customer response behavior return value $r_t$ and the next state $s_{t+1}$. |
| Step 3: Pretreatment$\Phi_{t+1} = \Phi(s_{t+1})$. |
| Step 4: Store in sample pool D$(\Phi_t, a_t, r_t, \Phi_{t+1})$ |
| Step 5: If $M > K$ has the number of pre-training steps, every $C_1$ steps: randomly extract small batch data $(\Phi_j, a_j, r_j, \Phi_{j+1})$ from sample pool D, set |
| $y_j = \begin{cases} r_j & \text{if this round ends at step J “+1”, otherwise} \\ r_j + \gamma Q_{target}(\Phi(s_{t+1}), argmax_a(\, Q_{main}(\Phi(s_{t+1}), a))) \end{cases}$ |
| Perform random gradient descent parameter update on$(y_j - Q_{main}(\Phi_j, a_j; \theta))$, |
| Step 6: Reset $Q_{target} = Q_{main}$ every $C_2$ steps |
| End for |
| End for |

Using the gradient descent algorithm to iteratively update the parameters $\theta$ and $Q(s_t, a_t; \theta_i)$, the learning goal is $r_t + \gamma max_a\big(Q(s_{t+1}, a; \theta_i)\big)$, where $i$ is the number of iterations, and the parameters are updated every $C_1$ step. Evenly extract experience sample

$(s_t, a_t, r_t, s_{t+1}) \sim U(D)$ from the storage sample pool.

In the pre training phase, the first K steps of the simulation use random strategies to generate parking platform actions and collect the initial data into the data pool. Then, the $\varepsilon^-$ greedy algorithm will be used for simulation, and the $\varepsilon$ value will be reduced from the initial value to the end value in the H annealing step.

To train the Q-network, the mean square error is used as the loss function:

$$L_i(\theta_i) = E_{(s_t,a_t,r_t,s_{t+1})-D}[r_{t=1} + \gamma \max Q(s_{t+1}, a_{t+1}|\theta) - Q(s_t, a_t|\theta)^2] \qquad (4.4)$$

$D = \{(s_t, a_t, r_t, s_{t+1})\}$ represents the set of state transition pairs formed by the interaction between the agent and the environment. For the loss function $L(\theta)$, batch gradient descent algorithm and its variants are used to train.

Using the $Q$ - network after training, the dynamic operation strategy of parking platform can be obtained througharg $max_a Q(s, a|\tilde{\theta})$, in which $\tilde{\theta}$ is the parameter in the stable state of the training process.

## 4.4 Optimization modeling of intelligent parking reservation platform

### 4.4.1 Parking optimization modeling considering only advance booking

First, the booking phase is divided into AB discrete time cycles, assuming that one time cycle can reach at most one booking. At the same time, the service link is also divided into $\Gamma$ discrete time periods, for example, 24 hours (a day) is divided into multiple discrete service time periods according to one hour or half an hour. Customers' parking time is not the same, so the initial parking cycle $r$ and the end cycle $s$ of customers are regarded as one product $(r,s)$. Let $\mathbf{C} = (C_{11}, C_{12}, ..., C_{1\Gamma}, C_{22}, .., C_{2\Gamma}, ..., C_{\Gamma\Gamma})$ denote the number of parking spaces in the fixed supply, where $C_{rs}$ denotes the capacity or capacity of the product $(r,s)$. In the booking phase, let $\mathbf{I} = (I_{11}, I_{12}, ..., I_{1\Gamma}, ..., I_{22}, ..., I_{2\Gamma}, ..., I_{\Gamma\Gamma})$ be the inventory (remaining quantity) of the product in the current cycle state, and $I_{rs}$ be the inventory quantity of the product $(r,s)$. The initial state is $\mathbf{I} = \mathbf{C}$. Let $F_t(\mathbf{I})$ be the expected total return from the reservation period $t$ to the end of the service period when the inventory status is $\mathbf{I}$.

Let $p_{rst}$ be the probability of $(r,s)$ demand for a product in the $t$ booking cycle. The parking sharing platform accepts and meets the predetermined product $(r,s)$ to obtain revenue

$f_{rs}^{b}$. When there is no product $(r,s)$ for a certain period of time, that is, the product is out of stock, the platform needs to decide whether to use the shared parking space for a longer period of time to meet the demand of the product or directly reject the reservation of the product. Let $u_{rs}(\mathbf{I}) = \{(l,k) \mid l \le r, k \ge s, I_{lk} > 0\}$ be the collection of products that can be used to meet the requirements of $(r,s)$. when $(l,k)$ is used to meet the requirements of $(r,s)$, the product $(l,k)$ will be divided into three products $(l,r)$ 、 $(r,s)$ and $(s,k)$.

Therefore, establish the Bellman equation:

$$F_t(\mathrm{I}) = \sum_{r=1}^{\Gamma}\sum_{s=r}^{\Gamma} p_{ijt} \max_{(l,k)\in v_{rs}} \left(f_{rs}^{b} + F_{t+1}\left(\mathrm{I} - e_{rs}^{(l,k)}\right), F_{t+1}(\mathrm{I})\right) + \left(1 - \sum_{r=1}^{\Gamma}\sum_{s=r}^{\Gamma} p_{ljt}\right) F_{t+1}(\mathrm{I}) \tag{4.5}$$

where $e_{rs}^{(l,k)}$ is the $(l-1)\Gamma - \frac{(l-2)(l-1)}{2}\Gamma + (k-l+1)$ component, and components $(l-1)\Gamma - \frac{(l-2)(l-1)}{2}\Gamma + (r-l)$ and $sT - \frac{(s-1)s}{2}\Gamma + (k-l)$ are $1 \times \frac{\Gamma(\Gamma+1)}{2}$ -dimensional vectors of 1. Boundary condition is $F_{T+1}(\mathbf{I}) = 0$. This equation is similar to the studies of Hosni et al. (2014) and J. Q. Ma et al. (2017).

### 4.4.2 Parking optimization modeling considering temporary arrival and advance booking

In the case of determining the supply, the above content analyzes the case of only booking users. However, in real life, there are many customers who do not have a reservation for temporary arrival. Such users will temporarily arrive at a parking point when they need to stop. Because booking in advance can reduce the uncertainty of the decision-making of the shared parking platform, the rental price of the reserved customers' parking space will be lower than that of the customers who arrive temporarily. When there are two types of customers, temporary customers and reserved customers, the decision of shared parking platform is more complex. It is necessary to decide which reservation requirements should be accepted or rejected in the reservation process. When entering the service phase, how to allocate the limited capacity between the two types of customers is a trade-off. If you accept too many advance reservations, you will find that the needs of temporary customers cannot be met, which will reduce the revenue of the parking platform. If the customers who book in advance accept too little, the parking space may be idle, which will also reduce the revenue of the parking platform.

Based on one kind of customers, the model of two kinds of customers is constructed. It is assumed that the arrival demand of temporary customers occurs in the service cycle. As mentioned above, if the shared parking platform accepts too many scheduled customers, it may lose some temporary customers who can charge higher prices in the service process. If too few reservation customers are received, there may also be no temporary customers arriving at the service link, resulting in many idle parking spaces and losses. Therefore, it is necessary to build the parking space reservation control optimization model under two types of customers. Because there are two types of customers, advance reservation and temporary arrival, the status variable $\mathrm{X} = (x_{11}, x_{12}, \dots, x_{TT})$ is the product reservation status, where $x_{rs}$ represents the product and $(r, s)$ represents the quantity that has been reserved. Using $F_t(\mathrm{X})$ to represent the expected total revenue from the $t$ initial advance booking cycle to the end of the service cycle, the following Bellman equation can be established:

$$F_t(\mathrm{X}) = \sum_{r=1}^{\Gamma}\sum_{s=1}^{\Gamma} p_{rst}\, max\left(f_{rs}^{b} + F_{t+1}\left(\mathrm{X} + e_{h_{rs}}\right), F_{t+1}(\mathrm{X})\right) + \left(1 - \sum_{r=1}^{\Gamma}\sum_{s=1}^{\Gamma} p_{rst}\right) F_{t+1}(\mathrm{X}) \tag{4.6}$$

This equation is supported by the studies of B. W. Jiang and Fan (2020).

where $h_{rs} = (r-1)\Gamma - \frac{(r-2)(r-1)}{2} + (s-r) + 1$, $e_{h_{rs}}$ are the $h_{rs}$-dimensional vector whose component $\frac{\Gamma(\Gamma+1)}{2}$ is 1.

When the temporary demand arrives at the service stage, let $d_{rs}^{w}$ be the quantity of the temporary demand for product $(r, s)$, and assume that $d_{rs}^{w}$ is an independent general distribution. Because the customers who arrive temporarily arrive randomly, only the products with time period $(r, s)$ are considered to meet the temporary needs of product $(r, s)$. Let table $y_{rs}^{w}$ be the capacity used to meet the temporarily arrived customer demand $(r, s)$ in the $r$ service cycle, and $f_{rs}^{w}$ be the income when the temporarily arrived customer demand of product $(r, s)$ is met. According to the actual situation, the unit price of the temporary arrival demand of products in the same period is higher than the advance booking demand, that is $f_{rs}^{w} > f_{rs}^{b}$. If the customers who book in advance do not have parking space at the service stage, it will bring great loss to the reputation of the platform enterprise. Therefore, the situation that the shared parking platform refuses to book in advance at the service stage to meet the temporary arrival customers is not considered.

Let the total supply be $q_{rs}, r = 1,2, \ldots, \Gamma, s = r, r+1, \ldots, \Gamma$. When entering the service cycle, the accepted reservation status is X, and $\eta = x_{rs} + y_{rs}^{w}$ is the quantity of two types of products $(r, s)$ actually accepted. After entering service period $r$, because meeting the needs of temporarily arriving users can obtain higher income, after meeting the needs of pre ordering product $(r, s)$, the capacity of the remaining product $(r, s)$ will fully meet the needs of temporarily arriving, let $\pi(\mathrm{X})$ is the expected income of the service cycle, as in equations (4.7), (4.8) and (4.9) (Kaspi et al., 2014; Kaspi et al., 2016).

$$\pi(X) = \max E\left(\sum_{r=1}^{\Gamma}\sum_{s=r}^{\Gamma} a_{rs}^{(m,n)}\, min\{(\eta_{rs} - x_{rs})^{+}, d_{rs}^{w}\}\right) \tag{4.7}$$

s.t.

$$\sum_{m=1}^{\Gamma}\sum_{n=m}^{\Gamma} a_{rs}^{(m,n)}\, \eta_{mn} \leq q_{rs}, s = r, r = 1,2, \ldots, \Gamma \tag{4.8}$$

$$\eta_{rs} \in Z_{+}, r = 1,2, \ldots, \Gamma; s = r, r+1, \ldots, \Gamma \tag{4.9}$$

The objective function (4.7) expresses the expected return to meet the temporary demand. The constraint formula (4.8) indicates that the total amount of products allocated to two types of customers is less than or equal to the total amount of supply.

The parking space reservation control problem under the two types of demand constructed above obeys the general distribution for the assumption of temporary demand arrival. Therefore, the traditional method of designing approximation algorithm is not suitable for solving this kind of problem, so the deep reinforcement learning algorithm is also designed to solve this kind of extended model.

### 4.4.3 Parking optimization modeling under stochastic supply and stochastic demand

The above content, under the determination of supply, first investigates the reservation control and pricing strategy problem in the case of only one type of customer with advance reservation and then expands to consider the situation of two types of customers with advance reservation and temporary arrival.

Next, we will mainly analyze the situation of two types of suppliers. In practice, in addition to having two types of customers on the demand side, there are also two types of suppliers on the supply side of shared parking platforms: One type is to determine the supplier, who can provide information about idle parking spaces to the parking platform in advance and sign a relatively stable supply contract; One type is random providers, who are unable to provide parking space information to the parking platform in advance due to temporary travel, which is a temporary behavior. For the platform, the number of parking spaces provided is random and unstable. Under two types of supply and two types of demand, the core decision of the shared parking platform is still to optimize the matching of supply and demand to achieve maximum revenue. However, in the case of stochastic supply and demand, optimizing supply and demand matching is complex and difficult. In cases where supply is also stochastic, if too many reserved customers are accepted, but the supply of parking spaces is insufficient, it will lead to the inability to meet the demands of the already accepted reserved customers; If too few reserved customers are accepted, but there may be a large supply of parking spaces leading to idle parking spaces in the future, both of which will result in a decrease in the revenue of the parking platform.

Following the above settings, the parking platform still has two stages: reservation and service. In the booking process, it is determined that the supplier and the reserved customer are respectively providing parking spaces and demand arrival. It is assumed that the demand arrival of the pre booked user occurs after the supply is confirmed. In the service process, random suppliers and temporary arriving customers respectively provide parking spaces and demand arrival.

After the booking process, there will be random supply and random demand in the service process. Let $O_{rs}$ be the random supply of service link product $(r, s)$, and assume that $O_{rs}$ is an independent general distribution. Because there is random supply in the service stage, when a product $(r, s)$ is out of stock, the parking platform needs to decide whether to reject the reservation of the product or use a longer parking space to meet the reservation demand of product $(r, s)$ . $y_{rsk}^{b}$ is the reservation quantity of service cycle product $(r, k)$ to meet product $(r, s)$ , $k \geq s$ . If the shared parking platform rejects the $(r, s)$ of the accepted subscription product demand, a penalty cost $\pi_{rs}$ will be incurred. Similarly, for the random demand of temporary arrival, the shared parking platform only uses the product $(r, s)$ to meet the temporary demand $(r, s)$. Let $\widetilde{q_{rs}} = \sum_{(m.n)\in A_{rs}}(C_{mn} + O_{mn})$ be the total number of parking spaces from service period $r$ to $s$. since stochastic supply is included, $\widetilde{q_{rs}}$is a random variable. If the parking platform refuses to book customers' needs in advance, it will bring bad experience to customers and will greatly affect the reputation of the platform. Therefore, suppose$\pi_{rs} > f_{rs}^{w} > f_{rs}^{b}$, that is, the service link, the shared parking platform will give priority to customers who book in advance. When the advance booking status is X, the revenue $\pi^{Z}(X)$ in the service link is given by Molnar et al. (2019) and C. Y. Shao et al. (2016):

$$\pi^Z(X) = maxE\left(\sum_{r=1}^{\Gamma}\sum_{s=r}^{\Gamma} f_{rs}^{w}\, min\{y_{rs}^{w}, d_{rs}^{w}\} - \sum_{r=1}^{\Gamma}\sum_{s=r}^{\Gamma} \pi_{rs}\left(x_{rs} - \sum_{k=s}^{\Gamma} y_{rsk}^{b}\right)\right) \quad (4.10)$$

s.t.

$$\sum_{k=s}^{\Gamma} y_{rsk}^{b} \le x_{rs}, r = 1,2,\dots,\Gamma; s = r, r+1,\dots,\Gamma \quad (4.11)$$

$$\sum_{l=1}^{r}\left(\sum_{s}^{k} y_{lsk}^{b} + y_{lk}^{w}\right) \le \sum_{l=1}^{r}(C_{lk} + O_{lk})\,, r = 1,2,\dots,\Gamma; \mathrm{k} = \mathrm{s}, \mathrm{s}+1,\dots,\Gamma \quad (4.12)$$

$$y_{k}^{b}, y_{rs}^{w} \in Z_{+} r = 1,2,\dots,\Gamma; s = r, r+1,\dots,\Gamma; \mathrm{k} = \mathrm{s}, \mathrm{s}+1,\dots,\Gamma \quad (4.13)$$

The boundary condition with random supply is $V_{T+1}(\mathrm{X}) = \pi^2(\mathrm{X})$. The objective function (4.10) represents the total expected revenue of the service cycle, which consists of two parts: the revenue obtained by satisfying random demands and the penalty cost of rejecting some advance booking demands. The constraints (4.11) represent that the quantity of products allocated to reserved customers is less than or equal to the advance booking quantity. The constraints (4.12) represent that the total quantity of products allocated to two types of customers cannot exceed the total supply of the two types of customers.

The above constructs a parking space reservation and pricing operation management problem under random supply, where both temporary arrival demand and temporary supply are assumed to follow a general distribution. Traditional methods of designing approximate algorithms are difficult to solve such models and cannot obtain the structural properties of the optimal strategy. Therefore, deep reinforcement learning algorithms are also designed to solve this problem.

## 4.5 Optimization design of operation and management process for smart parking reservation platform

### 4.5.1 Feasibility analysis of parking reservation

There is relatively little works on the practical application of parking reservation both domestically and internationally. In China, the following aspects are examined from national policies, commercial value, technological level, economic benefits, data collection and analysis, management and service capabilities:

(1) National policies. With the increasing number of cars in China, the general requirement of the government for parking is to thoroughly implement the spirit of the 19th National

Congress of the Communist Party of China, focus on building a public service support system in accordance with the concept of innovative, coordinated, green, open and shared development, stimulate the endogenous demand of the "Internet Ten Parking" market, create an industry ecology for sharing parking resources, improve the efficiency of intensive utilization of urban parking resources, alleviate the contradiction between supply and demand, and cultivate new drivers of the sharing economy through the development of new models and new business types. In terms of policy, in order to alleviate urban parking facility resources. In 2015, the State Council issued the Guiding Opinions on Actively Promoting the "Internet X" Action GF [NO.2015140]. The National Development and Reform Commission (NDRC) issued a notice in 2017 on carrying out pilot and demonstration work for urban parking lots (NDRC Basic [NO.20173475]). The Chengdu Municipal Government issued the Implementation Opinions on Strengthening the Construction and Management of Parking Facilities in the City in 2017 (Chengfu Letter [NO.20173176). The Chengdu Municipal People's Government issued policy documents in 2018, including the "Implementation Opinions on Encouraging and Supporting the Sharing and Utilization of Parking Resources" Chengban Letter (NO.2018231), to fully support the utilization of parking resources.

(2) Business value and economic benefits: Parking reservation can improve the utilization rate of parking lots, which is beneficial for parking management to improve the turnover and occupancy rate of parking spaces. While receiving the reservation fee, it can also increase the income of parking fees. For car owners, it is possible to immediately book an empty parking space, solve the fundamental problem of finding a parking lot, and save time. For the design and users of the reservation platform, it can effectively increase the number of registered users on the client side. The data platform can also have data such as the number of information releases, transaction amounts, and transaction volumes. For the government and society, alleviating some parking problems, improving parking space utilization, and reducing the time spent searching for parking spaces can indirectly reduce carbon emissions.

(3) Technical level. In recent years, China's technological level has developed rapidly, mainly manifested in the following aspects: Mature software and hardware. Thanks to China's ability to share parking platforms, system architecture and solutions, and interface integration in hardware and software development, parking reservation software and parking management hardware can be developed and used. With the rapid rise of mobile Internet. The vigorous use of WeChat official account, applet and app client has provided a good carrier for parking reservation. Electronic payment is popular. Consumers do not carry cash and do not need to set up multiple online payment QR codes. The owner of a QR code can directly realize electronic

payment through WeChat, Alipay, UnionPay, ETC. The payment methods are flexible and diversified, making payment more convenient and faster.

(4) Data collection and analysis. Many local governments have local data centers, and many companies also have their own data platforms to provide guarantees for data collection. The company platform is built on cloud servers, with dedicated wired networks and local servers to achieve dual point backup of cloud and local data to ensure data security. The security of data protection methods is quite high, and it is difficult for anyone to crack them without the key holder leaking.

(5) Management and service capabilities. The operational management level of the parking industry in China is relatively efficient, and parking operation management is an important component of enterprise marketing strategy management. The problem that operations management needs to solve is how to formulate operational strategies, in what ways and means to make customers aware and understand the output content, and then generate interest and make consumption decisions. By implementing standardized operational management, we aim to provide services to the company and various regions, improve operational strategy market response speed, compete for customers, and expand the market. Parking services include offline parking data operation and user operation. Offline parking operation refers to the operation of the parking management party promoting the use of parking spaces and monthly rental to customers, and engaging in vehicle parking with consumers or users. Data operation refers to analyzing and making decisions on vehicle data through its own data platform. User operation refers to putting users at the center, setting operational activities and rules according to their needs, formulating operational strategies and objectives, strictly controlling the implementation process and results, in order to achieve the expected set operational goals and tasks. Based on operational goals and market conditions, the operations center plans, budgets revenue, organizes implementation, and has a mechanism for handling disputes and complaints, for any abnormal situations in this project, priority should be given to handling phone calls for assistance. Technical engineers or on-site administrators should analyze and diagnose the situation, promptly resolve operational issues, and submit inspection reports to users to ensure normal parking for vehicle owners and users.

In summary, it is feasible for travelers to make parking reservations and parking lot managers to manage parking reservations. To achieve parking reservations, the following challenges need to be addressed:

(1) How to publish available parking reservation information and enable travelers with parking needs to quickly access this information.

(2) How do travelers make parking reservations after obtaining this information, how do they achieve successful reservations, and how do they pay for parking fees.

(3) How to choose the optimal parking lot among multiple available reservation parking lots when parking travel users are faced with multiple options.

(4) How can parking lot managers select available parking spaces for users when facing the booking needs of multiple parking users, and maximize the efficiency of parking lot utilization through reasonable arrangement and optimization.

(5) When a parking reservation user has multiple available parking spaces, how can the parking lot manager select the best parking space for the user among these available parking spaces.

(6) How to pay the parking fee to the parking lot (parking lot manager) when the parking reservation user completes the vehicle parking.

Based on the parking lot data platform and intelligent parking guidance system, this study develops an appointment platform and process to address the six main issues faced in parking reservation. Relevant information on available parking reservations will be released. When you use Alipay, WeChat payment, bank card and other users to get relevant information for parking, you can quickly make an appointment choice. Parking travel users can make parking reservations through mobile applications, online networks, telephones, in car terminals, and other means. When parking reservation users complete parking, they can pay parking fees through Alipay, WeChat payment, bank card, etc.

Based on the remaining parking spaces on the data platform, the system can reserve parking lots for users according to their personal needs. Based on the reservation platform, the location of the reserved parking lot can be conveniently and quickly displayed on the map, and the optimal driving path can be calculated to guide parking users to the reserved parking lot, and guide them to complete vehicle parking at the parking lot.

### 4.5.2 Parking reservation mode selection

Based on the previous text, there are mainly two types of parking reservation methods: one is to book a specific parking space, and the other is to only book a specific parking lot. By comparing the two parking modes, It can be observed that although the car owner knows their parking spot before departure, they must find a unique parking spot in the parking lot. The parking lot must have a complete parking number and communication network. Even if searching for a parking spot in this way requires a lot of time, and the reserved parking spot may be occupied by other temporary vehicles, further parking lock devices are needed to control it. So this thesis chooses the first method of booking to the parking lot to study.

After determining the parking reservation method, through analysis and research, the excess reservation mode (the number of reservations exceeds the number of actual needs) was proposed from a system perspective, and the fuzzy reservation method (details and arrangements were not determined when the time and place were agreed) was proposed from a user perspective. In theory, it can maximize the efficient utilization of parking resources.

(1) Excess reservation

Because in the real world, it is very likely that some users have reservations but do not come to park or cancel them. According to historical information and data obtained from the aviation and hotel industries, the average number of underachievers accounts for about 5% of total reservations. Since the reservation system in this study is a parking lot reservation system, users will not suffer too much loss due to not arriving, and the average rate of not arriving will be higher. In order to protect the system from losses caused by the above situation, the parking reservation system, like other reservation systems, usually makes excess reservations, meaning that the system needs to accept some additional reservations on the basis of the maximum number of reservations that can be processed. For example, during a certain period of time, there are 240 available parking spaces in a certain parking lot. If the system has already accepted the reservation of 240 users, the system will activate the over reservation. For example, setting the over reservation factor to 1.1 means that the system will accept the reservation of 24 more users on the original basis. The final number of user reservations accepted by the system is 264, which is the number of over reserved parking spaces by the system.

(2) Fuzzy reservation

In reality, considering the current parking situation, we often encounter the problem of insufficient parking spaces, especially during peak hours. In order to improve the overall utilization of parking resources, the concept of fuzzy reservation is proposed, that is when the expected time period requested by the user does not fully correspond, an appointment can still be made. For example, if a user requests an appointment for a time period between 9:00 and 10:00, and the system accurately reserves a full parking space at this time, but there are available parking spaces between 9:00-9:45 and 9:30-10:00, and the system will explain this information to the user. If the user accepts such reservations, this mode is called "fuzzy reservation". There are very advanced reservation systems in the hotel and aviation industries, but most of them have not solved the problem of fuzzy reservation matching. The situation of the parking lot reservation system is different. The time period for users to make parking reservations is more detailed and flexible. If the vehicle is already saturated and the parking space is exceeded and reaches the entrance equipment of the parking lot, it will not be allowed to enter, which can cause a poor experience or even complaints from car owners. Therefore, in practical use, excessive and vague reservations will not be used.

### 4.5.3 Optimization design of intelligent parking process under advance reservation

Users will use the parking reservation system and make reservations based on the available parking information provided by the system. The parking lot reserves available parking spaces for these users. These users are roughly classified according to their travel destinations: work, shopping, leisure, office, etc. Considering the different usage needs of these users for parking lots, most office users will use the parking spaces provided by the company. The parking lots studied by this system are mainly public parking lots, and only a very small number of office users may use the system to make parking space reservations. Therefore, the majority of users served by the system are for shopping, leisure, temporary office, and other purposes, they usually use parking spaces between half an hour and six hours. According to the survey results of parking lots in Xi'an, parking for residential purposes is the longest, followed by parking for work purposes. Shopping and leisure parking generally take about 2 hours. The specific operation is: before departure, the owner opens the WeChat official account applet, clicks the parking lot navigation. If the car owner has not planned a destination parking lot in advance, the interface will eliminate the current location of the car owner and recommend nearby parking lots for the car owner and display real-time information such as the number of parking spaces in the parking lot. Clicking on the parking lot will directly enter navigation mode. If the car owner has already planned the destination parking lot, simply enter the parking lot name to search and view the current information of the parking lot, and click to enter navigation mode. The system mainly serves reservation users, so users with reservations have priority over temporary users in using the parking lot, because once they make a successful reservation, the system can ensure that parking services are provided to them, while temporary users need to be determined based on the actual situation. As shown in the Appendix Figure 27.

### 4.5.4 Optimization design of intelligent parking process in the case of temporary arrival and advance booking

The parking space of the parking lot is divided into two parts, one part is used for the service of reserved users, and the other part is used for the service of temporary users. For example, if we say that 80% of the parking spaces are reserved, that is, 240 parking spaces can be reserved in a parking lot with 300 parking spaces, and the remaining 60 parking spaces are only for temporary users. Compared with reserved users, a small number of users will park in the parking lot without booking a parking space. We call such users temporary users. Temporary users usually have temporary affairs, forget to make an appointment, or have no time to make an appointment in case of emergencies, and they also have parking needs. Considering this situation, it is necessary for us to serve such users. When a temporary user arrives at a parking lot, the license plate recognition system at the entrance of the parking lot determines whether there are still vacant parking spaces in the parking lot. If there is a parking space available, the parking system will open the brake to let the vehicle enter; If there is no empty parking space, the parking system will not open the brake, and temporary users can also pay their parking fees through the online payment system when they leave. The time difference between the entry time and the exit time is confirmed by the license plate recognition machine as the parking payment period. The specific process of temporary user parking is shown in the Appendix Figure 28.

### 4.5.5 Optimal design of intelligent parking process under random supply and random demand

From the perspective of the overall effective utilization of parking resources, the parking lot may not reserve all parking spaces in some time periods (such as non-peak hours), some users with reservations temporarily cancel their reservations, or some users with reservations do not come to park, that is, some idle parking spaces will not be used. If there are temporary users arriving at this time and they need to park here, then we can provide them with vacant parking spaces without reservation. On the other hand, from the perspective of improving the income of parking managers, it provides available parking spaces for a few temporary users, which improves the utilization rate of parking spaces and correspondingly increases the income of parking managers. In general, the system mainly provides parking services for users with reservations and also provides parking services for a small number of temporary users, which is more reasonable and humanized, and also improves the overall use efficiency of parking resources (Appendix Figure 29).

In summary, within the framework of reinforcement learning, this paper designs a process targeting stochastic supply and demand, with the overall schematic diagram illustrated in Figure 4.6.

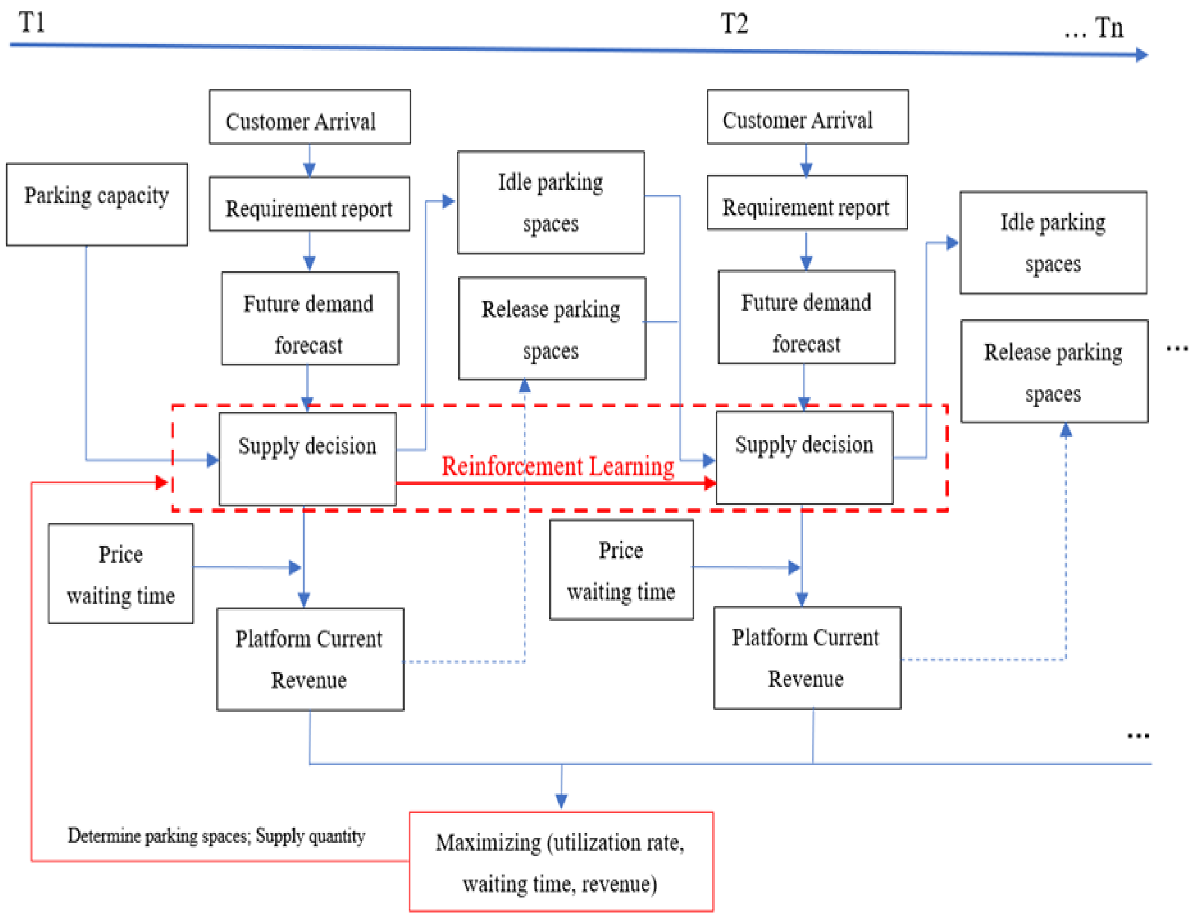


Figure 4.6 Process diagram in reinforcement learning mode

## 4.6 Business process design of parking reservation

### 4.6.1 Design of parking reservation management process

The parking process design divides the requirements into different types according to the number of cycles corresponding to the length of parking space occupied by different requirements. Since travelers send parking demands randomly, to improve the utilization of parking space resources, the platform starts at the beginning of each decision-making period t. It is necessary to decide in advance the number of parking spaces to meet different types of demand in the current decision-making period. During the decision-making period t, the platform successively received different types of parking demand, and used the supply parking spaces decided in advance to meet the emerging demand. In the subsequent decision-making period, the platform will repeat the above process until the end of the current operation period (Figure 4.7).

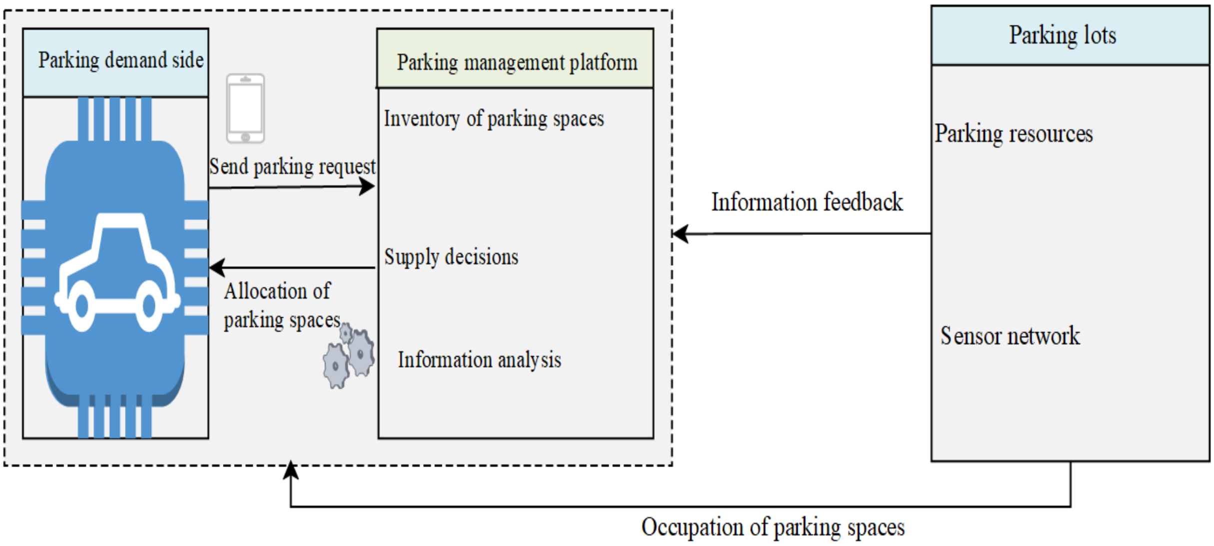


Figure 4.7 Intelligent parking process design

According to the analysis of parking space occupancy in Chapter 3, there are obvious tidal phenomena in commercial parking lots:

On non-working days, the peak time is from 9 a.m. to 8 p.m., reaching 100%. During this time, many people who need to consume may not be able to find parking spaces, so we use parking space reservation to book parking spaces in advance. During busy hours, the user pays the reservation fee plus parking fee. On weekdays, on the contrary, the peak time is basically the same, from 17 to 22 p.m., with the occupancy rate of more than 80% and the maximum of 98%. However, before 17:00 p.m. on weekdays, the occupancy rate is less than 80%, and there are a lot of idle parking resources in shopping malls, which are not well utilized. In order to make use of the parking resources in this period, we use the parking space reservation for drainage. The store management of the user who has made an appointment will give a discount. At leisure, the user pays the parking fee minus the reservation discount fee. According to the Ultra dilute phenomenon, we need to design the process for two cases.

### 4.6.2 Appointment user process design

The payment process of parking reservation fee considers the real traffic conditions in the real world. Some users will encounter traffic delays and may arrive in about 5 to 10 minutes. It is unreasonable to refuse these users. Therefore, it is recommended that the minimum time limit for the front and back ranges is 30 minutes, to maintain high utilization while ensuring the service level of users. That is, it is reasonable to use 30 minutes as the appointment time. For example, if a vehicle reservation time is 10:30, plus the grace period of the first 30 minutes is 10:00, plus the grace period of the next 30 minutes is 11:00, the reservation time period is

10:00-11:00, and the user pays the reservation fee for admission within the reservation time period. Plus, the parking fee charging rules at the time of admission, the total fee paid by the user is the total fee (the parking fee will be calculated when the vehicle is admitted by default); The specific graphic analysis of reservation fees and parking fee periods is shown in Appendix Table 4.

In this system, users can make an appointment 24 hours in advance at the earliest and complete the appointment at least 1 hour before arriving at the parking lot; When making an appointment, the user needs to select the parking time he needs (such as 8:00-9:00, 15:00-16:00, etc.). If the user needs to continue parking after the expiration of the appointment time, the subsequent parking time will be charged according to the temporary vehicle. In the system studied in this thesis, it is suggested that the user is allowed to make an appointment for one hour. The system reserves a parking space for the user. The owner enters the parking lot and finds an empty parking space to park. When the user leaves, he will pay his parking fees through the online payment system. Use the parking lot billing software and bind it with online payment systems such as Alipay, credit card or WeChat for direct payment.

### 4.6.3 Design of busy hour parking reservation process

During busy hours, we use parking space reservation to reserve parking space in advance, and users pay the reservation fee plus parking fee. For the payment of reservation fee, the system requires the user to pay a certain reservation fee when making an appointment. If the user goes to the parking lot and then parks here, the user will directly pay the parking fee when he leaves the parking lot. If the reservation user cancels the reservation or fails to arrive, the reservation fee will not be returned as compensation for the loss of the parking lot manager. The specific process of booking a user's parking line during busy hours is shown in the Appendix Figure 30.

### 4.6.4 Design of idle parking reservation drainage process

In order to make use of the parking resources during this period of time in idle time, we use the parking space reservation for drainage during this period, and the store management of the user who made the reservation will give a discount. We use parking space reservation to book parking spaces in advance, and users pay parking fees minus reservation discount fees. The reservation user enters the parking lot directly, and the parking management system has calculated the parking fee minus the reservation discount fee when the user leaves the parking lot. If the reservation user cancels the reservation or does not arrive, the parking fee will not be included in the reservation discount fee. The specific process of reserving parking for users in idle time is shown in the Appendix Figure 31.

When designing the process of booking users, it is necessary to consider the characteristics of booking users. Delayed arrival or delayed departure is impossible in the real world to expect all users to arrive and leave on time at the time of their booking, because some users may encounter traffic jams, emergencies, etc., so it is impossible to achieve complete punctuality. Considering the above situation, the system needs to provide such users with a reasonable range period, which is the controllable time given to the reserved users. The user is allowed to be late for a period of time, and the reservation user can park the vehicle within the time range of the appointment start time. If the user arrives before the reservation range, and the system cannot identify the reserved car, it will be regarded as a temporary user. If the user arrives after the reservation scope period, he will lose the reservation authority and will be regarded as a temporary use. For example, the reservation period is 10:30, plus 30 minutes before and after, that is, 10:00-11:00. If the user arrives at the parking lot before or after 10:00, which belongs to the unacceptable timeout range, he will be judged as a temporary vehicle by the system. The design method of reservation parking process is shown in the Appendix Table 5.

## 4.7 Design of reservation information system

### 4.7.1 Structure design and function of parking reservation system

#### 4.7.1.1 System structure design

The structure of the reservation system is the core of the parking reservation system. In order to better understand the structural design of the parking reservation system, the whole system is divided into three layers for analysis:

(1) Control layer

The control layer is the core layer of the whole system. The control center of the parking reservation subsystem constitutes the control layer. The parking space reservation system completes the system configuration, realizes the collection, transmission, processing and release of parking reservation related information, and provides travelers with practical application functions such as query, reservation or unsubscribe.

(2) Operation layer

The operation layer is composed of parking lot management end. The parking lot management end collects and processes the parking space use, reservation and cancellation information through the information collection and processing system. The control center of parking reservation system manages and processes all information by category and makes corresponding decisions.

(3) User layer

The user layer is composed of parking information publishing terminal and parking reservation system client. The parking information release terminal releases the relevant parking information (parking lot name, geographical location, usage, reservation, etc.) of each area in real time through the Internet, mobile phones, vehicle terminals and other publishing methods. Travelers who need parking can query, reserve and unsubscribe through the parking reservation system client. The user terminal system is composed of a user interface for booking, inputting the parking lot, parking demand time and making payment. Users can use the network to apply for an appointment before going to the destination. The system mainly provides real-time information about the status of the parking lot. The user is given a choice to indicate which parking lot entrance he will enter from.

#### 4.7.1.2 System function

Reservation based intelligent parking system information users include parking lot managers and travelers with parking needs. In order to realize the interaction and contact between travelers and parking lot managers, the system should meet the following functions:

(1) Realize the interaction between the reserved parking lot site and the control management center, focusing on the management and regulation of parking resources based on data analysis; Realize the connection of software and hardware between parking lot management system and parking reservation system;

(2) Realize real-time collection of parking space use information and reservation information in the parking lot, and timely transmit it to the control and management center, so as to better provide comprehensive parking information services for travelers with parking needs;

(3) The management center has strong data processing functions, including the processing of parking space information, parking lot management information and the reliability of data release information; The algorithm designed for the central server system is efficient, so that it can effectively handle a large number of user activities in the parking lot (such as reservation and exit), and quickly respond to user requests and system changes;

(4) The system control management center provides available parking information to drivers through online, mobile phones, vehicle terminals, etc., queries and accepts parking

space reservations or cancellations, and reserves parking spaces for reserved users. The system can also provide parking services for a small number of temporary users (users without advance reservations);

(5) Realize the automatic management of the parking lot, the entry and exit of vehicles, and the payment is fully automated;

(6) If the parking lot has a parking guidance system, the parking reservation system can be compatible with the parking guidance system.

### 4.7.2 Analysis and design of parking data flow in reservation system

The reservation system is based on the parking management system, and its data flow is composed of four parts: the parking management system control center, the parking reservation system control center, the parking information release center, and the parking reservation client terminal, The data flow design of the parking reservation system is shown in the following Figure 4.8.

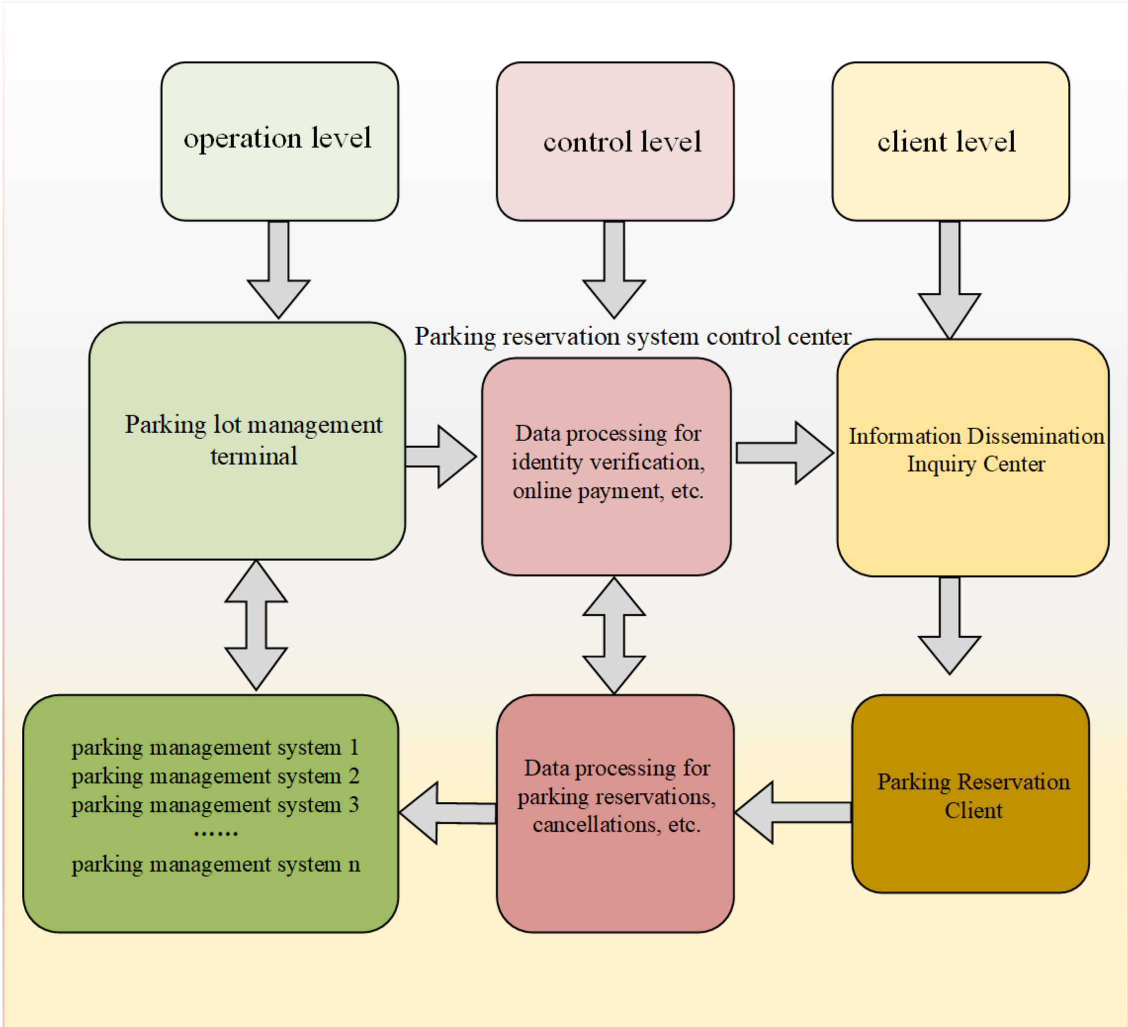


Figure 4.8 Data flow design of parking reservation system

Data flow design of parking reservation system: The parking lot management terminal collects and processes parking space use, reservation and cancellation information through the information collection and processing system. Then upload the data information to the control center of the parking reservation system.

After processing the information, the control center will release the relevant parking information (parking lot name, geographical location, usage, reservation, etc.) in real time through the Internet, mobile phones, vehicle terminals and other publishing methods. Travelers who need parking can query, reserve and unsubscribe through the parking reservation system client. The control center of the parking reservation system receives and processes the relevant parking information of the parking reservation system client. Finally, the control center of the parking reservation system will send the parking reservation users to the corresponding parking lot, and the parking lot management system will provide good parking services for the reservation users according to the instructions.

### 4.7.3 Design of parking reservation payment module

In China, based on the rise of mobile Internet and payment, a large number of parking lots use electronic payment. Therefore, in the design of the payment module, two kinds of fees should be designed during busy and idle hours. The design drawing of the parking reservation payment module is observed in Figure 4.9:

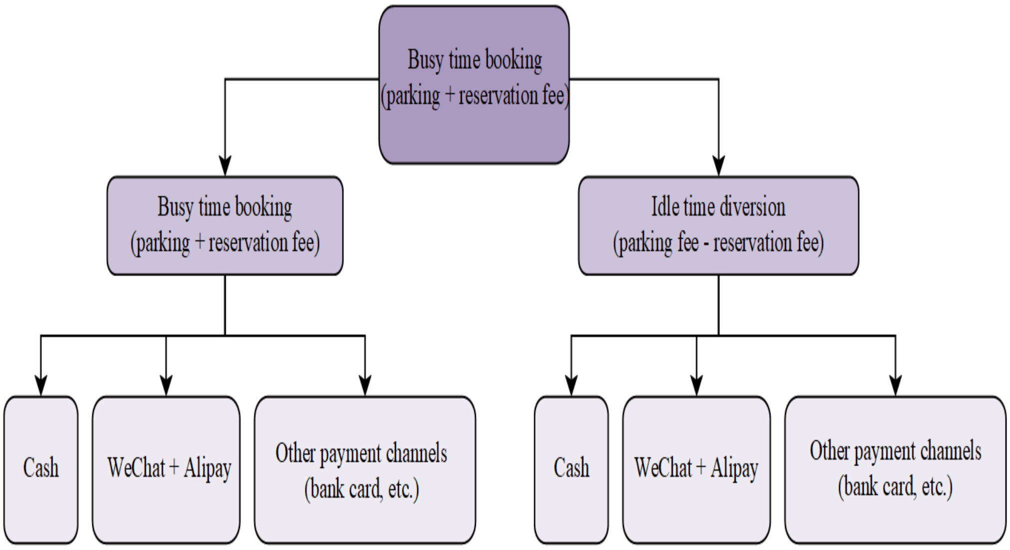


Figure 4.9 Design of parking reservation payment module

Considering that there are many other payment methods in addition to cash card swiping, such as WeChat, Alipay, UnionPay, Tianfutong, Bank payment, Electronic deduction, etc., now the domestic technology has realized aggregate payment, without the need to set up multiple online payment QR codes, owners can directly pay parking fees through one QR code, which greatly improves the experience of car owners and the efficiency of entering and leaving the parking lot. The figure of electronic payment methods in China is shown by Appendix Figure 32.

## 4.8 Summary

This chapter first analyzed the parking data, puts forward the problems to be studied, that is, when the parking sharing platform is facing a reservation, it needs to decide whether to accept the reservation demand. If there are no parking spaces in the predetermined time period, it needs to further decide which longer time period to meet the demand. Secondly, in this thesis, the parking reservation situation is divided into three cases: only advance reservation, temporary arrival and advance reservation, and random supply and random demand. The optimization modeling is carried out for the three cases, and the depth enhancement algorithm is designed to solve them. Finally, based on the previous model, the parking process optimization design is carried out for the above three parking reservations.

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# Chapter 5: Numerical Experiment and Simulation

## 5.1 Analysis of algorithm effectiveness

In order to comparative test the effectiveness of the Deep Reinforcement Learning algorithm and the approximation algorithm designed in the traditional literature, the experimental environment of this thesis is designed according to the research of L. F. Zhang et al. (2023), assume that the service cycle $T = 5$ (including 15 products). Suppose that the determined supply of products follows three kinds of distribution, namely normal distribution, uniform distribution and Poisson distribution. The arrival demand of each product is independent and identically distributed. The product demand of the determined supply and different booking periods is randomly generated, and the unit booking price $\bar{f}^b$ of each product is equal. According to different parameter values and random distribution, repeat the experiment for 200 times, and take the average value of income under different distribution of each algorithm as the estimated value of total income. In order to intuitively explain the effectiveness of the algorithm, the total revenue ratio is defined as the value of the total revenue obtained by each algorithm $V^{TUP}$, and $V^{TUP}$is the theoretical upper bound of the optimal solution of the model and its specific definition.

The numerical results are shown in Figure 5.1 and Figure 5.2.

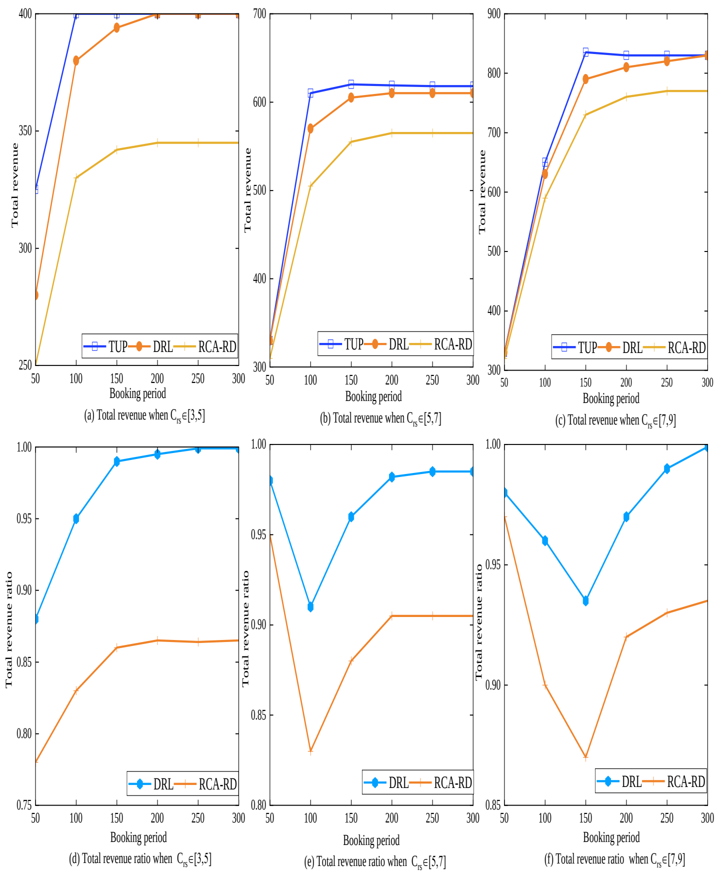



Figure 5.1 Revenue change of each algorithm under different booking periods (Unit/RMB)

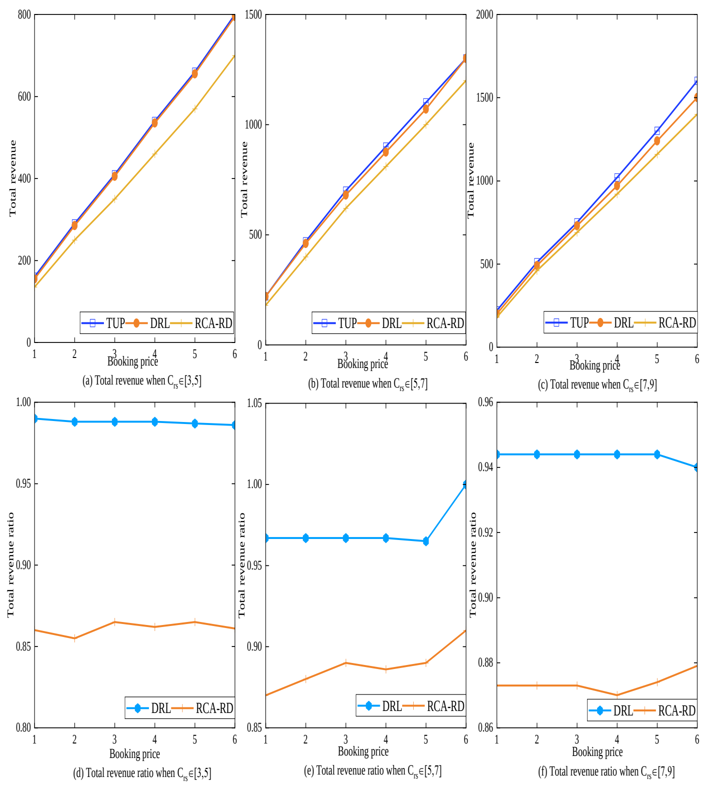



Figure 5.2 Revenue change of each algorithm under different booking prices (Unit/RMB)

According to Figure 5.1 and Figure 5.2, we can see that with the increase of booking cycle and booking price, the rental income of parking platform parking space obtained through deep reinforcement learning (DRL) and Reservation control algorithm based on resource decomposition (RCA-RD) algorithm has increased significantly. With the gradual increase of the booking cycle, the revenue tends to be stable due to the limited supply quantity. In addition, under different reservation periods, when the reservation period is very short and the supply quantity is insufficient, the income obtained by DRL algorithm performs better with the increase of the reservation period. Under the condition of short booking cycle, RCA-RD gains more and more revenue with the increase of booking cycle and supply. Under the heterogeneous unit price, the effectiveness of the two algorithms has little difference, and both the effectiveness of the two algorithms is better under different booking prices. To sum up, the effectiveness of the Deep Reinforcement Learning algorithm is always significantly better than the effectiveness of the approximation algorithm, regardless of the booking cycle or the booking price.

It can be observed from Figure 5.1 that when the supply quantity $C_{rs} \in [5,7]$, the effectiveness of the two algorithms has a downward trend when the number of booking cycles is 100. This is because when the number of booking cycles is 100, the theoretical upper limit value of the optimal solution combined with the total income has reached a stable value, while the income of the two algorithms has decreased, so the ratio shows a decline. Therefore, although the revenue of the shared parking platform can be increased by extending the booking cycle, due to the restriction of the supply quantity, there will be a threshold for the number of optimal booking cycles. If it is less than this threshold, the revenue obtained by both machine learning and traditional algorithms will increase, and if it is greater than this threshold, the revenue under the two algorithms will tend to be stable. As a consequence, when designing the number of reservation cycles for the shared parking platform, it is necessary to obtain the number of reservation cycles under the stable value of the tight upper bound from the relevant exogenous variables, and then formulate the optimal number of reservation cycles.

Compared with the traditional algorithm, the Deep Reinforcement Learning algorithm has high effectiveness, so it is more applicable for the parking sharing platform to adopt this algorithm in the parking space reservation control strategy. Next, we will further analyze the effect of parking space reservation strategy under DRL algorithm and define two kinds of ratios. Service rate of shared parking platform is equal to the total number of bookings accepted/total number of bookings required. Parking space utilization rate of shared parking platform is equal to the total number of parking spaces accepted in service cycle/total number of parking spaces in service cycle. Next, we study the change trend of the two kinds of ratios under the Deep Reinforcement Learning algorithm.

The specific results are shown in Figure 5.3.

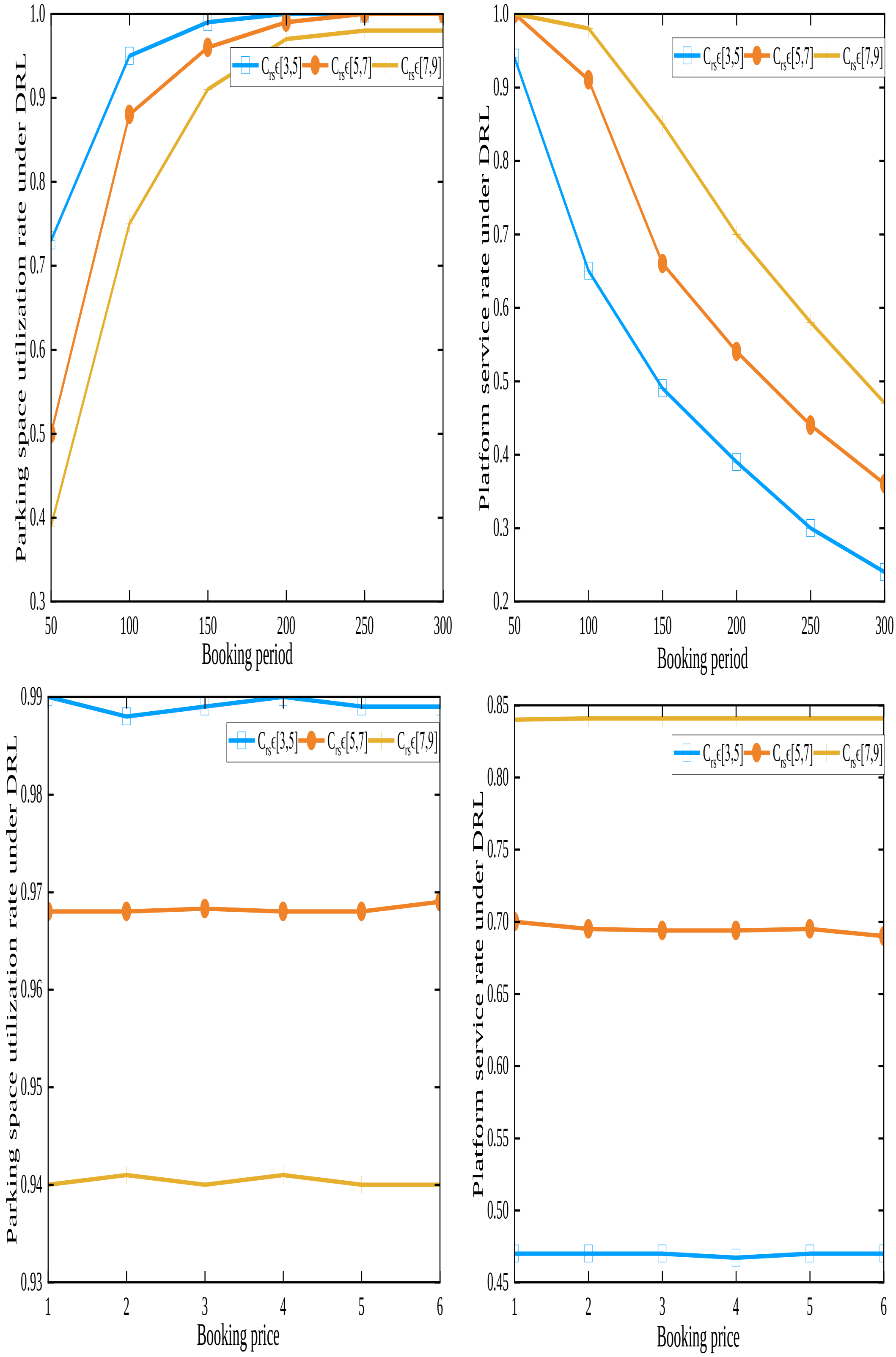
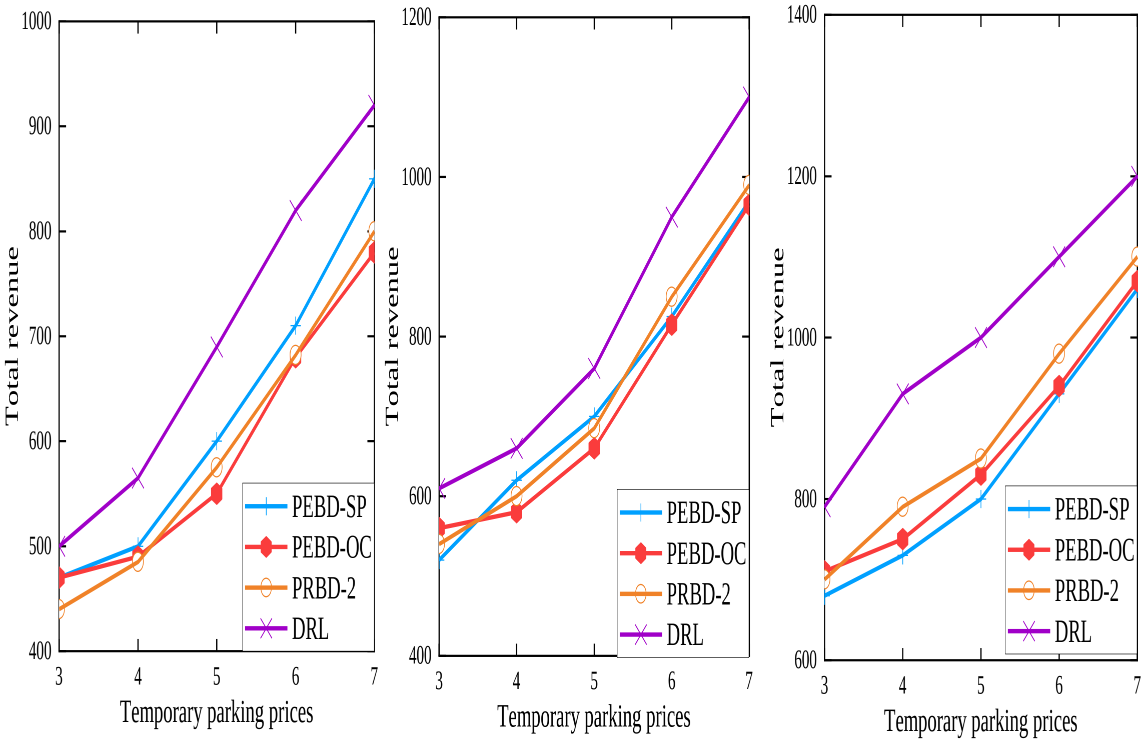



Figure 5.3 Change trend of two kinds of ratios under deep reinforcement learning algorithm

According to Figure 5.3, when the supply is small, as the length of the parking space reservation cycle increases, the parking space utilization rate under the DRL algorithm also gradually increases and approaches 1. Almost all parking spaces are rented out by the platform. With the increase of the supply, the parking space utilization rate shows a downward trend. With the increase of the length of the booking cycle, the service rate of the parking platform also gradually decreases. Due to the demand for booking increases, but the supply does not increase accordingly, so the proportion of customers who can meet the advance booking is relatively reduced, resulting in the decline of the service rate of the parking platform. However, when the length of the booking cycle is large enough, the utilization rate of parking space tends to remain unchanged and the revenue also tends to remain unchanged, in this case, if the number of booking cycles further increases, the service rate of the platform will decrease, and the revenue will not increase. Therefore, the length of booking cycle is not the longer the better but should be combined with other parameters to determine an optimal length of booking cycle. The reservation price has little impact on the reservation control under different supply quantities. In addition, with the increase of parking space supply, the utilization rate of parking space will also decrease under the same booking demand, but because of the increase of parking space supply, the service rate of the platform will increase.

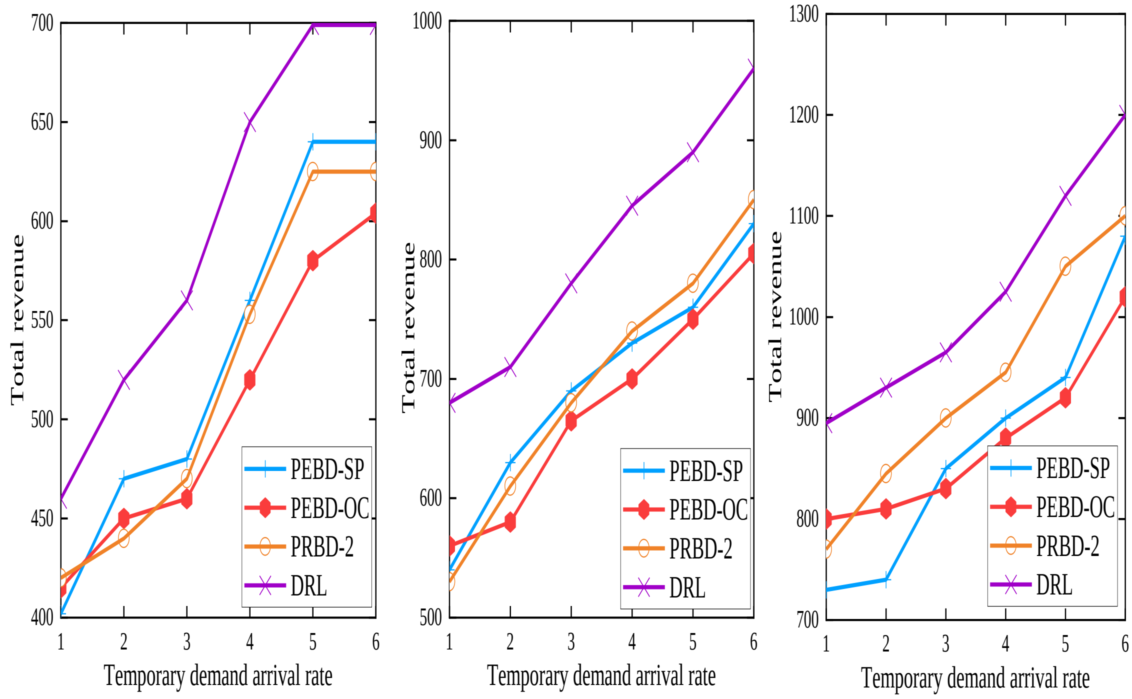
In order to compare and analyze the effectiveness of the machine learning algorithm and the traditional approximate algorithm proposed in the literature in the case of two types of customers (L. F. Zhang et al., 2023), the temporary parking price, the temporary arrival rate and different parameters for determining the supply were selected respectively, and the supply and reservation demand were randomly generated. The different effects of the randomness of supply and demand on the revenue of the parking platform were verified by multiple numerical simulations (A method of using a computer program to solve an approximate solution of a mathematical model), and the rest settings were consistent with the case of one type of customers. (*Note that PEBD-SP is referred as approximate algorithms of period-based decomposition model (PEBD) model based on single period policy, and PBED-OC is approximate algorithms of PEBD model by opportunity cost. PRBD-2 is approximate algorithms of two-products-based decomposition model (PRBD-2)).*

The specific results are shown in Figure 5.4 and Figure 5.5.




(a) Total revenue when $C_{rs}\in[3,5]$ (b) Total revenue when $C_{rs}\in[5,7]$ (c) Total revenue when $C_{rs}\in[7,9]$

Figure 5.4 Impact of temporary parking price on parking platform revenue




(a) Total revenue when $C_{rs}\in[3,5]$ (b) Total revenue when $C_{rs}\in[5,7]$ (c) Total revenue when $C_{rs}\in[7,9]$

Figure 5.5 Impact of temporary arrival rate on parking platform revenue

According to Figure 5.4, with the increase of the unit price of temporary parking and the number of parking spaces provided, the revenue of parking platform increases under all algorithms. According to Figure 5.5, it can be concluded that as the arrival rate of temporary demand increases, the revenue of parking platform also increases under all algorithms. Compared with various traditional approximation algorithms, machine learning algorithms have obvious advantages. The benefits obtained by machine learning algorithms are higher under different parameters, while traditional algorithms have different performance under different parameters.

The above content analyzes the effectiveness of the algorithm. Next, we will further analyze the allocation strategies of two types of customers under different algorithms by defining two types of ratios, Service rate of parking platform is equal to the number of reservations accepted by the platform/total number of reservation requirements; Parking space utilization is equal to the number of reserved parking spaces in the service cycle/total number of parking spaces in the service cycle. If the service rate is low, it means that the platform is willing to reserve more parking spaces for temporary arriving users, because there are many kinds of products and the service rate of parking platform is high, but the utilization rate of parking spaces is not necessarily high. Therefore, two kinds of reservation control strategies for parking platform are introduced at the same time. The parking unit price of temporary arriving customers is set to 5, and different reservation prices, different determined supply numbers, and different arrival rates of temporary demand are used for calculation. Superscripts 1 and 2 in the figure indicate that the determined supply follows the distribution of different parameters. The specific simulation results are observed in Figure 5.6 and Figure 5.7.

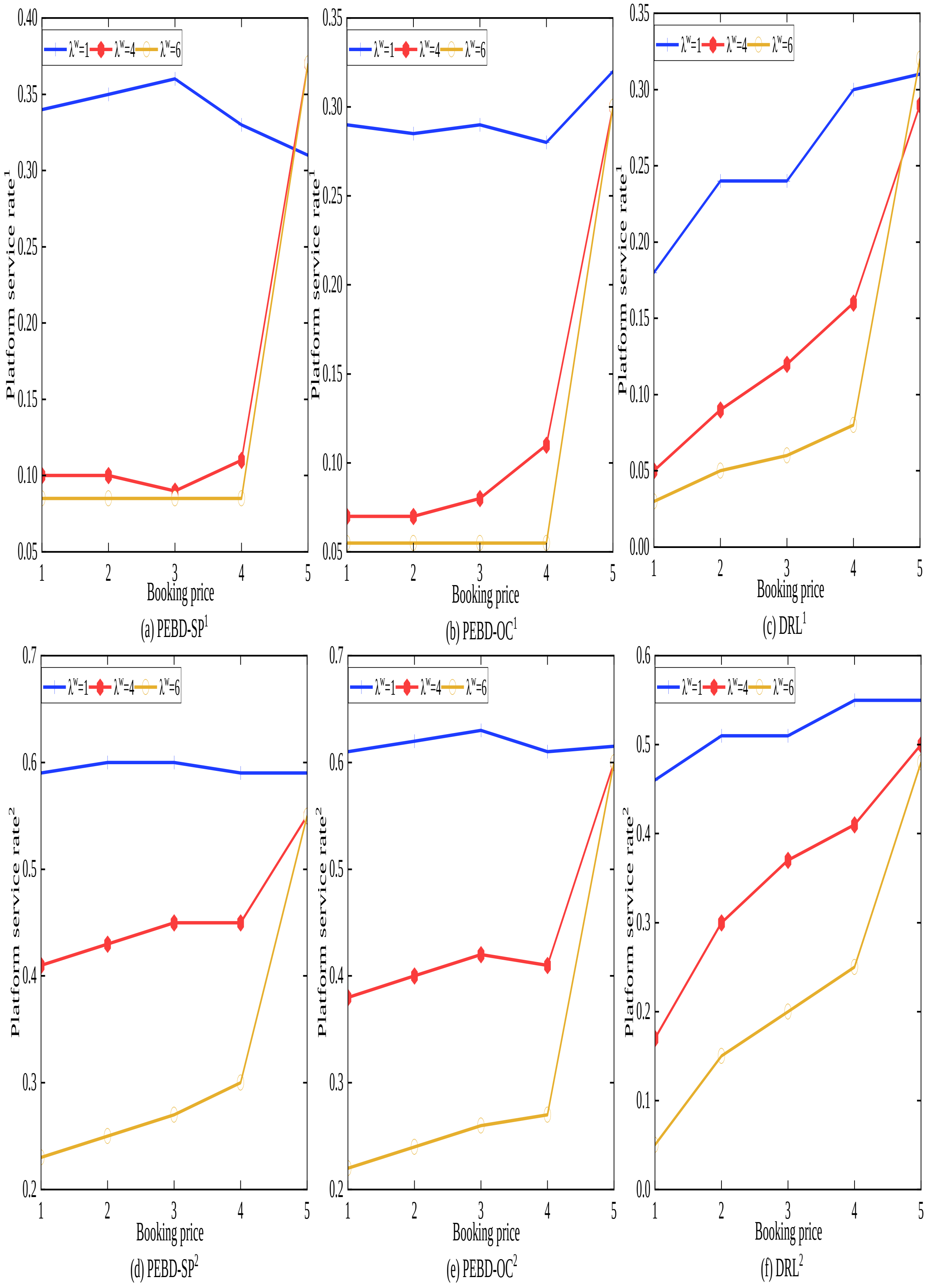



Figure 5.6 Impact of reservation price on service rate

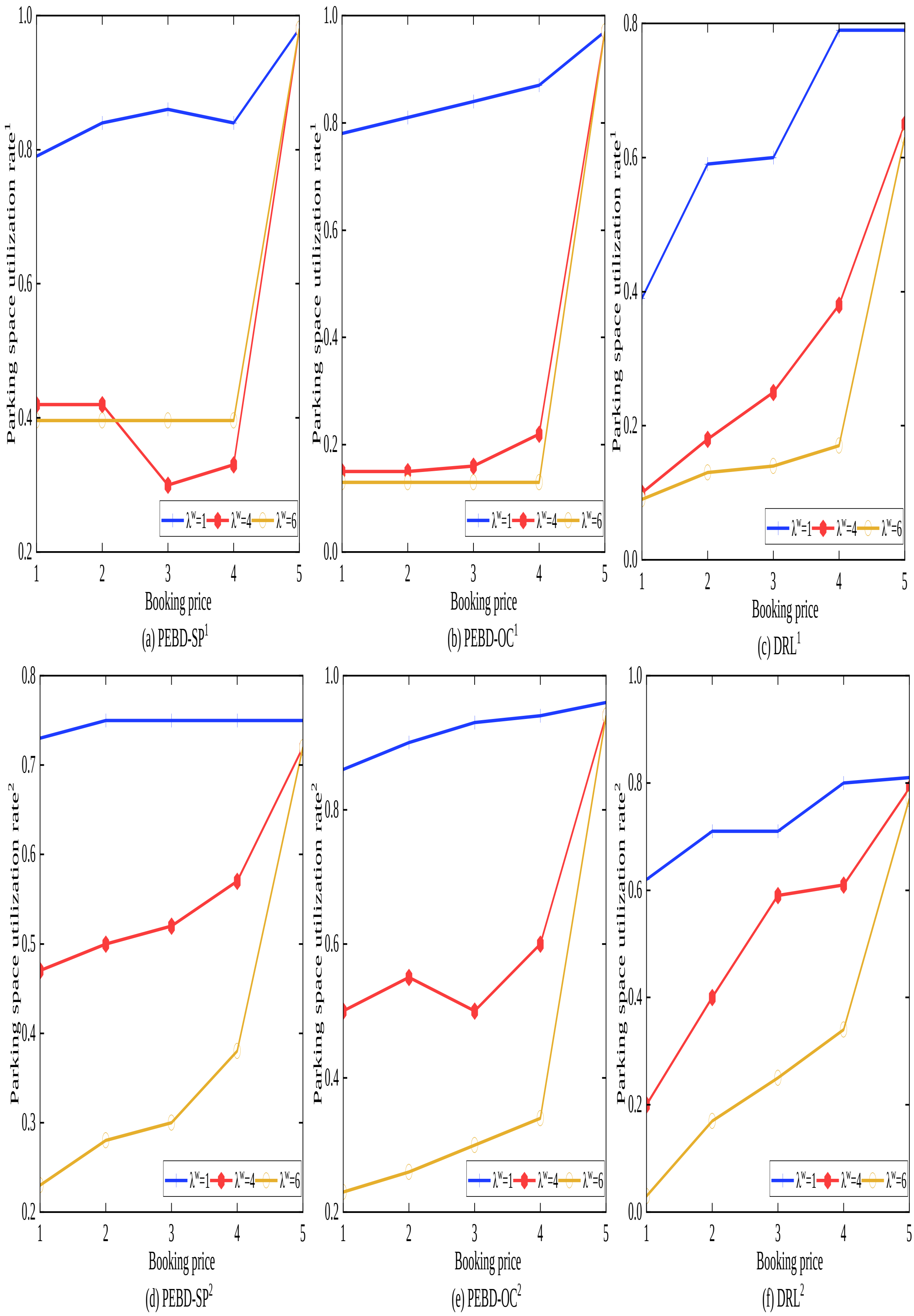



Figure 5.7 Effect of reservation price on parking space utilization

Figure 5.6 shows the impact of different determined supply quantity, arrival rate of temporary demand and reservation price on service rate. The number of bookings that the platform is willing to accept under each algorithm increases with the increase of the booking price and decreases with the increase of the temporary arrival rate. The service rate of the parking platform increases rapidly when the price level of the scheduled customers increases. When the supply quantity is determined to be large, the increase of the service rate of the platform is small when the scheduled price increases. When the reservation price is much lower than the temporary arrival parking price, the parking platform is not willing to accept the reservation and is more willing to reserve the parking space for the temporary arrival customers. When the temporary arrival rate is small, the sensitivity of each algorithm to the reservation unit price is low, and the number of reservations accepted is high. With the increase of the temporary arrival rate, each algorithm is greatly affected by the reservation price. Due to the variety of reservation products, although the number of reservations can reflect the effect of reservation control, it can not fully explain the rental situation of parking spaces. Therefore, next, the impact of exogenous variables on parking space utilization is analyzed.

It can be observed from Figure 5.7 that the increase in the booking unit price leads to an increase in the utilization rate of parking spaces. When the booking unit price is almost the same as the temporary parking unit price, the utilization rate of parking spaces rises rapidly, and the parking platform will not reserve more parking spaces for temporary customers. If the unit price of temporary parking is higher than the reservation unit price, the increase of temporary arrival rate will lead to the reduction of parking space utilization, and the parking platform will reserve more parking spaces for customers who arrive temporarily. In the case of different supply quantities, different temporary arrival rates, and different relative sizes of booking and temporary arrival charges, the booking control strategies are also different. Therefore, when making decisions on the parking platform, reservation control should be carried out in combination with the actual background to maximize revenue.

In the case of random parking space supply, in order to compare and analyze the effectiveness of machine learning algorithm and traditional approximation algorithm and different reservation control strategies, the parameters are set as follows:

The reservation period is set at 50 and the service cycle is 5, including 15 products and considering the product capacity in the supply and generate it randomly with Poisson distribution. The arrival rate of the temporary supply of each product is equal to the arrival rate of the temporary demand, and both obey the Poisson distribution. The unit booking price, temporary parking price and penalty cost are set to 3, 4 and 5 respectively. The following content mainly analyzes the impact of Stochastic Supply and demand on income. Different parameters are selected for numerical simulation of temporary supply arrival rate and temporary demand arrival rate to verify the impact of randomness on income. (*Note that PBED$^s$-SP is referred as approximate algorithms of period-based decomposition model based on single period policy, and PBED$^s$-OC is approximate algorithms of PEBD model by opportunity cost under stochastic supply. PRBD-D is approximate algorithms of single-product-based decomposition model*). The simulation results are shown in Figure 5.8 and Figure 5.9.

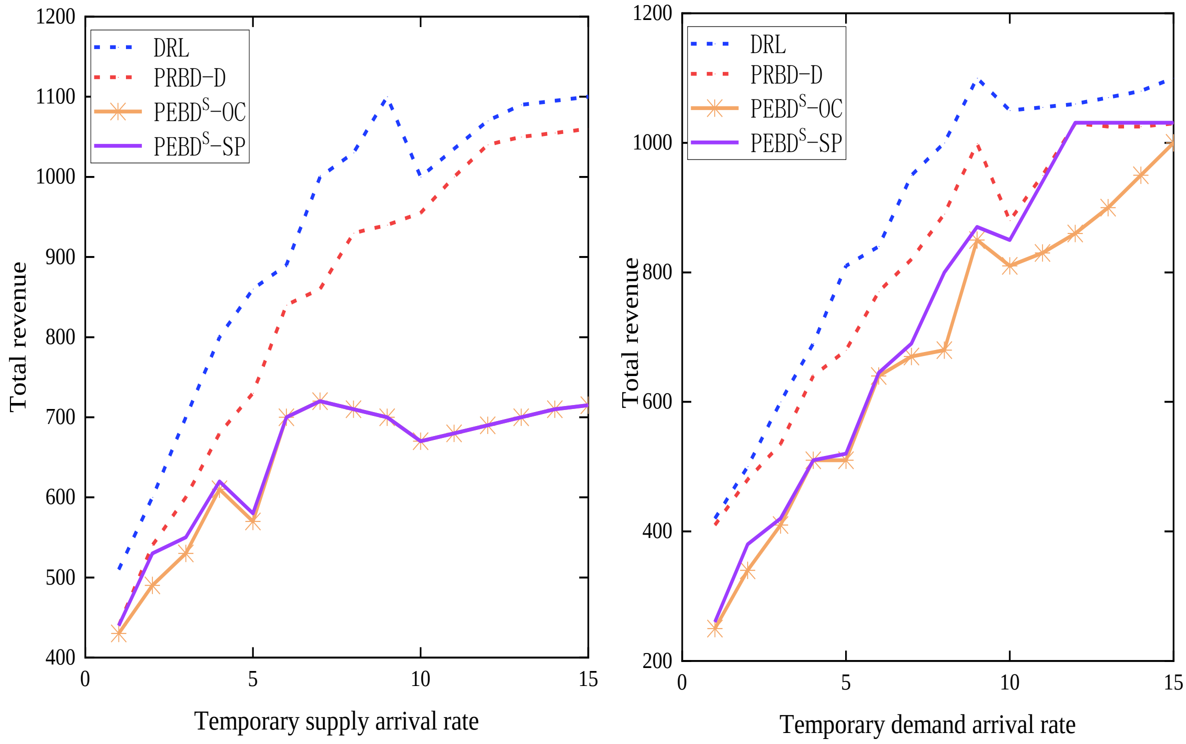



Figure 5.8 Impact of temporary demand arrival rate on total revenue

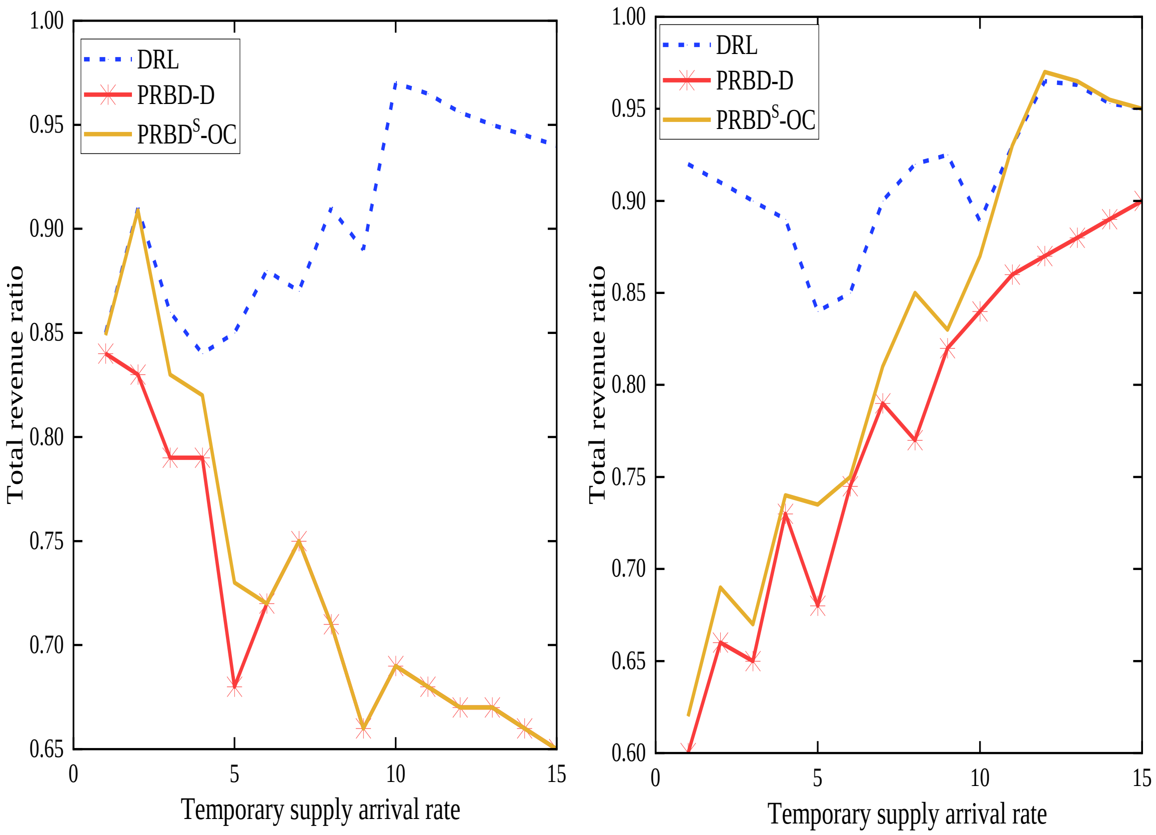



Figure 5.9 Impact of arrival rate of temporary supply on total income

From Figure 5.8, we can see that the effectiveness of the deep reinforcement learning algorithm and the PRBD-D algorithm in the traditional approximation algorithm increases with the increase of the arrival rate of temporary supply; While the other two traditional approximation algorithms are less effective when the temporary demand arrival rate is close to the temporary supply rate. From Figure 5.9, we can see that when the arrival rate of temporary supply is fixed, with the increase of the arrival rate of temporary demand, the effectiveness of the deep reinforcement learning algorithm and the PRBD-D algorithm in the traditional approximation algorithm are both increased, but the machine learning algorithm is still better, and the income is relatively high. In the case of two types of supply, the shared parking platform also needs to comprehensively consider various parameters for reservation control in order to achieve higher revenue.

Table 5.1 summarizes the similarities and differences between the deep reinforcement learning algorithm and the traditional heuristic algorithm.

Table 5.1 The similarities and differences between the deep reinforcement learning algorithm and the traditional heuristic algorithm

| | Deep reinforcement learning algorithm | Heuristic algorithm |
|---|---|---|
| Accuracy | Approximate solution, high accuracy | Approximate solution, low accuracy |
| Efficiency | Efficient | Inefficient |
| Practicality | Suitable for complex optimization problems | Not applicable to complex optimization problems |

## 5.2 Influence of exogenous variables on parking platform strategy

This section analyzes the impact of relevant exogenous variables (parameters) on parking platform strategy from the perspectives of parking space utilization rate, customer acceptance rate, service level, etc. Since the parking platform may have multiple parking lots, there may be great differences in the location, environment, size and other aspects of different parking lots and parking spaces in parking lots. Therefore, when there is no parking space available in a parking lot, using the parking space in the adjacent parking lot (heterogeneous parking space) to satisfy customers will bring negative utility to customers. Even in the same parking lot, parking spaces in different locations will bring different experiences to customers. In practice, the walking distance of customers to the destination is an important factor affecting customer satisfaction. The farther the walking distance is, the lower the customer satisfaction is. The heterogeneity of parking spaces is characterized by the walking distance of customers. When the distance between two parking spaces is far and the walking distance is quite different, the definition of two parking spaces is heterogeneous. Further, the parking platform can divide the parking spaces into different areas according to the distance between the parking spaces. The distance between parking spaces in the same region is relatively short, which does not have heterogeneity, while the distance between parking spaces in different regions is relatively long, which has heterogeneity. When the parking space in the parking area required by customers is insufficient, the parking platform will use the parking space in different parking lots to meet the demand. At this time, the walking distance of customers after parking will increase, leading to a decline in customer satisfaction, which will bring losses to the platform. Therefore, the platform needs to optimize the allocation of parking spaces according to the parking information provided by different users.

Assuming there are $J$ heterogeneous regions on the platform, each with $N_j(j = 1,2,\dots,J)$ parking spaces. Therefore, there are a total of $N = \sum_{j=1}^{J} N_j$, N parking spaces available. The distance between different regions is $D = \left(d_{ij}\right)_{J\times J}$, where $d_{ij}$ represents the distance from the $i$ region to the $j$ region, assuming $d_{ij} = d_{ji}$ . Due to the involvement of multiple heterogeneous regions, the parking position status is represented by the variable $G = \left(g_{nj}\right)_{NJ}$.

$$g_{nj} = \begin{cases} 1, \text{the } n \text{ parking space is divided into the } j \text{ area} \\ 0, \text{the } n \text{ parking space is not divided into the } j \text{ area} \end{cases}, n = 1,2, \dots, N; j = 1,2, \dots, J$$

Considering that there may be parking space suppliers and demanders providing parking space information to the platform in each cycle, the newly added parking space supply information in cycle $k$ should include the available time period and location status of the parking space. The available time period for $k$-cycle parking spaces can be represented by the variable $A^k = \left(a_{nt}^k\right)_{NT}$:

$$a_{nt}^k = \begin{cases} 1, \text{the } n \text{ parking space provided in cycle } k \text{ is available in cycle } t \\ 0, \text{the } n \text{ parking space provided in cycle } k \text{ is not available in cycle } t \end{cases}$$

$$n = 1,2, \dots, N; t = 1,2, \dots, T$$

Assuming there are $M^k$ new parking space demands in cycle $k$, since the demand information for parking spaces includes the customer's reserved parking time and parking space location, the customer's reserved time is represented by the variable $\Theta^k = \left(\vartheta_{mt}^k\right)_{M^k \times T}$:

$$\vartheta_{mt}^k = \begin{cases} 1, \text{the } m \text{ parking requirement added in cycle } k \text{ is reserved for cycle } t \\ 0, \text{the } m \text{ parking demand added in cycle } k \text{ has not been reserved for cycle } t \end{cases}$$

$$m = 1,2, \dots, M^k; t = 1,2, \dots, T$$

Assuming that the customer's demand and supply time are continuous cycles. If $\vartheta_m^1$ represents the demand vector of the m customer in the first cycle, then $\vartheta_{mt}^k = (0,1,1,1,0, \dots ,0)$ represents that the customer needs to park for the 2nd, 3rd, and 4th cycles in the first cycle. To be able to record the parking space locations required by customers, the area divided by the platform is used as the parking space location for recording customer needs. The location information of the parking space reserved by the customer is represented by the variable $L^k = \left(l_{mj}^k\right)_{M^k \times J}$:

$$l_{mj}^k = \begin{cases} 1, \text{the demand for the } m \text{ parking space added in cycle } k \text{ has been reserved for the } j \text{ area} \\ 0, \text{the demand for the } m \text{ parking space added in cycle } k \text{ has not been reserved for the } j \text{ area} \end{cases}$$

$$m = 1,2, \dots, M^k; j = 1,2, \dots, J$$

In order to better reflect the reality, when allocating parking spaces, it is not allowed to consider moving vehicles to another parking space midway, that is, it is not allowed to use multiple supplies to meet one demand. The allocation decision variable for the $k$ cycle is defined as $X^k = (x_{mn}^k)_{M^\tau \times N}$, $m = 1,2, \dots, M^k$; $n = 1,2, \dots, N$. $x_{mn}^k = 1$ represents that the m newly added demand in the $k$ cycle is allocated to the nth parking space, and $x_{mn}^{k} = 0$ represents that the m newly added demand in the $k$ cycle is not allocated to the n parking space. According to the decision variables, the usage of $k$-period parking spaces can be recorded as:

$$Z_{N\times T}^{k} = \left(z_{nt}^{k}\right)_{N\times T} = \left(X_{M^k\times N}^{k}\right)' \Theta_{M^k\times T}$$

Where ( )$'$ represents the transpose of the matrix, $z_{nt}^{k} = \sum_{m=1}^{M^k} x_{mn}^{k} \vartheta_{mt}^{k}$. If $z_{nt}^{k} = 1$, it means that the $n$ parking space is occupied in the $t$ cycle during the $k$ cycle; On the contrary, if $z_{nt}^{k} = 0$, it means that during the $k$ cycle, the $n$ parking space has not been occupied for the $t$ cycle.

Assuming that for every successfully rented parking space on the platform, a fixed payment of $f_0$ is made to the parking space provider per unit time. The unit revenue obtained by the platform for each successful rental of a parking space is $\bar{f}$, so the total profit of the $k$-period platform is $\left(\bar{f} - f_0\right) \sum_{n=1}^{N} \sum_{t=1}^{T} z_{nt}^{k}$.

Use $H_{M^k\times J}^{k} = \left(h_{mj}^{k}\right)_{M^k\times J}$ to represent the status of customer allocation to each region, where $h_{mj}^{k} = \sum_{n=1}^{N} x_{mn}^{k} g_{nj}$. If $h_{mj}^{k} = 1$, it means that the $m$ demand in cycle $k$ is allocated to the $j$ region; If $h_{mj}^{k} = 0$, it means that the $m$ demand in cycle $k$ has not been allocated to the $j$ region.

Therefore, the demand and supply matching matrix for parking spaces is $E^{\tau} = \left(e_{ij}^{k}\right)_{J\times J} = \left(H_{M^k\times J}^{k}\right)' L_{M^k\times J}^{k}$, where $e_{ij}^{k} = 1$ indicates that the customer's reservation for the $k$ cycle is for the $j$ area to be actually allocated to the $i$-th area; $e_{ij}^{k} = 0$ indicates that the customer's reservation is for the $j$-th area that has not been actually assigned to the $i$-th area. Due to the scarcity of parking spaces, there may be situations where customers' reserved areas are already full. In such cases, the platform may use parking spaces from other areas to meet customers' booking needs. However, parking spaces in different regions have heterogeneity, and allocating parking spaces in other regions to customers will change the walking distance, thereby affecting customer satisfaction. The farther the walking distance, the lower the customer satisfaction and the higher the penalty cost faced by the platform. Therefore, the impact of parking heterogeneity on platform decision-making can be quantified by the penalty cost brought by walking distance. If the penalty cost for each additional unit of walking distance on the platform is $\pi$, then the penalty cost for allocating parking spaces in the $i$-th area to customers in the $j$-th area with demand in cycle $k$ is $\pi e_{ij}^{k} d_{ij}$. The penalty costs brought by parking spaces in different regions are different, so the degree of heterogeneity in parking spaces in different regions can be quantified by $\pi e_{ij}^k d_{ij}$. Due to the total walking distance $d^k = \sum_{i=1}^J \sum_{j=1}^J e_{ij}^k d_{ij}$ for $k$-cycle customers, the platform incurs a total penalty cost of $\sum_{i=1}^J \sum_{j=1}^J \pi e_{ij}^k d_{ij}$ in allocation due to the heterogeneity of parking spaces.

In summary, the total profit obtained by the $k$-cycle platform is composed of the profit from renting parking spaces and the penalty cost caused by the heterogeneity of parking spaces. The specific expression is as follows: $f_k = (\bar{f} - f_0) \sum_{n=1}^N \sum_{t=1}^T z_{nt}^k - \sum_{i=1}^J \sum_{j=1}^J \pi e_{ij}^k d_{ij}$. Introduce the following indicators as criteria for testing the effectiveness of allocation.

(1) Customer acceptance rate: Acceptance rate refers to the ratio of the number of accepted customers to the total number of demands. The acceptance rate is defined as in Zhang et al. (2023):

$$\theta = \sum_{k=1}^{T} \sum_{m=1}^{M^k} \sum_{n=1}^{N} x_{mn}^k \Big/ \sum_{k=1}^{T} M^k \tag{5.1}$$

(2) Average walking distance: Since the walking distance of customers will affect the convenience of using parking spaces, the average walking distance is introduced to evaluate the service quality:

$$\bar{d} = \sum_{k=1}^{T} \sum_{i=1}^{J} \sum_{j=1}^{J} e_{ij}^k \, d_{ij}^k \Big/ \sum_{k=1}^{T} \sum_{m=1}^{M^k} \sum_{n=1}^{N} x_{mn}^k \tag{5.2}$$

(3) Parking space utilization: One of the purposes of the proposal of shared parking spaces is to improve the utilization rate of parking spaces. The ratio of the total time customers use parking spaces to the total supply time provided by suppliers is used as a measure of the utilization rate of parking spaces,

$$u = \sum_{k=1}^{T} \sum_{n=1}^{N} \sum_{t=1}^{T} z_{nt}^k \Big/ \sum_{k=1}^{T} \sum_{n=1}^{N} \sum_{t=1}^{T} a_{nt}^k \tag{5.3}$$

(4) Allocation rate of parking spaces with different supply and demand positions: Considering that if the penalty cost caused by walking distance is low, the platform will assign customers to other areas, so the parking space assignment rate with different supply and demand positions (hereinafter referred to as parking space assignment rate) is introduced to describe the allocation strategy.

$$r = \sum_{k=1}^{T} \sum_{i=1}^{J} \sum_{j \neq i} e_{ij}^k \Big/ \sum_{k=1}^{T} \sum_{i=1}^{J} \sum_{j=1}^{J} e_{ij}^k \tag{5.4}$$

In order to study the impact of unit price $s$ (price or income per unit cycle, which is also the unit profit of parking platform under the assumption of zero cost) on parking space allocation, take different values for unit price $s$, and the parameter settings are as follows: The parking platform has six parking lots located at different locations, making $J = 6$, each parking lot has $N_j$ parking spaces $(j = 1,2,3,4,5,6), N_j = 100,90,80,70,60,50, j = 1,2,\dots,6$ . The distance between parking spaces obeys uniform distribution, assuming that there are four kinds of uniform distribution, namely [10,50], [15,45], [10,45], [15,50], and finally taking the average value of the four kinds of uniform distribution. Take the average value of 1000 simulations of the above four indicators to study the impact of unit price change on total profit, scheduled acceptance rate, average walking distance, parking space utilization rate and parking space assignment rate. In order to study the effectiveness of the allocation of different parking lots, the case where customers do not accept walking (that is, customers whose demand is the $i$-th area are not allowed to be allocated to the $j$-th area, $i, j = 1,2,\dots,6$) is selected for comparison. The results are shown in Table 5.2 and Table 5.3:

Table 5.2 The impact of unit cycle pricing on allocation strategies (T=20)

| Value of “s” | Total profit | Acceptance rate | Walking distance | Utilization rate | Assignment rate |
|---|---|---|---|---|---|
| 3 | 2010/2655 | 0.61/0.76 | -/0.23 | 0.52/0.61 | -/0.03 |
| 6 | 4380/5430 | 0.61/0.77 | -/0.56 | 0.52/0.63 | -/0.04 |
| 9 | 6571/8056 | 0.61/0.78 | -/0.79 | 0.52/0.66 | -/0.05 |
| 12 | 7866/11192 | 0.61/0.79 | -/1.25 | 0.52/0.69 | -/0.06 |
| 15 | 10953/14175 | 0.61/0.79 | -/1.26 | 0.52/0.69 | -/0.06 |
| 18 | 13140/17166 | 0.61/0.89 | -/1.26 | 0.52/0.70 | -/0.06 |

Table 5.3 The impact of unit cycle pricing on allocation strategies (T=40)

| Value of “s” | Total profit | Acceptance rate | walking distance | Utilization rate | Assignment rate |
|---|---|---|---|---|---|
| 3 | 4089/5311 | 0.73/0.78 | -/0.76 | 0.59/0.79 | -/0.038 |
| 6 | 8726/10861 | 0.73/0.81 | -/1.39 | 0.59/0.79 | -/0.061 |
| 9 | 13142/16112 | 0.73/0.81 | -/1.39 | 0.59/0.81 | -/0.072 |
| 12 | 15779/22613 | 0.73/0.82 | -/1.50 | 0.59/0.83 | -/0.078 |
| 15 | 21899/28761 | 0.73/0.83 | -/1.91 | 0.59/0.85 | -/0.092 |
| 18 | 26379/34336 | 0.73/0.83 | -/2.39 | 0.59/0.85 | -/0.093 |

Note: the symbol "/" in Table 5.2 and Table 5.3 indicates that the customer whose demand is the $i$-th area is not considered to be assigned to the $j$-th area, and the latter indicates that the customer accepts the result of walking.

By examining the data in Table 5.2 and Table 5.3, it can be observed that when the penalty cost caused by walking distance is low, the profit of the parking platform adopting the cross-parking lot allocation strategy is much higher than that of matching the supply and demand of parking spaces in the same area. Through the supply and demand matching of cross parking integration, the utilization rate of parking space and the acceptance rate of reservation are effectively improved, so as to alleviate the problem of parking difficulty. In the case of short decision-making cycle, with the increase of price, the allocation rate, acceptance rate, utilization rate and walking distance of parking spaces will increase, and when the penalty cost of price is relatively large, the cross-parking lot allocation strategy will no longer be affected by the price.

Considering that the heterogeneity of parking spaces (parking space distance in different parking lots) will affect customer satisfaction, and customer satisfaction is measured by the penalty cost brought by walking distance, the greater the penalty cost, the stronger the heterogeneity of parking spaces, and the greater the impact on customer satisfaction. In order to study the impact of heterogeneity of parking spaces on allocation strategies, different values of penalty cost are taken to study its impact on acceptance rate, average walking distance and parking space utilization. The detailed simulation results are shown in Table 5.4 and Table 5.5:

Table 5.4 Impact of penalty cost on parking space allocation (T=20)

| Value of $\pi$ | Total profit | Acceptance rate | Walking distance | Utilization rate | Assignment rate |
|---|---|---|---|---|---|
| 0.01 | 4631/5206 | 0.71/0.94 | -/4.96 | 0.52/0.61 | -/0.126 |
| 0.05 | 4631/5162 | 0.71/0.94 | -/4.96 | 0.52/0.61 | -/0.126 |
| 0.1 | 4631/4930 | 0.71/0.94 | -/4.96 | 0.52/0.61 | -/0.126 |
| 0.3 | 4631/4791 | 0.71/0.89 | -/0.77 | 0.52/0.56 | -/0.062 |
| 0.5 | 4631/4656 | 0.71/0.86 | -/0.21 | 0.52/0.53 | -/0.013 |
| 1 | 4631/4631 | 0.71/0.71 | -/0 | 0.52/0.52 | -/0 |

Table 5.5 Impact of penalty cost on parking space allocation (T=40)

| Value of $\pi$ | objective function | Acceptance rate | Walking distance | Utilization rate | Assignment rate |
|---|---|---|---|---|---|
| 0.01 | 6739/13586 | 0.30/0.79 | -/7.69 | 0.39/0.76 | -/0.181 |
| 0.05 | 6739/13028 | 0.30/0.79 | -/8.32 | 0.39/0.76 | -/0.186 |
| 0.1 | 6739/12893 | 0.30/0.79 | -/8.60 | 0.39/0.78 | -/0.190 |
| 0.3 | 6739/10765 | 0.30/0.79 | -/4.32 | 0.39/0.77 | -/0.088 |
| 0.5 | 6739/99281 | 0.30/0.70 | -/3.01 | 0.39/0.70 | -/0.056 |
| 1 | 6739/91369 | 0.30/0.69 | -/2.39 | 0.39/0.69 | -/0.037 |

According to Table 5.4 and Table 5.5, as the cycle increases, the effect of cross parking lot allocation is gradually significantly better than that of non-cross parking lot allocation. When the decision-making cycle is long, the profit, customer acceptance rate and parking space utilization rate after cross regional distribution are much higher than those without cross parking lot distribution. Therefore, when the penalty cost caused by customers' walking is low, the cross-parking lot allocation is better than matching directly according to the parking lot. With the increase of penalty cost, that is, the heterogeneity of parking spaces increases, and the difference between different parking spaces for customers is large, the benefit of cross parking distribution gradually decreases, and finally there will be a critical value of penalty cost, so that when the critical value is exceeded, the parking platform will not be allocated across parking lots.

## 5.3 Mechanism design of reserved parking space

The experiment uses the Any Logic simulation platform proposed by Borshchev (2014) to obtain the discrete event simulation of the parking lot. When designing different numbers of parking spaces as reserved parking spaces, the simulation counts the occupancy rate of the parking lot, the number of users lost and the congestion degree of the parking lot.

The experiment assumes that there are 120 parking spaces in the parking lot, and uses the real data of the parking lot on May 11 and May 13 to simulate the parking demand on weekdays and weekends, and assumes that 1/2 of the users are reserved users and 1/2 of the users are temporary users. There are different processes for the parking process of reservation users and temporary parking users. The reservation user makes a parking reservation before departure. When there are reserved parking spaces in the parking lot, the user successfully makes an appointment to the designated area of the parking lot, and then drives to the corresponding area of the parking lot to finish parking quickly. When there is no available parking space in the parking lot, the user fails to make an appointment and chooses other travel modes to cancel parking in the parking lot. For temporary parking users, no parking space reservation is made before departure. If there are temporary parking spaces after arriving at the parking lot, they will enter the parking lot and spend time cruising to find parking spaces by themselves; If there is no parking space available, drive away to cancel the parking demand in the parking lot. The user parking process simulation design as shown in Figure 5.10.

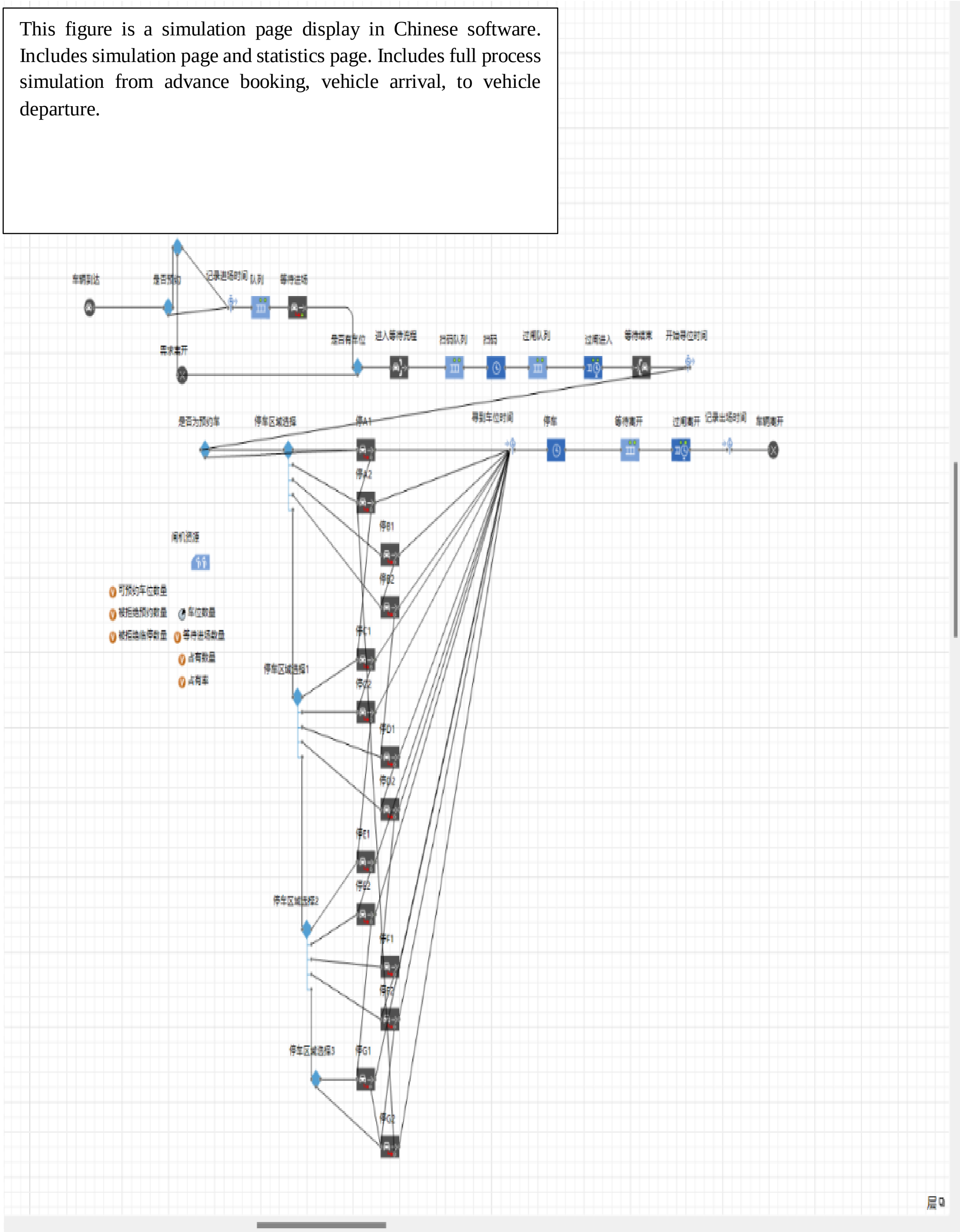



Figure 5.10 User parking process simulation design

From Figure 5.11, the simulation experiment of parking data on May 11 shows that the 120 parking spaces in the parking lot can basically meet the parking needs of all users during working days, but the number of parking spaces that can be reserved needs to be correctly set. Based on the assumption that 1/2 of the parking users are reservation users and 1/2 of the users are temporary parking users, the simulation results show that when the number of parking spaces that can be reserved is about 60, the parking space utilization rate is high, and the occupancy rate can reach 90%. When the number of parking spaces that can be reserved is too large (greater than or equal to 75) or too small (less than or equal to 45), the occupancy rate can only reach 80%.

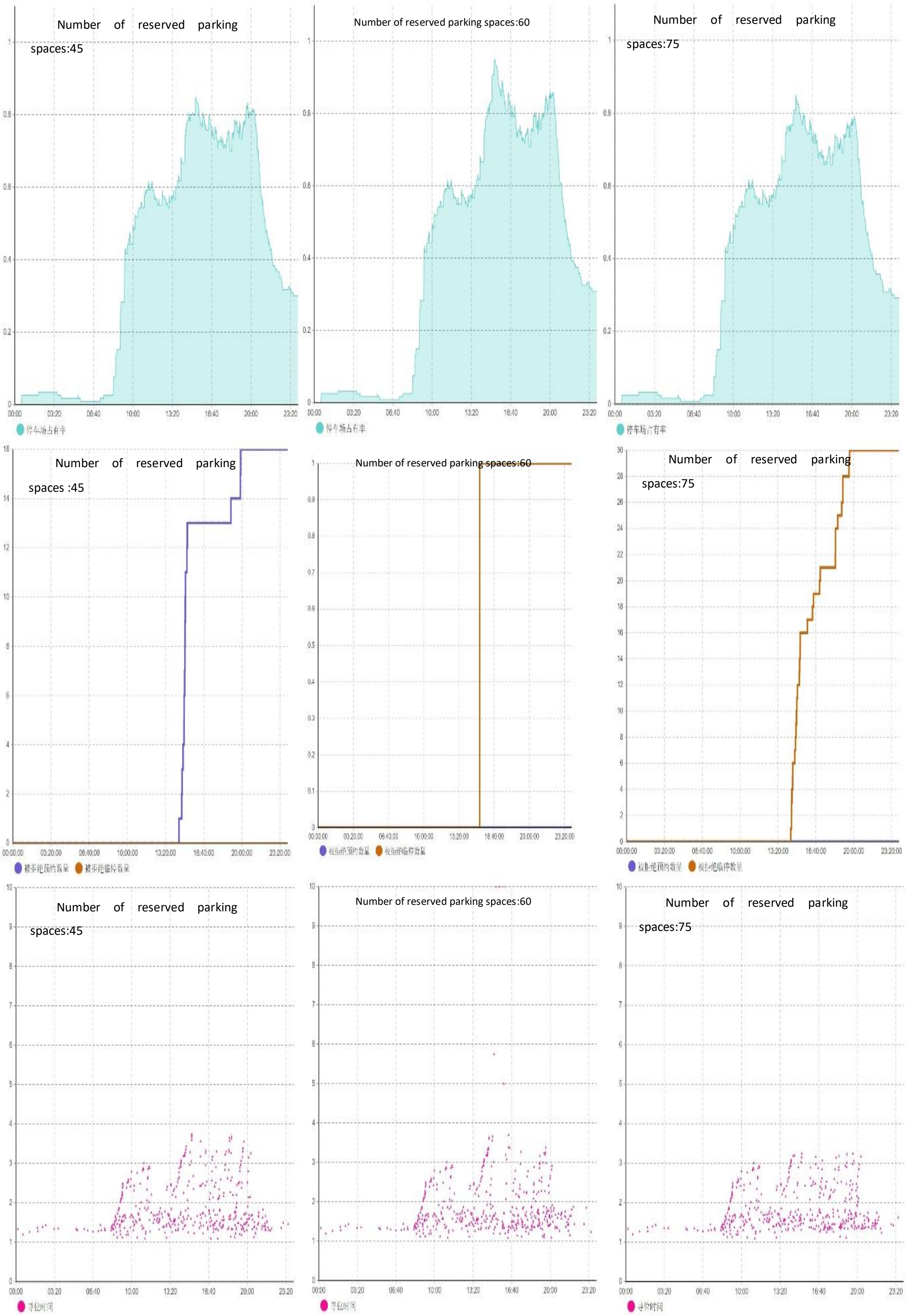



Figure 5.11 Parking simulation on May 11 (working day) May 11 (working day)

From the perspective of the number of parking users rejected, when the number of parking spaces available for reservation is about 60, the parking demand rejected is the least, and only one temporary parking user's demand is not met; When the number of parking spaces that can be reserved is 45, there are 16 users who can reserve parking and the users are rejected; When the number of parking spaces that can be reserved is 75, the number of temporary parking users rejected is 30.

In addition, due to less demand on weekdays, the occupancy rate of the parking lot is not high. Users can find parking spaces within 4 minutes after arriving at the parking lot, and the parking experience is relatively good.

From Figure 5.12, the simulation experiment of parking data on May 13 shows that the 120 parking spaces in the parking lot cannot meet the parking needs of all users during weekends or holidays. In this scenario, 45, 60 and 75 parking spaces are set in the parking lot for reservation, and the occupancy rate of the parking lot will be 100% at the peak of parking demand. In addition, the demands of a large number of reservation users and temporary stop users will be rejected. At this time, if 45 reserved parking spaces are set, many potential reservation users have to give up self driving travel and choose other modes of transportation instead, and fewer temporary parking users will be rejected. Although it can meet the needs of more self-driving users, the relatively crowded parking lot leads to a long time for users to find parking spaces, and some users need to cruise inside for more than 10 minutes to find empty parking spaces, which reduces the user's parking experience. Not only that, the overall operational efficiency of the parking lot is also negatively affected, as prolonged parking space searches can lead to traffic congestion within the parking lot and may further reduce the service quality of the parking lot. If 75 parking spaces can be reserved, although the temporary parking users with more self- driving trips will be rejected and find other parking lots to complete the parking demand, due to the large number of reserved users, the reserved users can quickly complete the parking in the designated area of the parking lot. The vast majority of users can find parking spaces within 4 minutes, and the user parking experience is enhanced. At the same time, it has to some extent alleviated the parking pressure during peak hours.

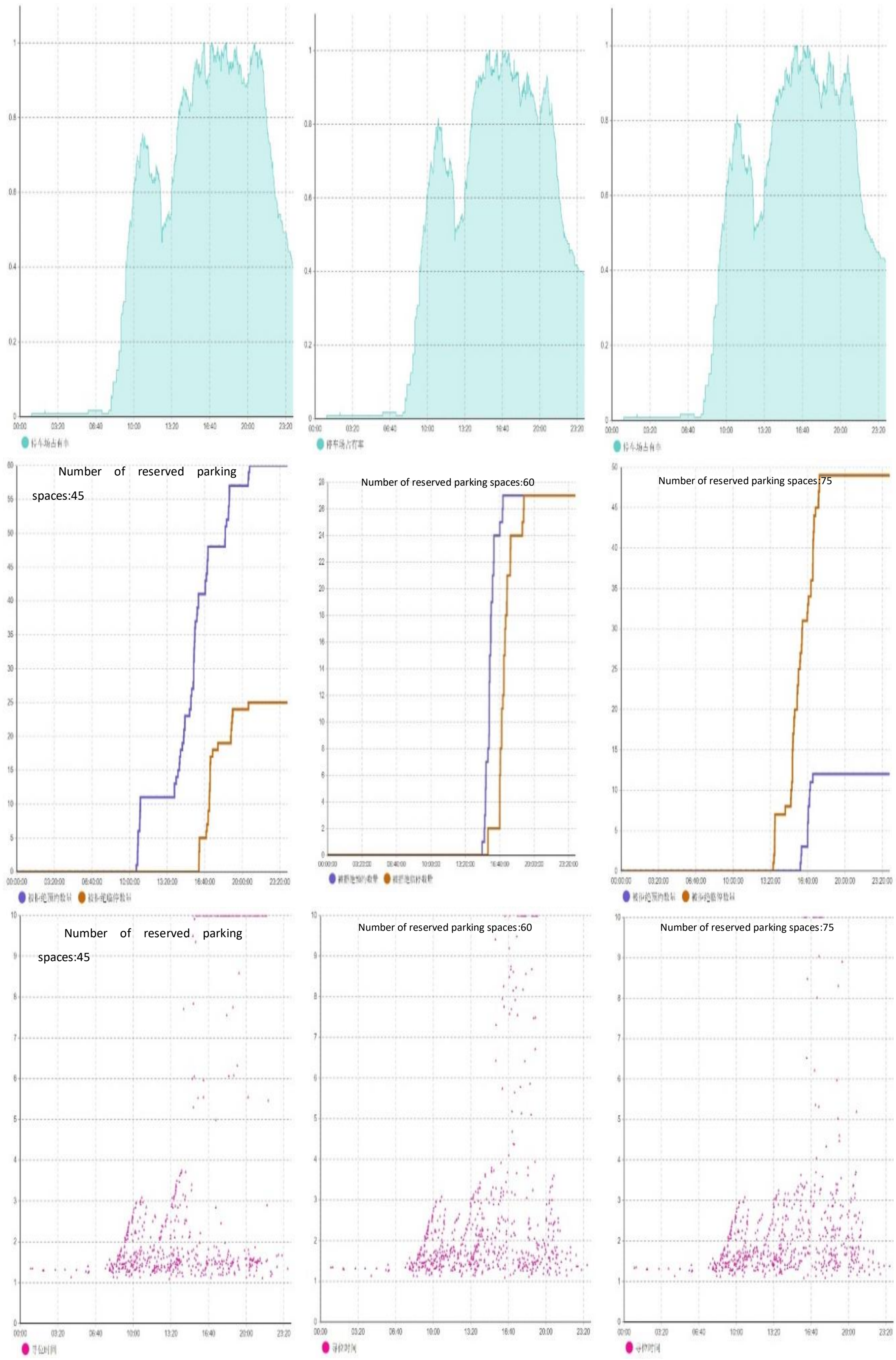



Figure 5.12 Parking simulation on May 13 (weekend)

To sum up, in weekday scenarios, due to relatively low user parking demand, parking lots need to fully utilize intelligent parking systems to accurately identify and dynamically analyze the proportion of reserved parking users among all parking users. Based on this, setting a reasonable number of parking spaces for reservation can not only avoid idle and wasteful parking resources, but also meet the needs of reservation users and temporary parking users as much as possible, achieving a balance between resource utilization efficiency and user satisfaction.

On weekends or holidays, due to a significant increase in parking demand, parking lots need to take effective measures to cope with the pressure of peak usage. In such scenarios, parking lots should actively encourage users to use reservation parking methods and plan parking arrangements in advance through the reservation system. This method can not only help users lock their parking spaces before arrival, reducing the time spent searching for parking spaces in the parking lot, but also improve the management efficiency of the parking lot, effectively divert pedestrian and vehicular traffic, and alleviate congestion during peak parking periods.

## 5.4 Summary

This chapter designs simulation experiments to compare the effectiveness of reinforcement learning algorithms with traditional approximate algorithms. The results of the numerical experiments demonstrate that the algorithms, models, and processes developed in this study exhibit significant optimization effects, greatly enhancing the utilization rate and revenue of parking facilities.

# Chapter 6: Conclusions

Through the discussion in the previous five chapters, the whole parking lot reservation process has been analyzed and discussed in detail. On the basis of the previous chapters, this chapter summarizes the whole research process and the final research results. The first part is an overview and summary of the study. The second part focuses on the theoretical and practical contributions of this thesis. The third part discusses the limitations of the study and future research directions.

## 6.1 Main conclusions

Based on the current difficulties of parking in major cities in China, this thesis designs a better parking reservation management process through field research, questionnaire survey, literature review and parking data analysis to help car owners find parking spaces and improve the parking utilization rate of parking managers. The main research contents and conclusions of this thesis are summarized as follows:

Firstly, how to use mathematical and statistical analysis to uncover periodic patterns and characteristics of parking behavior?

Based on the historical parking data of the underground parking lot of a large shopping mall in Chengdu, this thesis uses the correlation analysis and a statistical method to analyze the monthly, weekly and daily changes of vehicle access on weekdays and weekends.

The results of the data analysis in this study reveal the following:

(1) The majority of customers generate parking demand due to shopping and consumption activities;

(2) 80% of customers park for less than 4 hours;

(3) Parking periods exhibit a concentrated pattern, with consistent trends observed from Monday to Friday.

Based on the business scenario, through the data statistics method, the actual operation situation of the parking lot in terms of parking space turnover rate and parking space occupancy rate is analyzed, and the cycle law of users' parking and peak and low peak periods are obtained. Specifically:

(1) On weekdays during the daytime (8:00-15:00), the utilization rate is below 60%, with

many available parking spaces; from 17:00 to 21:00, the parking space usage rate exceeds 80%.

(2) On weekdays during the nighttime (22:00-7:00), the utilization rate is even lower, below 20%, with a significant number of idle parking spaces.

This indicates that during periods of low utilization, sharing parking spaces can help improve both the utilization rate and the overall efficiency of the parking lot.

However, on non-working days, the parking lot usage rate at this mall exceeds 80% from 09:00 to 21:00, reaching 100% during multiple time slots, indicating a fully occupied state. This suggests that on weekends, customers may face parking challenges, and designing a parking reservation process could enhance customer experience and parking revenue.

Secondly, how to provide parking reservation services for busy periods (high parking turnover rate) and idle periods (low parking turnover rate)?

For reserved parking spaces, this study conducted a survey among customers regarding the determining factors for parking reservations and their willingness to pay. The data shows that 81.33% of customers are willing to reserve parking spaces, with greater attention given to factors such as reservation effectiveness, distance, price, and safety. Regarding reservation fees, if a fee equivalent to 50% of the hourly parking rate is charged, it would gain support from 86.86% of customers. As for parking fee discounts, if the discount is below 50%, it would receive support from 55.13% of customers. These results indicate that parking lots can charge reservation fees during peak hours and offer discounted reservation rates during off-peak hours to enhance parking revenue.

Thirdly, how should the parking reservation platform make decisions under conditions of random supply and demand?

Due to the bilateral characteristics of the shared parking platform, the time periods of unused parking spaces are different. This thesis constructs the parking space reservation and pricing operation management problem under random supply. On this basis, it is constructed the dynamic decision-making model to maximize the parking demand and revenue of the parking platform under the three situations of advance reservation, temporary arrival and advance reservation, and random supply and random demand. For the complex structure of the model, the traditional method of designing approximation algorithm is difficult to solve this kind of model, and can't get the structural properties of the optimal strategy. Therefore, this thesis designs a Deep Reinforcement Learning algorithm to solve it. Based on the previous data summary, this thesis analyzes and selects the feasibility and mode of parking reservation. Combined with the results of the previous model, the parking process optimization design is carried out for advance reservation, temporary arrival and advance reservation, as well as random supply and random demand. In addition, this thesis also complements the parking reservation business process design, mainly including the busy hour parking reservation process design and the idle hour parking reservation drainage process design. This study addresses the issues by constructing parking reservation algorithms and models, optimizing the parking process, and effectively resolving parking reservation challenges under conditions of random supply and demand.

Finally, how to design and validate the effectiveness of parking reservation algorithms and processes?

This thesis uses numerical simulation experiments to verify the effectiveness of the deep enhancement algorithm and the operation and management process of smart parking reservation platform. This study is based on the parking lot's 120 parking spaces, which can generally meet the parking demands of all users on weekdays. However, it is necessary to set a specific number of reservable parking spaces. Simulation results indicate that when the number of reservable parking spaces is around 60, the utilization rate of the parking lot reaches its highest, increasing the occupancy rate from 60% to 90%. On weekends or holidays, the 120 parking spaces are insufficient to meet the parking demands of all users. In this scenario, setting 45, 60, or 75 reservable parking spaces all result in a 100% occupancy rate during peak parking demand periods. Under these conditions, setting 75 reservable parking spaces allows most customers to find a parking space within 4 minutes, achieving the optimal balance between service efficiency and overall benefits. Through numerical simulation experiments, compared with the approximation algorithm designed in the traditional literature, it is found that the effectiveness of the Deep Reinforcement Learning algorithm is always significantly better than that of the approximation algorithm in terms of the predetermined cycle and the predetermined price.

To sum up, this study has addressed all the questions proposed. This thesis provides new ideas and inspiration for the reservation parking platform in the business scenario in terms of the parking reservation operation management mode, solution algorithm, pricing rules, etc., which can improve the revenue of the management and make full use of parking space resources, and can help alleviate the current parking problem in China.

## 6.2 Research contribution

### 6.2.1 Theoretical contribution

The current parking reservation mode is mainly divided into real-time reservation mode and shared reservation mode. For example, Sun et al. (2020) proposed an integer programming model on the basis of the traditional shared parking operation management, which can realize the consent decision on the rental of idle parking spaces and the allocation of parking requests. Cai et al. (2018) proposed a network level Parking Space Allocation Method (PSAM), which allocates parking demand to parking lots, and then allocates parking spaces. Users are divided into M users (building users) and P users (public users). The shared parking strategy is analyzed from the aspects of open windows, parking fees and the proportion of reserved parking spaces. Hu et al. (2021) studied the parking choice behavior of the demanders in the shared parking mode, established the choice intention model of the demanders in the shared parking mode, and divided the effect path in the process of promoting the shared parking mode into the central path and the peripheral path. P. Yan et al. (2021) proposed a real-time reservation method based on the rolling horizon framework, which can allocate multiple drivers to a single parking space to make better use of scarce parking resources.

However, the real-time reservation mode can´t solve the problem of resource supply, and the shared reservation mode can´t solve the problem of randomness of parking. This research based on data-driven design of intelligent parking reservation platform operation management process can effectively solve the real-time and randomness problems of current users' parking, and can also maximize the revenue of the platform. In addition, this study designed a Deep Reinforcement Learning algorithm. The effectiveness of the Deep Reinforcement Learning algorithm is always significantly better than that of the traditional approximation algorithm in terms of the predetermined cycle and the predetermined price.

In conclusion, this study has a high degree of theoretical significance. This thesis starts from the real parking data, establishes the decision-making model based on the analysis of the data results, designs the depth enhancement algorithm to solve, and optimizes the current parking reservation management process. This study can form a supplement to the existing parking reservation management process system, and can form a theoretical reference for the design of new reservation management process.

### 6.2.2 Practical implication

With the development of economy, the number of cars in China will continue to increase in the future. However, due to the limited land resources, the parking problem will be more serious in China. Based on the current parking problem in China, this study designed the intelligent parking reservation management process, and found a more effective way to use parking resources.

First, the reservation service designed in this study allows users to book a parking space in advance before arriving at the destination and quickly find a parking space after arriving at the destination, which can effectively save users' time and improve parking efficiency;

Secondly, the parking reservation management process designed in this study can help the platform effectively improve the utilization rate of parking spaces, reduce the vacancy rate of parking spaces, avoid unnecessary waste of resources, and maximize the revenue of the platform;

Finally, the intelligent reservation management process designed in this study can effectively reduce vehicle parking time, reduce carbon emissions and vehicle exhaust, reduce environmental pollution, and effectively reduce traffic accidents, which can promote the improvement of congestion around the parking lot.

To sum up, the operation and management process of smart parking platform designed in this study can effectively alleviate the current practical problem of parking difficulty, and provide a new idea and method for the government and major commercial places to solve the parking problem.

## 6.3 Limitation

There are still some challenges in this study. In the future, more in-depth exploration will be carried out from the following points:

(1) The research data of this thesis comes from the underground parking data of shopping malls. Due to certain differences in the environment and parking behavior of users in different regions or lots, the research results have certain limitations. If the research results of this thesis are to be widely popularized, it is necessary to conduct research in more different situations and more investigations and data calculation to verify;

(2) Based on the analysis of real data, this thesis divides the reserved parking situations into three categories, namely, advance reservation, advance and temporary reservation, and random supply and random demand. In the future, more users will be divided and more detailed analysis of the reservation situation will be carried out, so that users can have a better parking experience and better serve the reserved parking platform. To sum up, the operation and management process of smart parking platform designed in this study can effectively alleviate the current practical problem of parking difficulty, and provide a new idea and method for the government and major commercial places to solve the parking problem;

(3) The validation of the findings in this study primarily relies on numerical experiments.

These experiments are based on the data obtained in this paper. Due to the limited sources of these data and the variations in environments and user parking behaviors across different regions or areas, extensive promotion of the research outcomes presented in this paper would require further investigation and validation under more diverse scenarios.

## 6.4 Future work

This study focuses on optimizing the operational management of parking reservation platforms and validates the effectiveness of enhanced management processes through simulation experiments. The results indicate significant theoretical and practical value. Building on existing parking platform data and research outcomes, three key directions for future exploration are proposed:

First, the optimized parking operation management model can effectively enhance reservation efficiency. The author plans to implement it in the company's smart parking reservation system to enhance parking space utilization and operational revenue.

Second, given the novelty of the algorithms and models proposed, the author intends to file an algorithm-based invention patent with the intellectual property (IP) administration to create IP-driven commercial value for enterprises.

Finally, to address current limitations, future work will expand model optimization across broader scenarios, larger datasets, and diverse regions. Through iterative upgrades, the data-driven smart parking reservation platform is expected to improve parking resource efficiency, profitability, and user experience, thereby advancing industry development.

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# Annex A: Questionnaire

Dear Madam/Sir：

Thank you for taking the time to participate in this survey on parking behavior and preferences! We want to understand users' actual experience of parking behavior, their needs and preferences for parking reservation service through this questionnaire, so as to provide data support for the optimization of smart parking reservation platform. All questionnaires are anonymous and will not be released to the outside world. The results are only used for academic research. There is no right or wrong question, just reflect your real thoughts and actual situation. Please answer the following questions and select "√" in the selected option.

**Part I: Basic information**

1. What is your gender?

- Man
- Woman

2. Which of the following is your age?

- 18-25 years
- 26-35 years
- 36-45 years
- 46-55 years
- 56 years and over

**Part II: Travelers' parking traffic attributes**

3. Why do you often drive to the mall? (multiple choices are allowed)

- Shop
- Meals or other catering
- Go to the movies
- Work
- Training or play for children
- Other

4. In your city, do you find it difficult to park?

- Very difficult
- Harder
- Average
- Easier

5. When you go out to park, do you often encounter the situation that there is no parking space?

- Regularly
- Sometimes
- Not at all

6. How long do you usually find a parking space?

- 0-5 minutes
- 6-10 minutes
- 11-15 minutes
- 16-20 minutes
- 21-25 minutes
- 25 minutes over

**Part III: Travelers' parking reservation attributes**

7. If you can make a reservation in advance through the website or mobile client before going out, will you choose to make a reservation?

- Will
- No
- Other

8. Which way would you prefer to book a parking space?

- Cell phone software
- Computer network website
- Telephone
- Vehicle-mounted terminal
- Others

9. Would you like to pay for the reserved parking space?

- Willing
- Unwilling

10. What do you think is the proportion of the reasonable booking fee in the hourly parking fee during busy hours (when the parking space is tight)?

- Below 50%
- 50%-100%
- 100% or more

11. What do you think is the proportion of the discount reservation fee in the hourly parking fee during idle hours (when there are plenty of parking spaces)?

- Below 50%
- 50%-100%
- 100% or more

12. This option is an attention detection option. Please select sometimes.

- Often
- Sometimes
- Seldom

**Part IV: factors of concern for travelers' parking lot selection**

13. What factors will you consider when choosing a parking lot? (multiple choices are allowed)

- Can make an appointment to the parking space
- Parking lot reservation reliability
- Distance to destination
- Parking safety
- Parking fee price
- Booking fee cost
- Travel time
- Others

Thank you for your participation!

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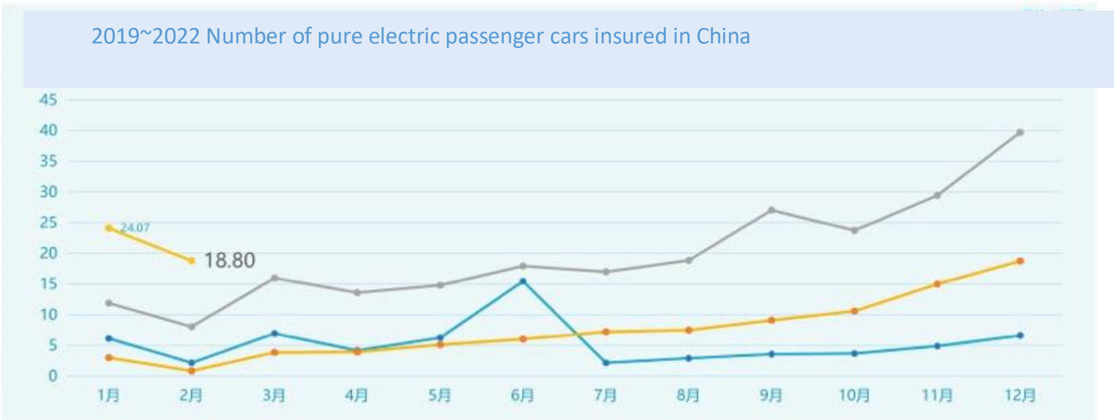
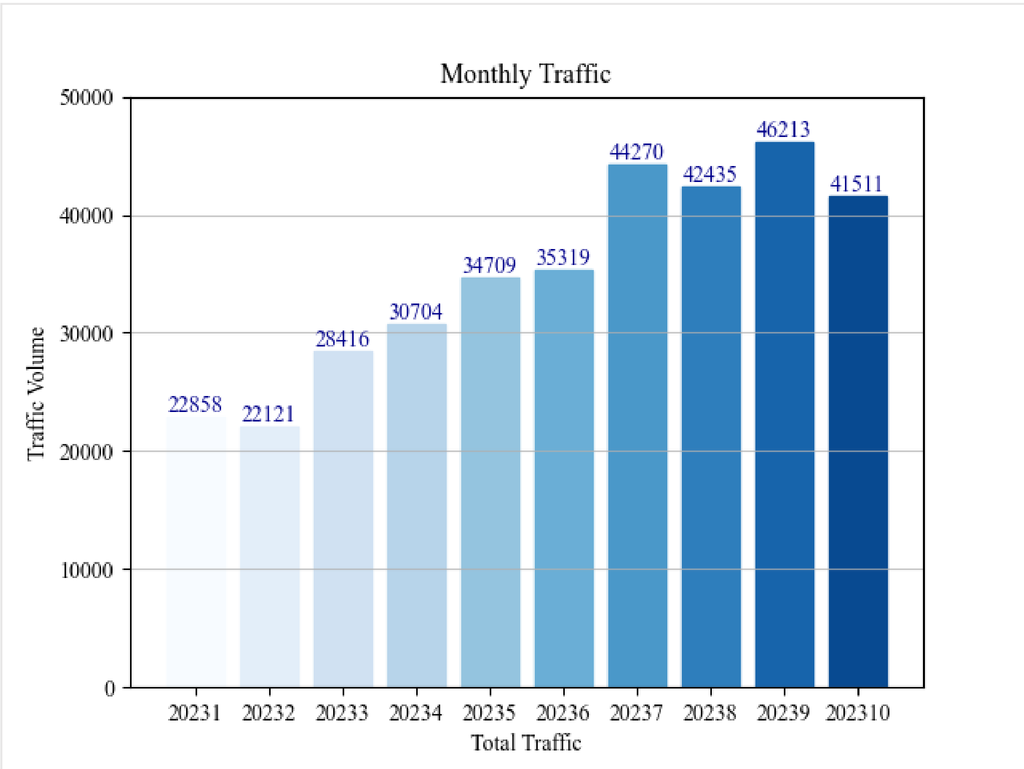
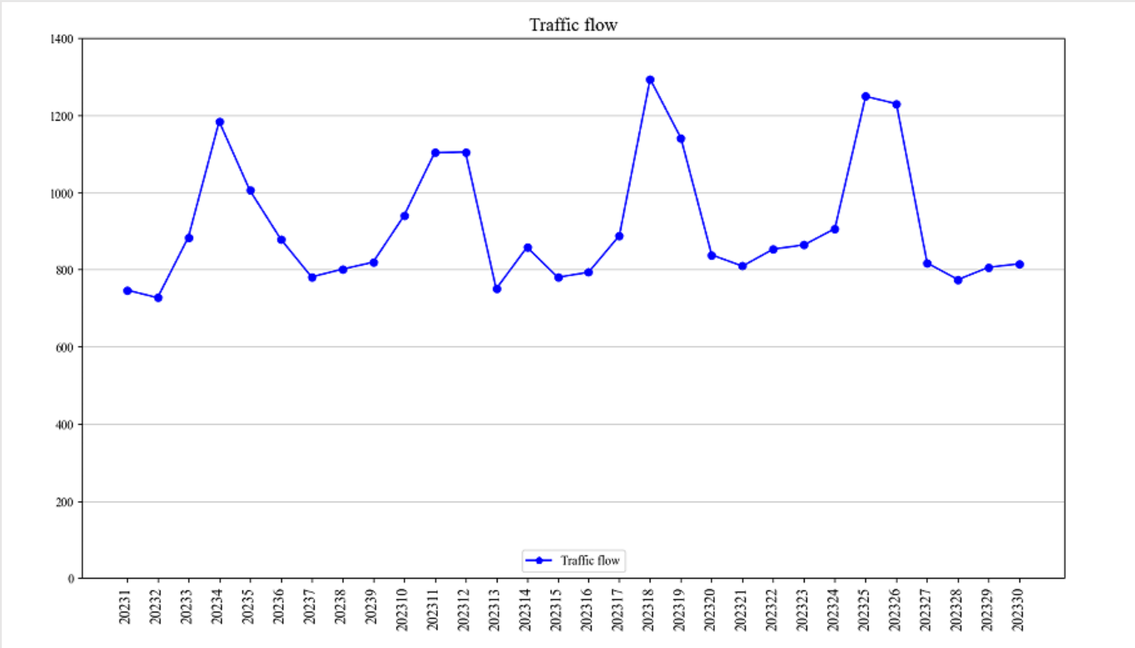
# Annex B: Figures



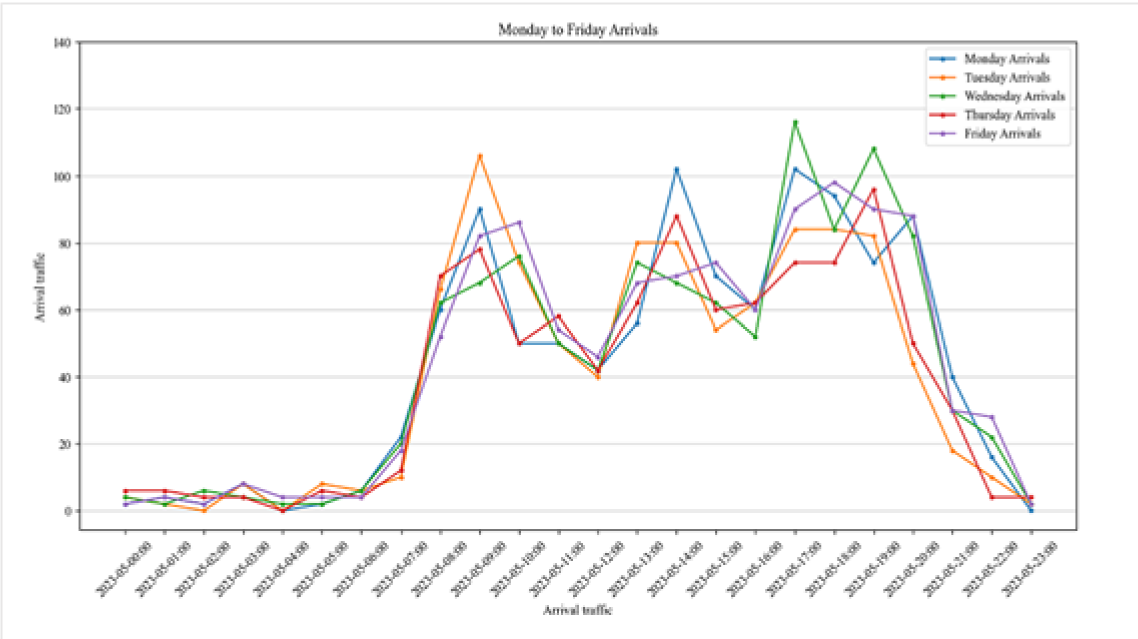

Appendix Figure 1 Number of pure electric passenger vehicles in China on insurance, 2019-2022



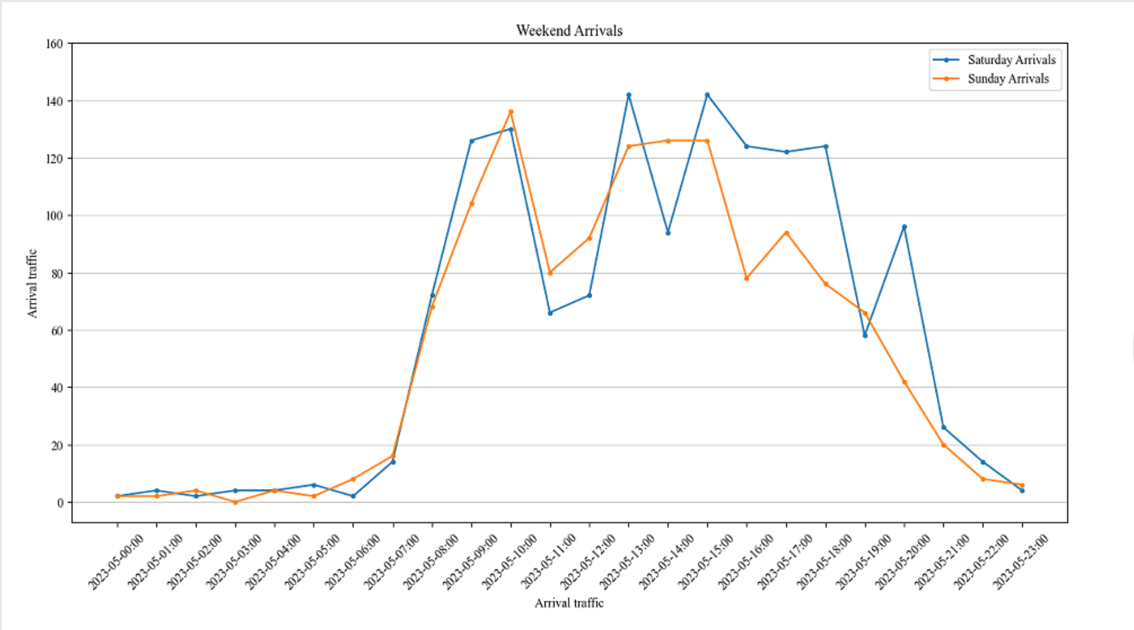

Appendix Figure 2 Monthly traffic flow



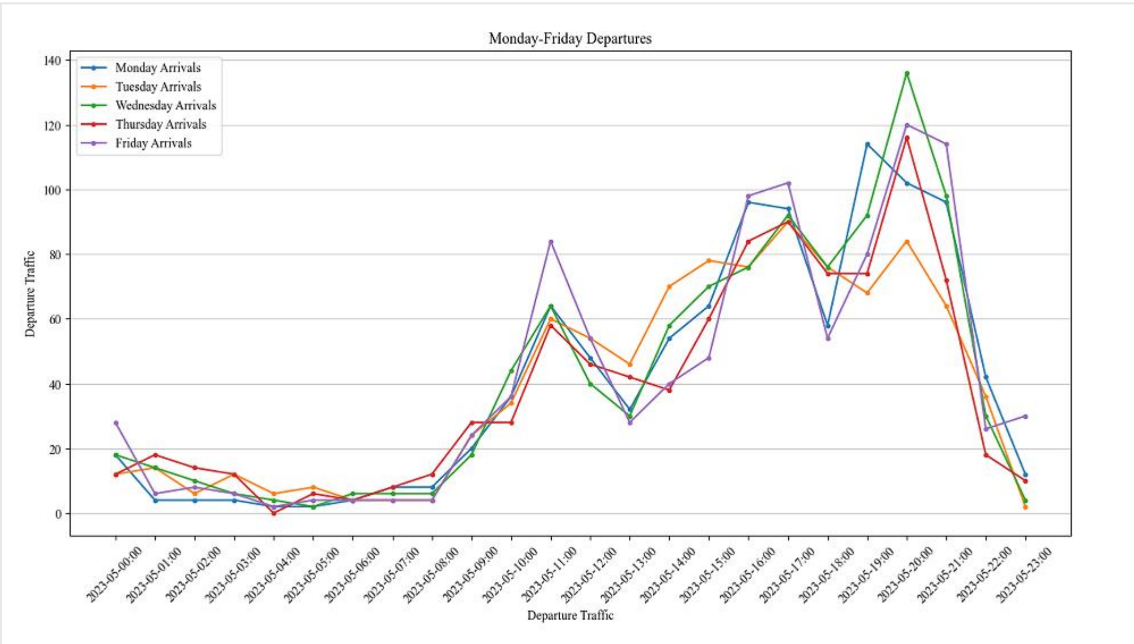

Appendix Figure 3 Daily vehicle admission in March 2023



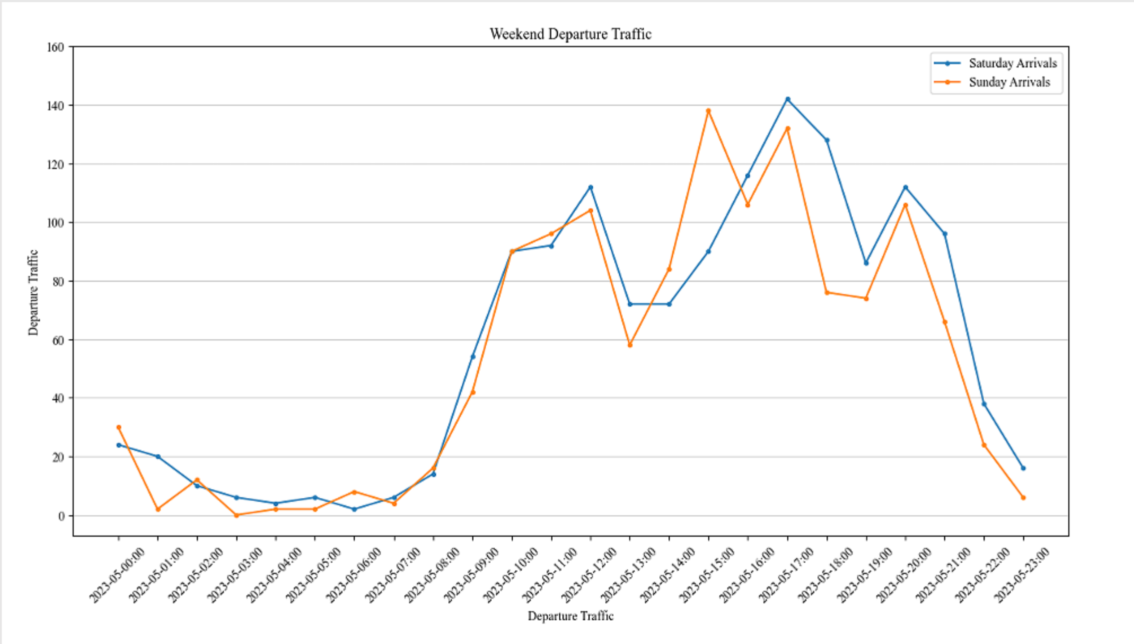

Appendix Figure 4 Distribution of vehicle arrivals in shopping malls and parking lots on weekdays (Monday to Friday)



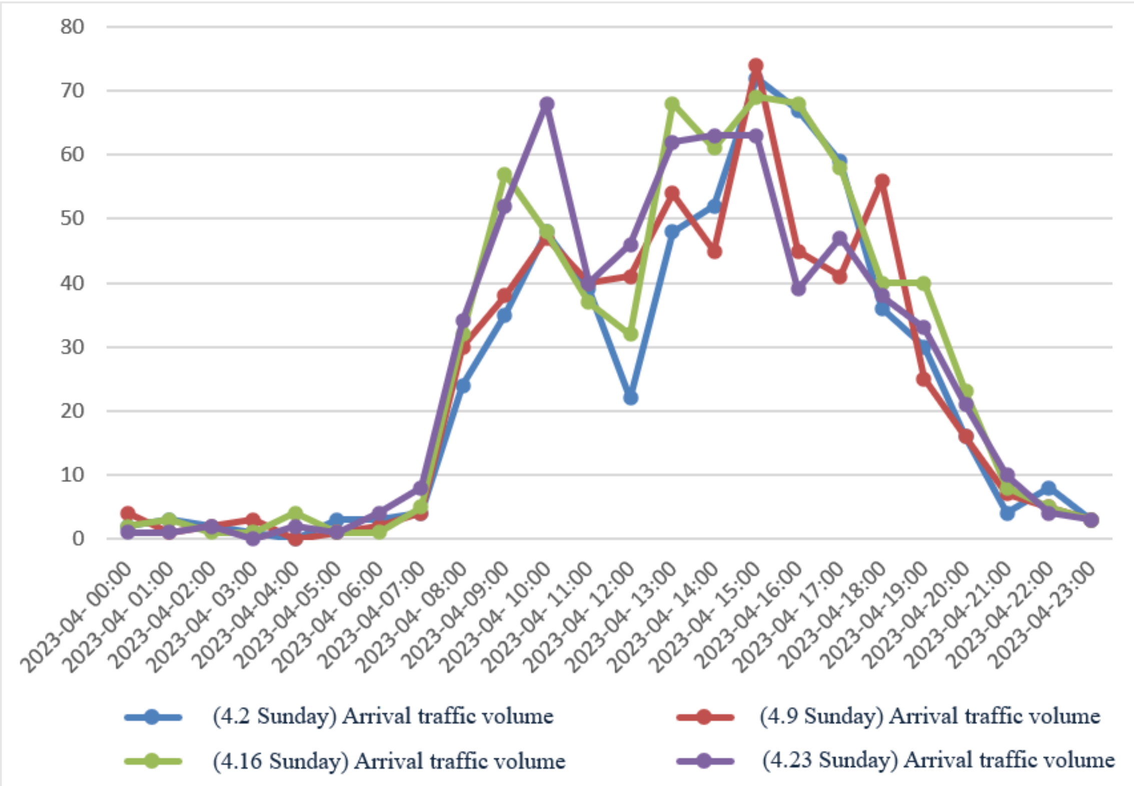

Appendix Figure 5 Distribution of vehicle arrivals in shopping malls and parking lots on non-working days (Saturday and Sunday)



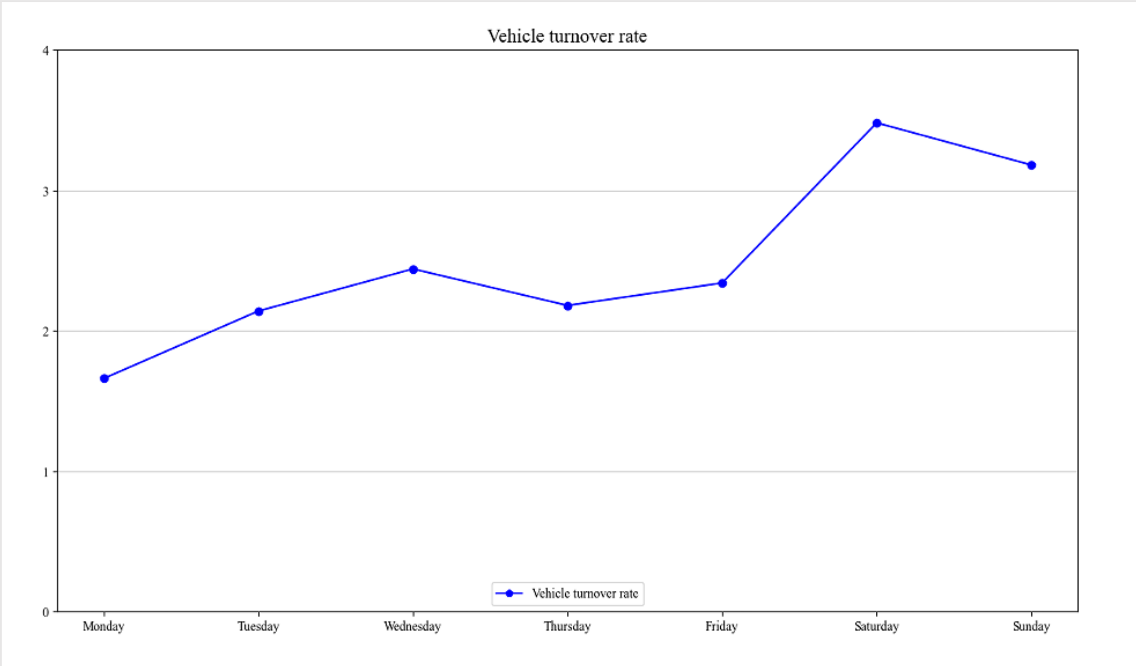

Appendix Figure 6 Distribution of vehicle departures in shopping malls and parking lots on non-working days (Saturday and Sunday)




Appendix Figure 7 Distribution of vehicle departures in shopping malls and parking lots on non-working days (Saturday and Sunday)

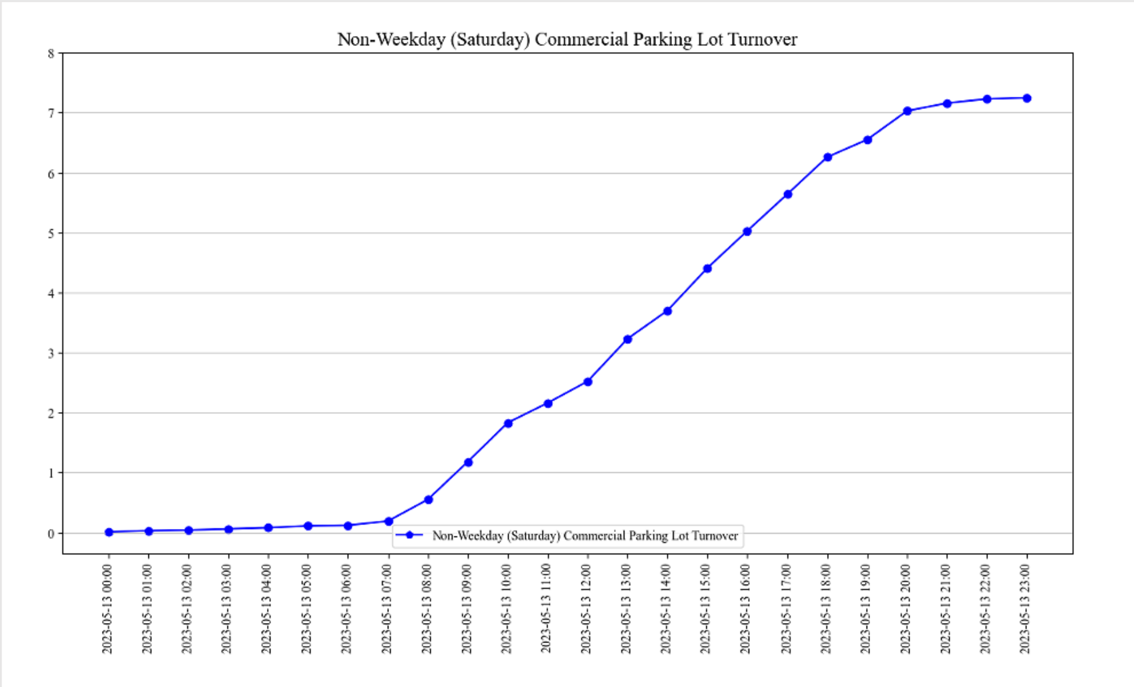



Appendix Figure 8 Statistics of vehicles entering the parking lot every Sunday in April

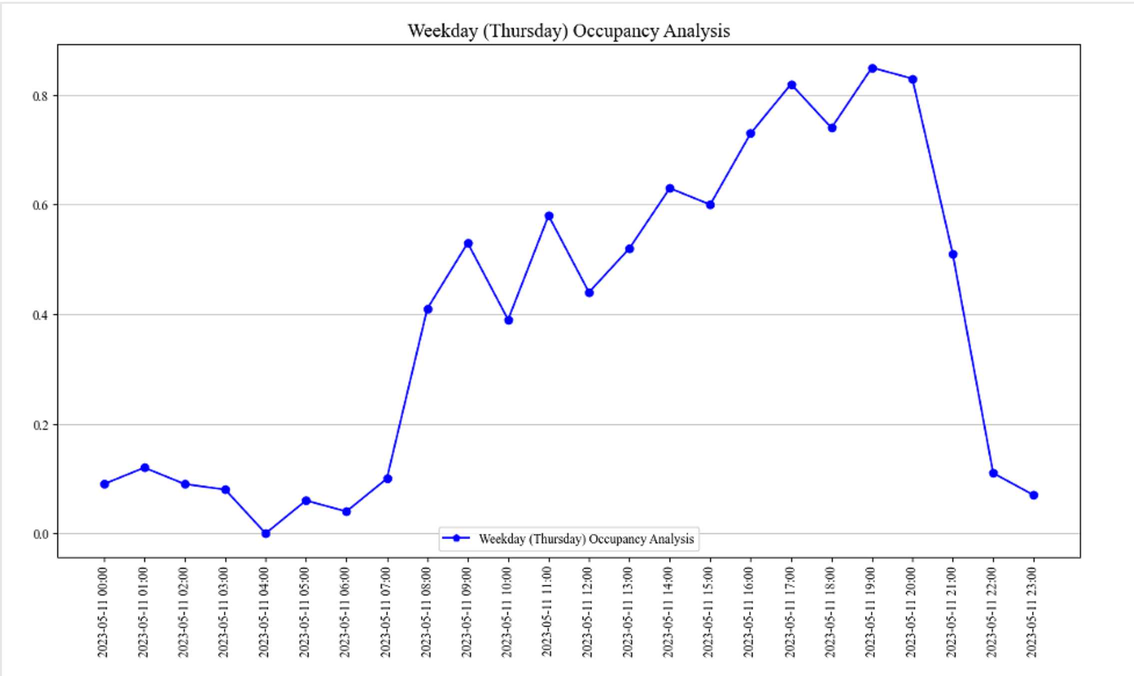



Appendix Figure 9 Average daily turnover rate in a week

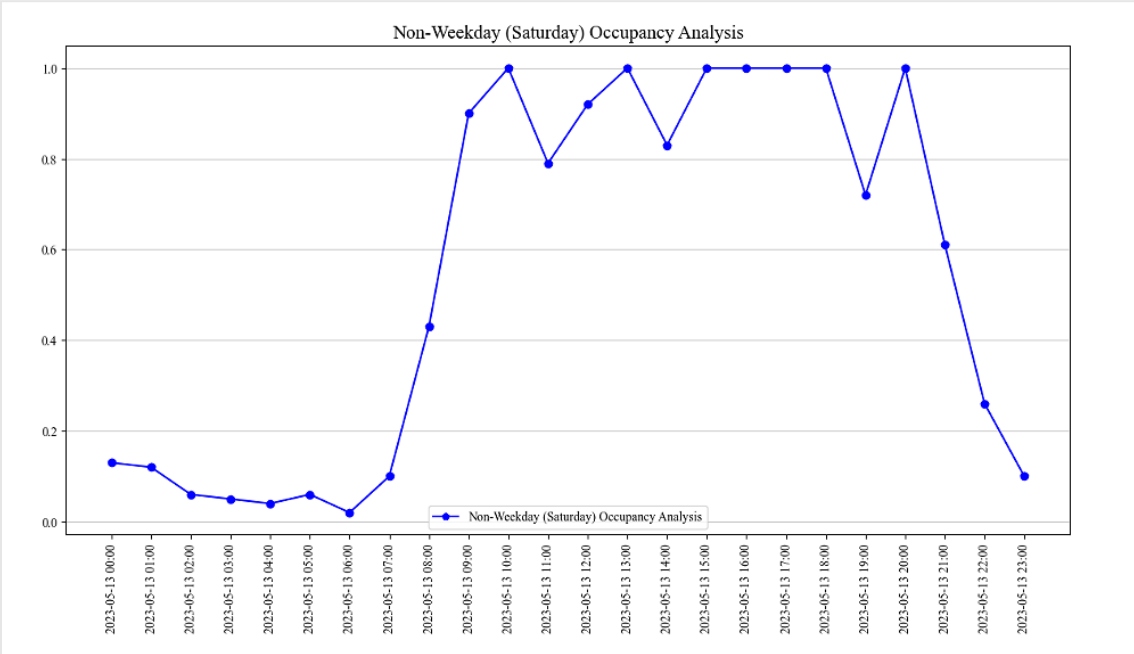

Appendix Figure 10 Turnover rate of commercial parking lots on weekdays (Thursday)



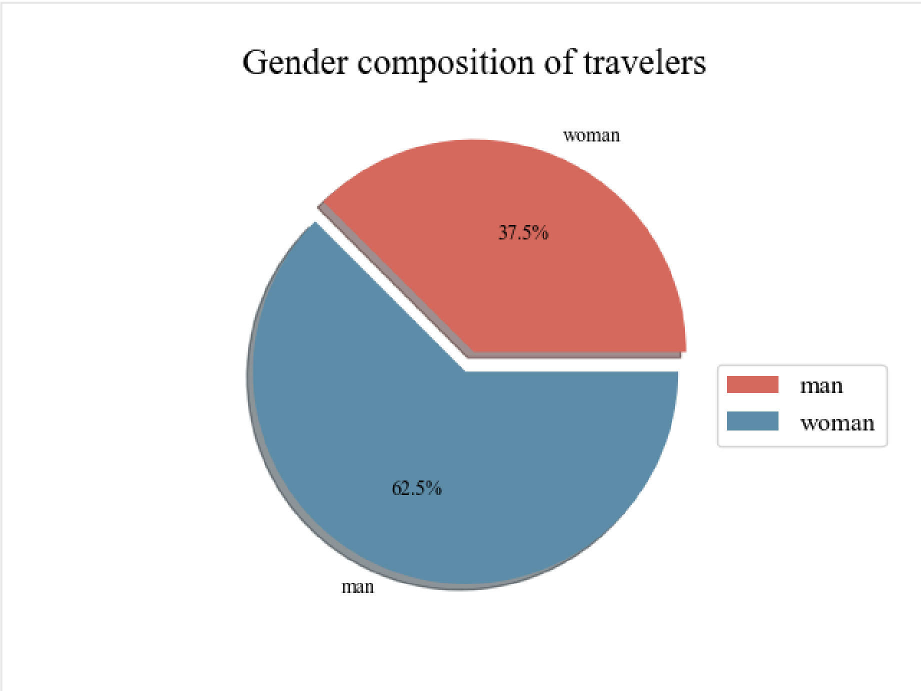

Appendix Figure 11 Turnover rate of commercial parking lots on non-working days (Saturday)



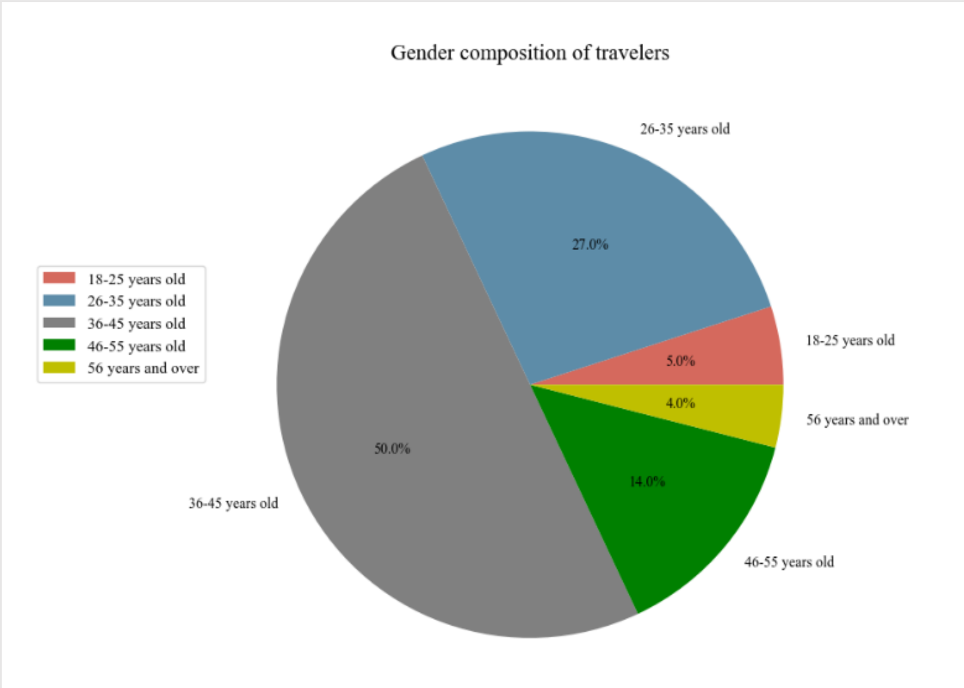

Appendix Figure 12 Changes in the proportion of berths occupied on weekdays (Thursday)



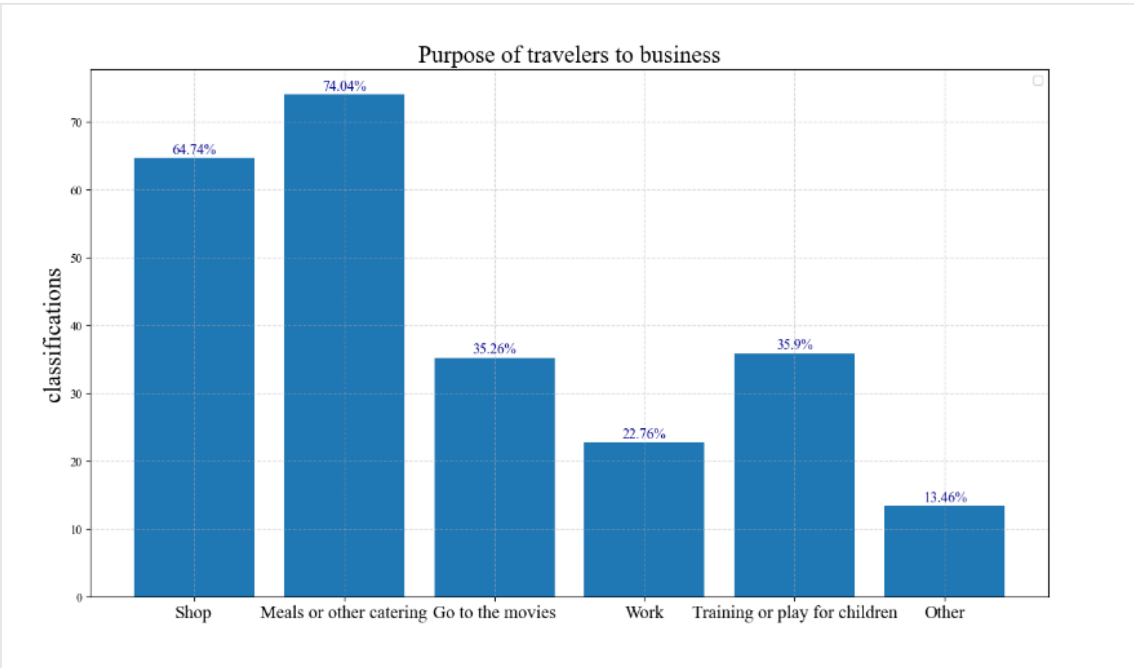

Appendix Figure 13 Changes in the proportion of berths occupied at weekends (Saturdays)



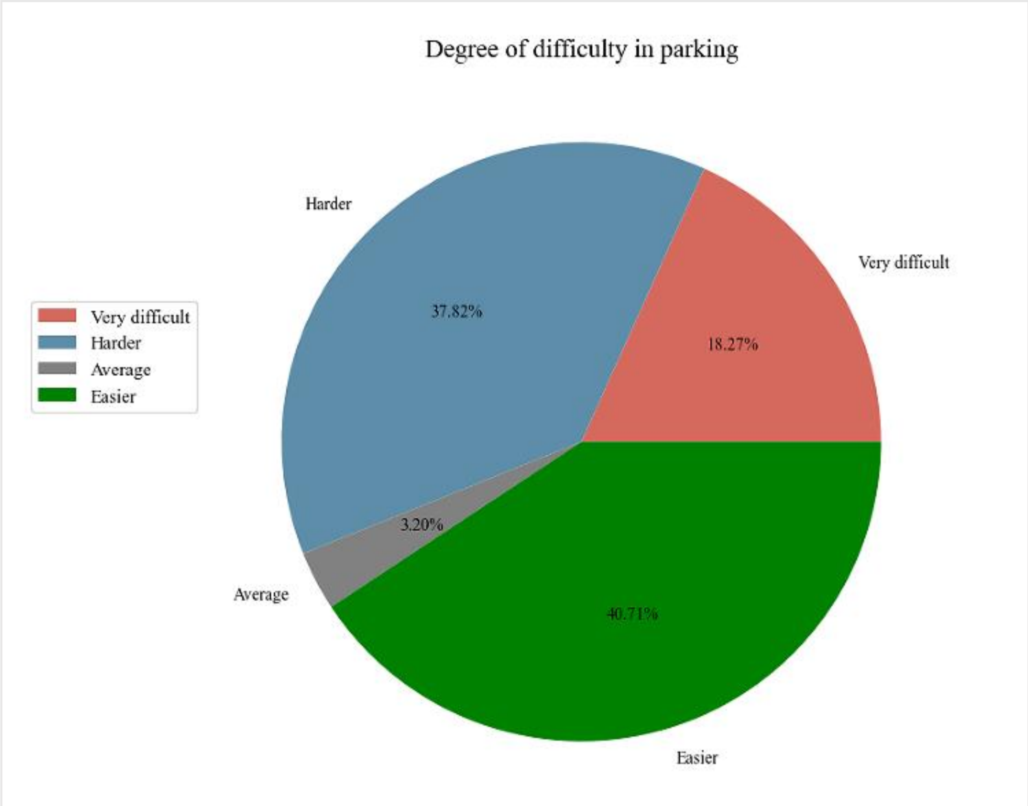

Appendix Figure 14 Gender composition of travelers



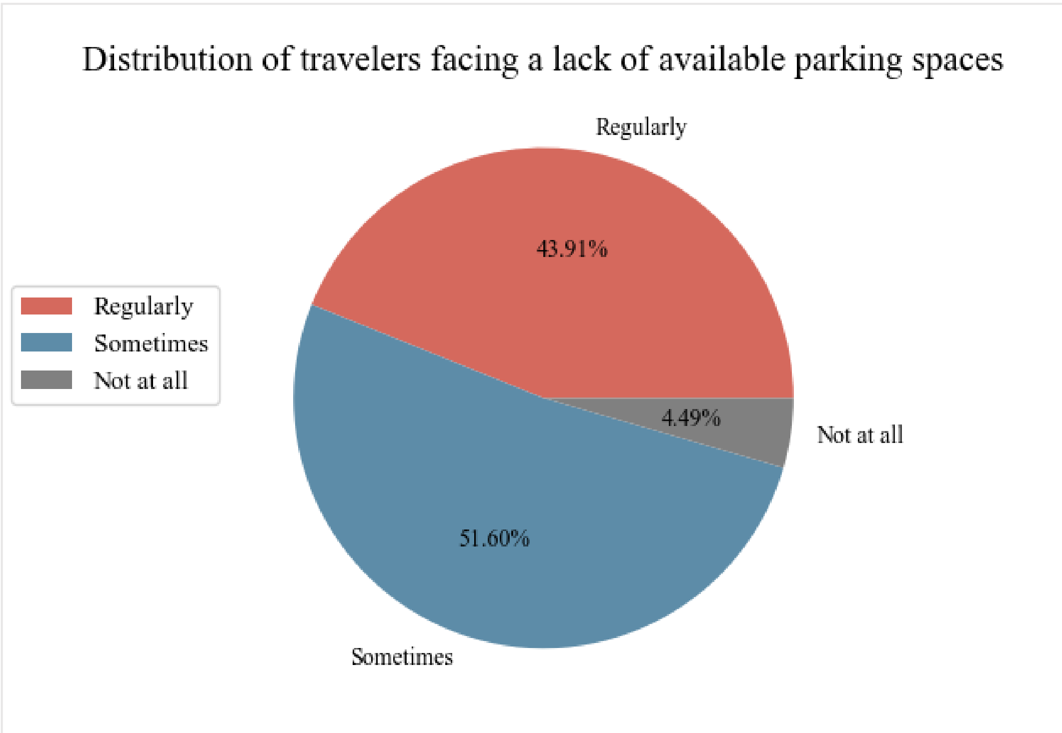

Appendix Figure 15 Age structure distribution of travelers



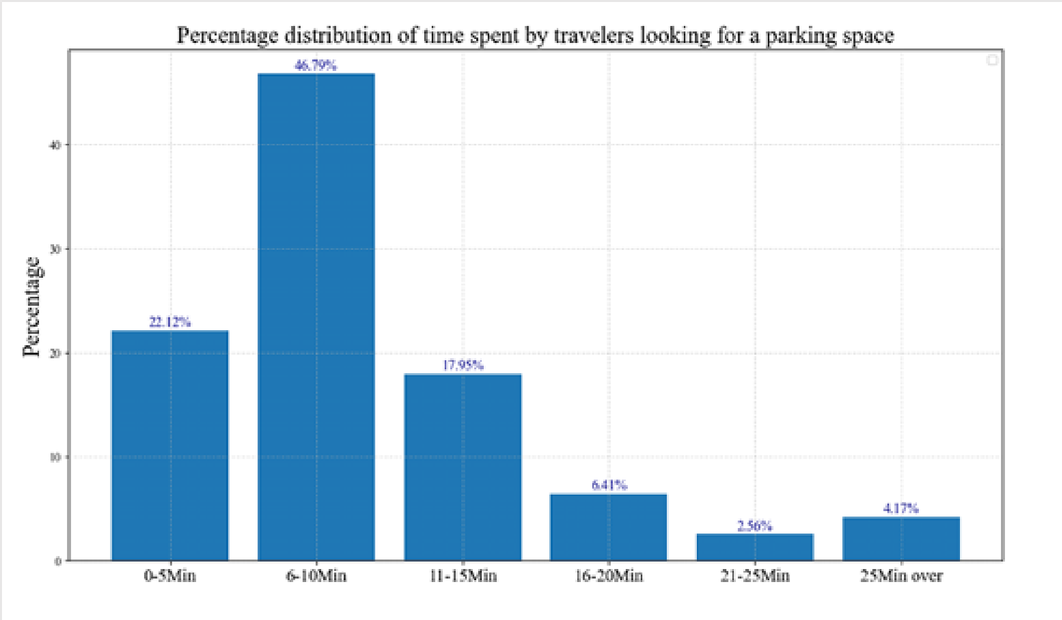

Appendix Figure 16 Purpose of traveler to business



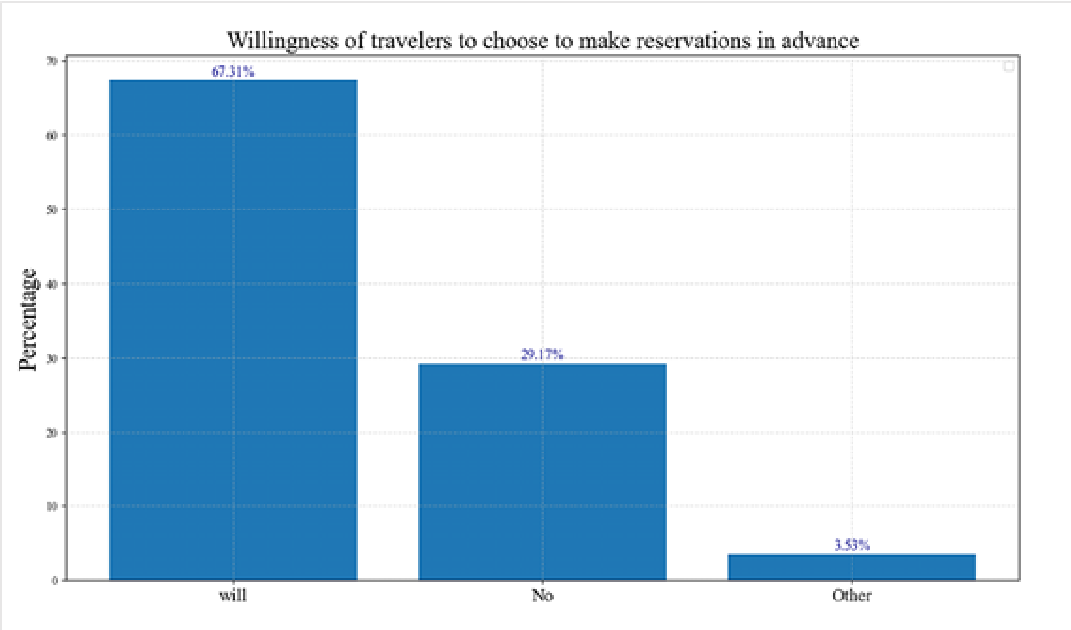

Appendix Figure 17 Distribution of parking difficulty



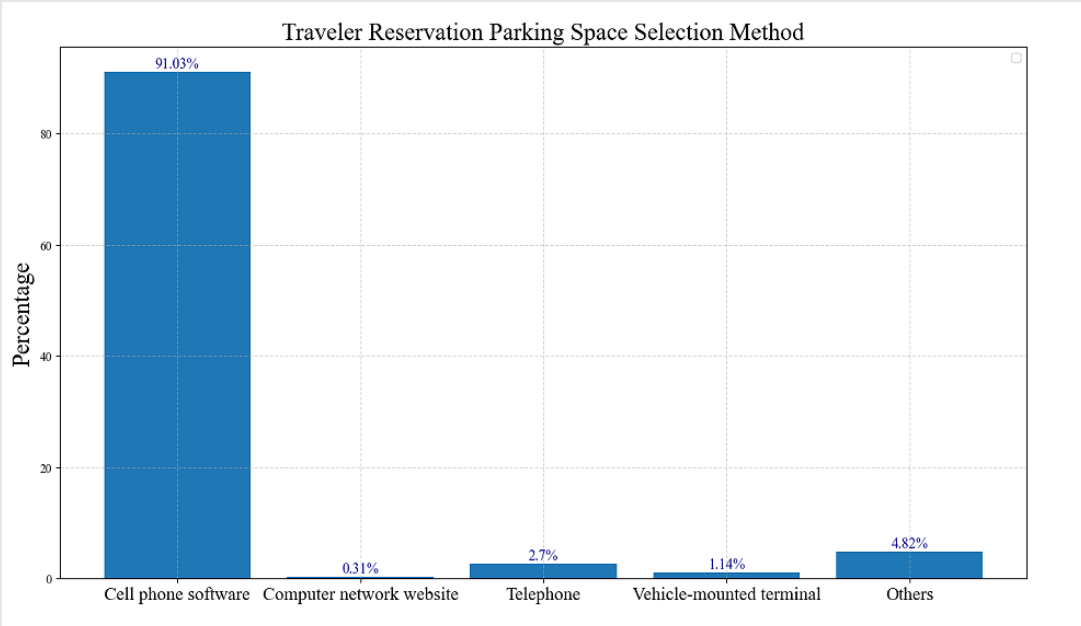

Appendix Figure 18 Distribution of travelers facing no available parking spaces



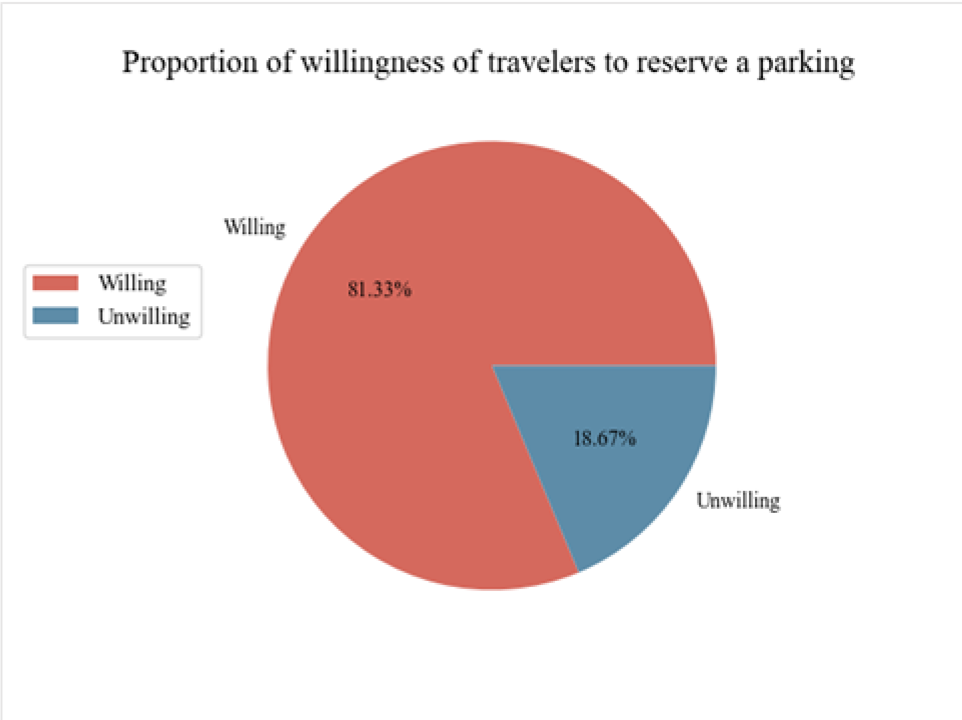

Appendix Figure 19 Percentage of time spent by travelers looking for parking spaces



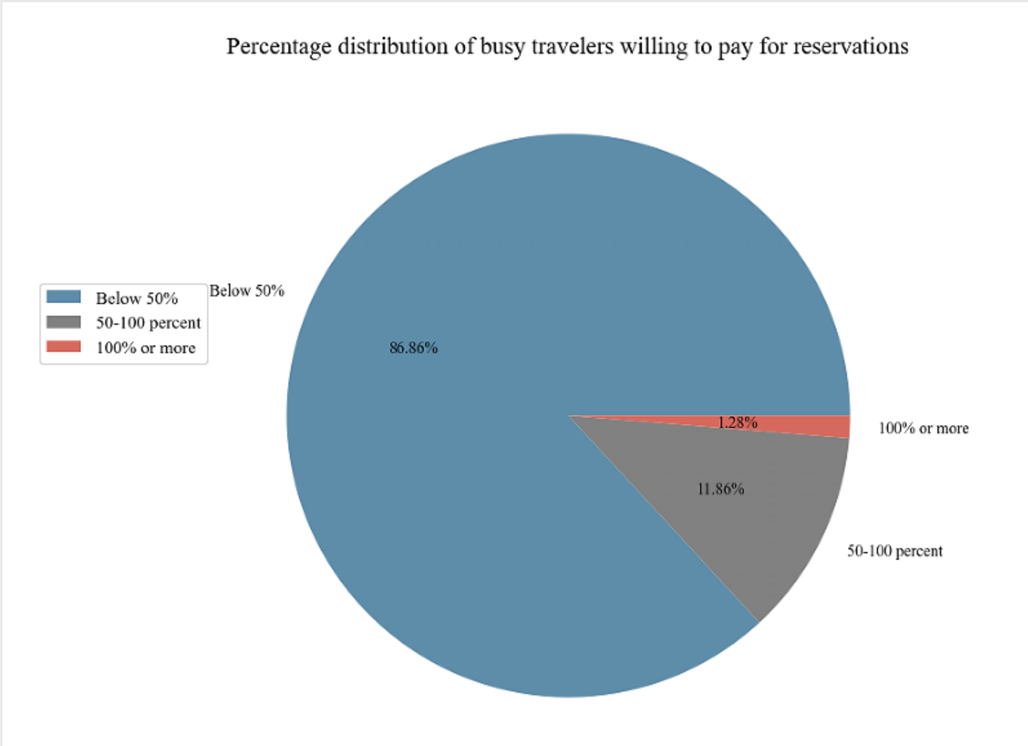

Appendix Figure 20 Travelers' willingness to choose advance booking



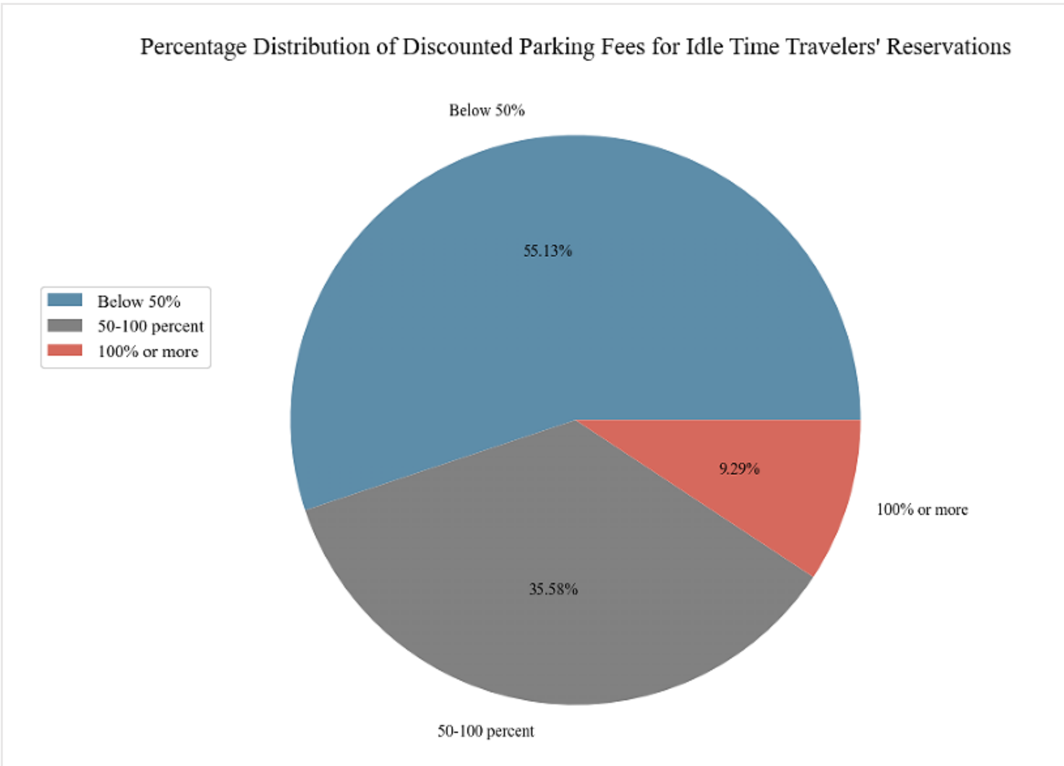

Appendix Figure 21 Selection method of travelers' reserved parking space



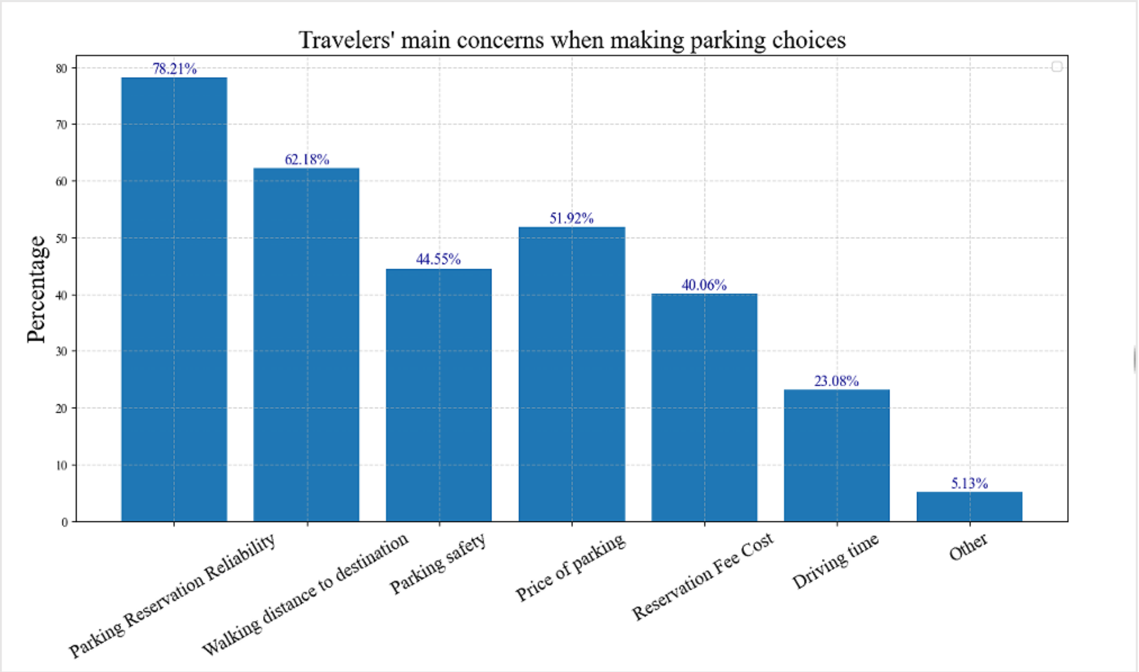

Appendix Figure 22 Proportion of travelers' willingness to choose reserved parking spaces



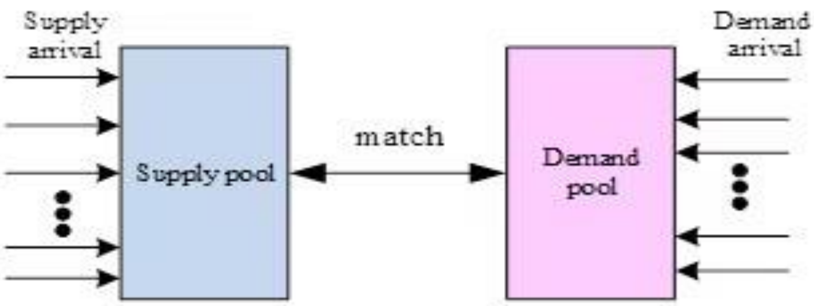

Appendix Figure 23 Percentage distribution of travelers' willingness to pay reservation fees during busy hours



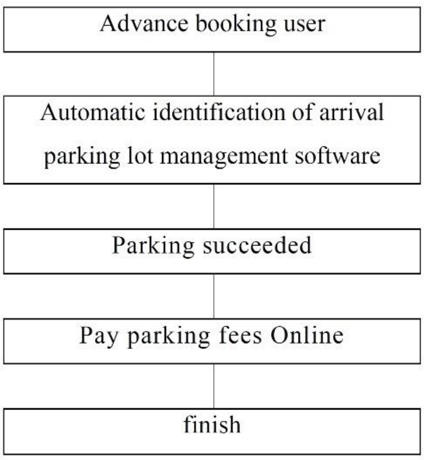

Appendix Figure 24 Percentage distribution of preferential parking fees for free time travelers



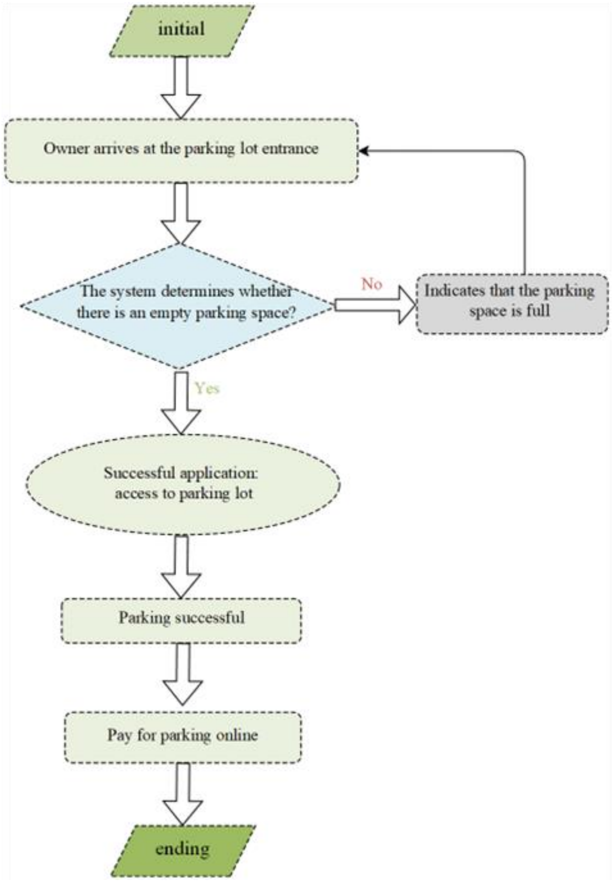

Appendix Figure 25 Main factors that travelers pay attention to when choosing parking lots



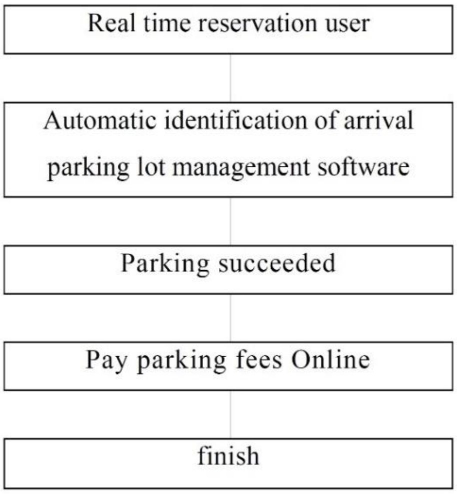

Appendix Figure 26 Operation logic of shared parking platform



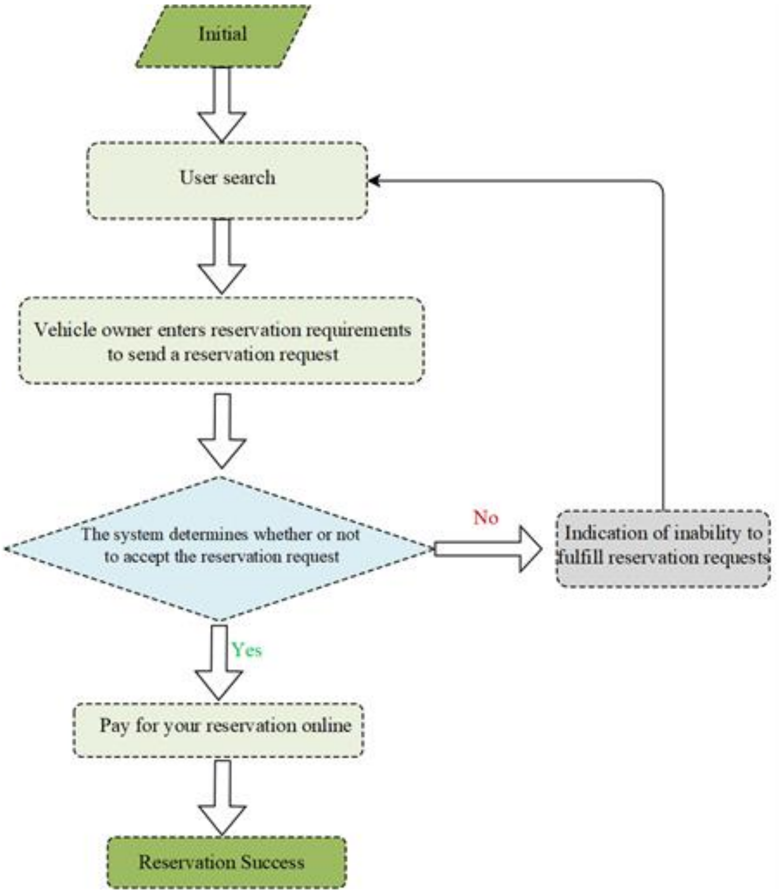

Appendix Figure 27 Offline process of pre booking user parking



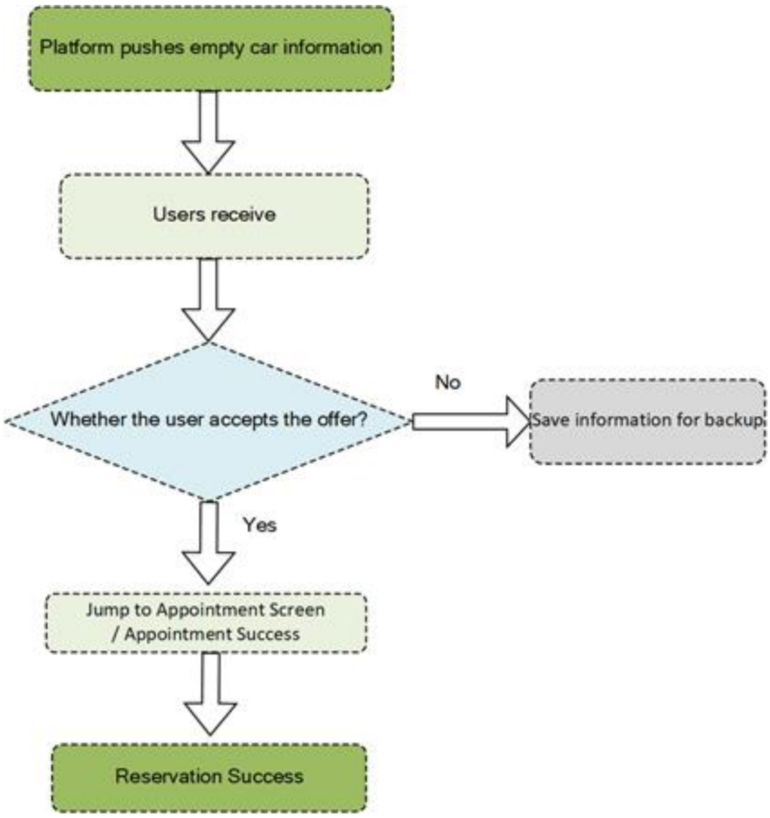

Appendix Figure 28 Temporary user parking process



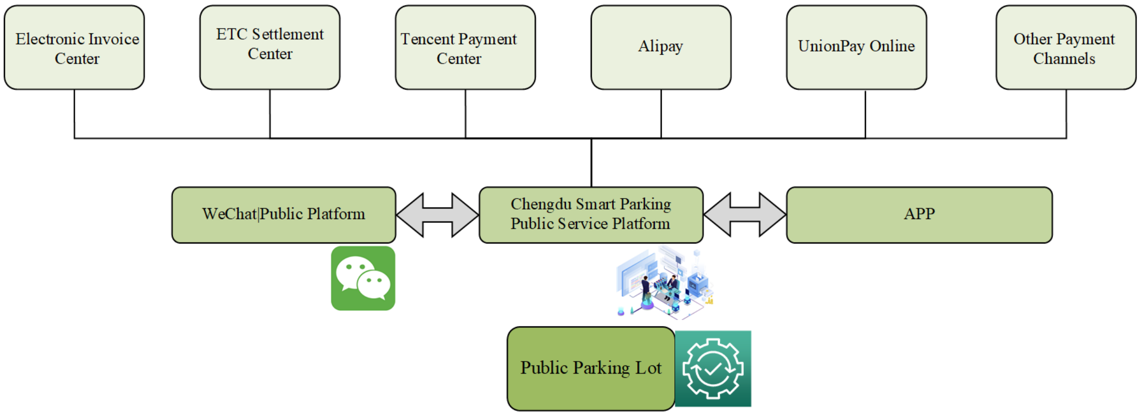

Appendix Figure 29 Offline process of real-time booking user parking




Appendix Figure 30 Process of booking users' parking lines during busy hours




Appendix Figure 31 Parking process of user reservation in idle time




Appendix Figure 32 Electronic payment methods in China

# Annex C: Tables

Appendix Table 1 Example of parking access data

| License plate number | Vehicle type | Channel type | Time | Access status | Release method |
|---|---|---|---|---|---|
| □F75*** | Small vehicle | export | 2023-05-07 14:57:47 | normal | System release |
| □A02*** | Small vehicle | entrance | 2023-05-07 14:55:00 | normal | System release |
| □A80*** | Small vehicle | entrance | 2023-05-07 14:54:35 | normal | System release |
| □A8K*** | Small vehicle | entrance | 2023-05-07 14:54:22 | normal | System release |
| □AF14*** | Small new energy vehicle | export | 2023-05-07 14:53:56 | normal | System release |
| □A0Q*** | Small vehicle | export | 2023-05-07 14:53:43 | normal | System release |
| □ADW1*** | Small new energy vehicle | export | 2023-05-07 14:53:24 | normal | System release |
| □AN3*** | Small vehicle | entrance | 2023-05-07 14:53:07 | normal | System release |
| □Z53*** | Small vehicle | entrance | 2023-05-07 14:52:58 | normal | System release |
| □ADK*** | Small vehicle | export | 2023-05-07 14:52:15 | normal | System release |

Appendix Table 2 Example of parking access data

| License plate number | Identity | Arrival time | Departure time | Parking time |
|---|---|---|---|---|
| 川 A35*** | Temporary vehicle | 2023-05-07 12:56:30 | 2023-05-07 22:36:50 | 9 hours 40 minutes 20 seconds |
| 川 A7A*** | Free vehicle | 2023-05-07 12:08:32 | 2023-05-07 19:55:15 | 7 hours 46 minutes 43 seconds |
| 川 A3L*** | Temporary vehicle | 2023-05-07 12:37:04 | 2023-05-07 17:46:47 | 5 hours 9 minutes 43 seconds |
| 湘 AJ3*** | Temporary vehicle | 2023-05-07 12:56:39 | 2023-05-07 17:10:21 | 4 hours 13 minutes 42 seconds |
| 川 ADZ*** | Temporary vehicle | 2023-05-07 12:22:39 | 2023-05-07 16:10:16 | 3 hours 47 minutes 37 seconds |
| 粤 BX1*** | Temporary vehicle | 2023-05-07 12:49:21 | 2023-05-07 15:39:21 | 2 hours and 50 minutes |
| 川 A24*** | Temporary vehicle | 2023-05-07 12:50:33 | 2023-05-07 15:35:30 | 2 hours 44 minutes 57 seconds |

| | | | | |
|---|---|---|---|---|
| 川 AAP6*** | Free vehicle | 2023-05-07 12:08:40 | 2023-05-07 15:20:46 | 3 hours 12 minutes 6 seconds |
| 川 A86*** | Temporary vehicle | 2023-05-07 12:29:29 | 2023-05-07 15:07:56 | 2 hours 38 minutes 27 seconds |

Appendix Table 3 Comparison and analysis of two reservation modes

| **Reservation method** | **Description** | **Need other auxiliary technology or equipment** | **Advantages** | **Disadvantages** |
|---|---|---|---|---|
| Make an appointment to the parking lot | Only make an appointment to a specific parking lot | none | Convenience | The car owner did not know his parking position before entering the parking lot. |
| Make an appointment to the parking space | Make an appointment to the only parking space in the specific parking lot | Communication network, parking space guidance system or map, parking space number, parking lock, etc. | The car owner knows his parking position before entering the parking lot. | 1. It takes time to find the parking space. 2. It also requires the parking lot to have a perfect number and communication network. 3. It is better to have a parking space guidance system and map, which is expensive<br>4. If the only reserved parking space is likely to be occupied, further parking lock equipment is required to control it |

Appendix Table 4 Payment of reserved users

| 10: 30 appointment of user admission time | 10:00—11:00 | 11:00—— |
|---|---|---|
| Fees for users entering the parking lot at 10:00 | | |
| Fees for users entering the parking lot at 10:30 | | |
| Fees for users entering the parking lot at 11:00 | | |
| Legend | Booking fee | Parking fee |

Appendix Table 5 Design method of parking reservation overtime and early arrival process

| 10: Before 00 | 10:00—11:00 | After 11:00 |
|---|---|---|
| ←<br>Temporary vehicle | Reserved car | →<br>Temporary vehicle |