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Evaluation of Parking Guidance Information System with Multi-agent Based Simulation

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Qian LI

To
my family

Abstract

This D.Phil. thesis presents an agent-based approach to evaluate economic effect of parking guidance information (PGI) system by modeling drivers' behavior under different parking guidance scenarios: with PGI and without PGI. An agent-based model (ABM) is established to explicitly capture car following behavior, drivers parking space searching and decision behavior after received all various information. To explicitly capture and explore the PGI impact on drivers' parking choice behavior, RP data are collected and the experiments have been conducted in year 2012 and 2013. During the experiments, there are three types of displayed information – Null information (PGI shows no information), ASL information (PGI shows the number of available space and location) and ECF information (PGI shows occupancy status information as empty, congested and full). Drivers' behavior response to these three different types of displayed information are investigate for identify the main factors of choice model. It is suggested that that the walking distance factor significantly influence drivers' parking choice under the effect of all displayed type of information.

MNL model is applied to perform drivers' parking search process under different scenarios of with PGI (ECF information/ ASL information) and without PGI. And the estimated result of MNL model indicated that both the effect of ECF information and ASL information are significantly affect drivers parking choice behavior especially for the drivers who choose to park at block D to block I. Besides, the significance of variable of walking distance, dummy variable of occupancy information and variable of number of available space justify the hypothesis that drivers are sensitive to above three variables. A new framework of sequential parking choice model is also presented in this thesis. The presented sequential choice model offers an alternative to the traditional approach to estimate parking choice behavior especially given an assumption of no specific defined variable given in expected utility. Then the estimated result of MNL model is adopted in agent-based simulation process to perform drivers' parking choice behavior.

The applied part of thesis aims to evaluate the effectiveness of PGI system and partly bridge the gap between parking choice behavior model under PGI system and economic evaluation methodology, with application to Shimizu parking area located in the Shin-tomei expressway (Japan). The study may be regarded as one of the few studies to integrate multi-agents activities of parking choice process, Poisson distribution, GIS and a detailed traffic micro-simulation for economic evaluation of with and without PGI system. The simulation results of the number of lost agent, average searching time of all agents can be applied to evaluate the economic benefit of PGI system.

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1 Introduction

1.1 Background

1.1.1 Background of ITS

We live in a times filled with information, all kinds of information, entertainment, health care, education, recruitment, personal relationship, living, tourist, traffic and anything else that we have to do in our daily activities. In our life, we make decision from selecting a traffic mode for daily commute to applying a university for further education based on all these information. The ability of collecting, recognizing, managing, acquiring and exploring information decides if made a right decision from saving searching time for an empty space to heading to right direction for future life. Intelligent Transportation Systems (ITS) is an advanced communication, information and electronics technology to ease transportation problem like traffic jam, traffic safety, traffic conflict, transport efficiency and environmental conservation. ITS has been around since the 30s and it has been slowly creeping into our lives. The major developments on ITS were made in Europe, U.S. and Japan. Masaki (1998) divided the development process into three phases: preparation (1930~1980), feasibility study (1980~1995) and product development (1995~present).

After entering into 21st century, in Japan, many projects have been carried out, main efforts are focus on developing advanced systems and technologies such as Car Navigation System, VICS (Vehicle Information and Communication System), ETC (Electronic Toll Collection System), ASV(Advanced Safety Vehicle) and promote advanced products into market. The next goal for ITS in Japan is to achieve the mobility and reach the development of ITS in the long-term vision. The detail of development progress of ITS in Japan can be seen in the figure 1.1.

In Europe, in June 2001, the European Council proposed about 60 measures in the white paper of 'European transport policy for 2010: time to decide', aimed at developing a European transport system capable of shifting the balance between modes of transport, revitalizing the railways, promoting transport by sea and inland waterways and controlling the growth in air transport. From then on, many projects were carried out, for example, "eSafety Initiative", "Intelligent Car Initiative", "i2010" etc., and aimed at building a competitive transport system which will increase mobility, remove major barriers of fuel growth and employment in key areas, reduce Europe's dependence on imported oil and cut carbon emissions in transport.

In US, congress enacted the funding and authorization bill law, SAFETEA-LU (the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users) to improve and maintain the surface transportation infrastructure in the United States. After that, US continuous making effort in researching, prototyping, testing, evaluating, and transferring the next generation of ITS technology, and unveiled a new "ITS Strategic Research Plan, 2010~2014"(4) in January, 2010. Moreover, US regards to maximizing the effectiveness of real-time traffic information, ATMS (Advanced Transportation Management Systems), progressing on vehicle-to-infrastructure and vehicle-to-vehicle integration, such as IntelliDrive.

Combining with recent years' achievement in ITS made by Europe, US and Japan, and the three phases of ITS development process which Masaki summarized in 1998, the writer thinks ITS development process should be divided into four phases: preparation (1930~1980), feasibility study (1980~1995), product development and marketing promoting (1995~2010) and mobility and international standardization (2010~present).

As a result of advanced technology development in communication infrastructure that support vehicle-to- infrastructure as well as vehicle-to-vehicle by enabling tags or sensors, and integration with real-time traffic information. This kind of advanced transportation management system or advanced information system is widely applied in the highways, expressways, service area and so on to reduce congestion, enable traffic to flow more smoothly, reduce carbon emissions in transport, maximize the capacity of roadways and reducing the need to build a new one. How to maximize the effectiveness of real-time information system integrated with human behavior analysis, design and display of advanced devices is a critical problem which needs to be solved for meeting above purposes.

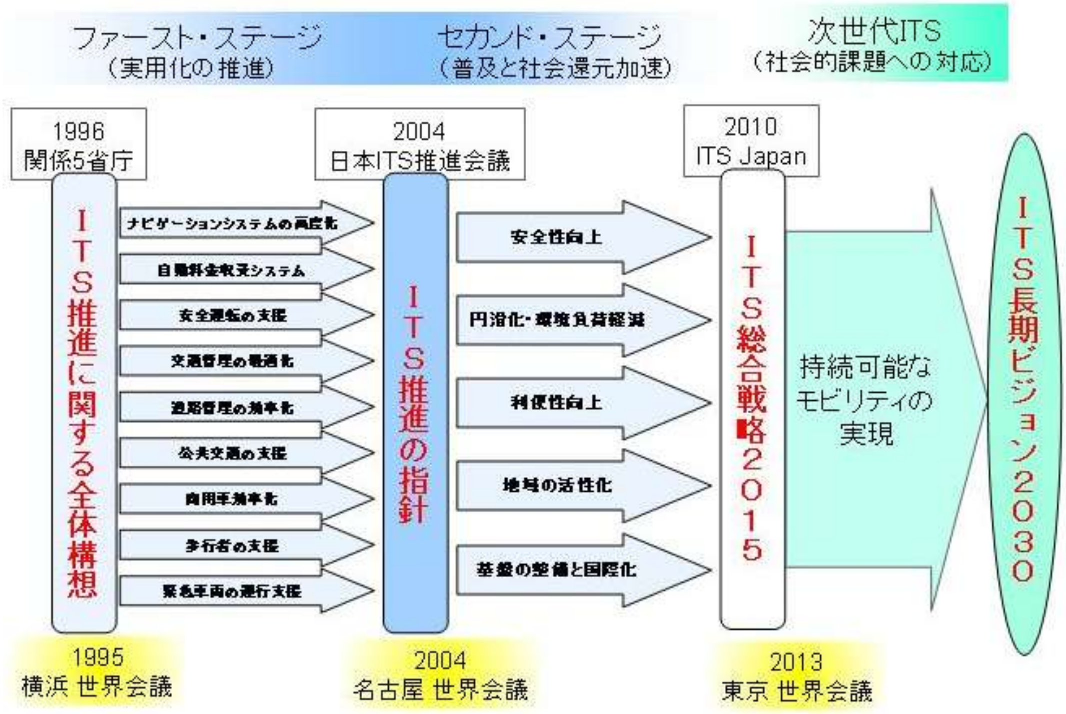

Figure 1.1: Development progress of ITS in Japan[2)]

1.1.2 Relationship between traffic information and driver response

In recent years, ITS combined the communication and information technologies to deliver the real-time information about traffic condition ahead such as accident, length of queuing vehicle, traffic congestion, speed limits and enable drivers to make more informed decision. Variable message sign (VMS) is an electronic traffic sign often used on roadways to provide above types of information. Moreover, VMS can also be applied with parking guidance information (PGI) system to guide driver to available car parking space. The success of PGI system or similar traffic navigation information system largely depends on driver response to the conveyed information. Therefore, it is essential to understand and describe drivers' decision making process under the effect of real-time traffic information.

There are two well-known methodologies for analyzing and exploring relationship between the real-time traffic information and drivers response: Revealed Preference (RP) and Stated preference (SP). RP, this concept is first described and defined by Samuelson (1938), and the initial terminology was "selected over"5). In the traffic field, Durand-Raucher (1993) and Kawashima (1991) conducted the study by applying RP approach. They analyzed driver behavior under the real situation based on drivers' actual trips record and observation of actual driver behavior through experiment studies in related field. SP is also referred as contingent valuation is first proposed by Ciriacy-Wantrup (1947) as a method to elicit market valuation of a non-market good. After that, it is also widely applied in the traffic field. Peeta (2000), Wardman (1997) and Ullman (1994) adopted the SP approach to analyze driver's behavior by presenting individuals with a series of hypothesis travel alternatives. SP data and survey is commonly used in analyzing drivers' route choice behavior under real-time traffic information or transportation mode choice. The most common method to conducting traffic survey are residence-based telephone, mail-back and on-site surveys.

In this thesis, RP data is adopted by using the combination of advanced technology of communicating between magnetic field sensor and variable message signs. RP data, reflecting parking choice actually made in the actual environment. Because of the advanced technology of communicating between magnetic field sensor located at each space and variable message signs in the parking area, the data of arrival time and departure time of each vehicle parked at each space, and the time of changing information and the content of information on each VMS can be collected and used in this research.

In the chapter 3, drivers' response to the different types of displayed information have been investigated by applying the advanced technology in the study area and thousands data deeply analyzing. To compare and optimize factors affecting understandability of PGI, the multiple experiments were conducted in the same study area, 1) drivers' response under null parking guidance information; 2) drivers' response under parking guidance information of showing parking status of empty, congest and full (ECF) on information signs of each block; 3) drivers' response under parking guidance information of showing parking status of available space and location (ASL) on information signs of each block. In the chapter 4, the discrete choice model is established to perform drivers' parking choice behavior under different scenarios of without parking guidance information and with parking guidance information.

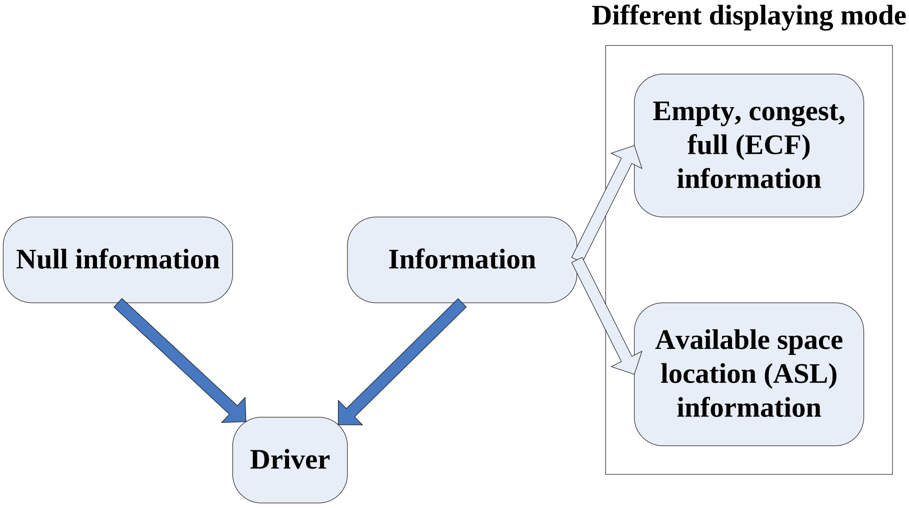

Figure 1.2: The relationship between driver and parking guidance information

1.1.3 Use agent-based modeling to evaluate traffic information

Before to explain the reason of why adopting agent-based modeling as an approach to evaluate the PGI system and model drivers parking choice behavior, this section first briefly introduces the basics of agent-based modeling and application. Michael and Charles (2007) stated that agents are the decision-making components in complex adaptive systems. Agents have sets of rules or behavior patterns that allow them to take in information, process the inputs, and then effect changes in the outside environment. Agent systems are known as the operation of agents which supported and managed by distributed software platforms. Bo and Harry (2010) explained that multiagent systems (MASs) generally refers to systems provide mechanism for agent management, agent communication, agent interaction, and agent directory maintenance. For performing the intelligent behavior of agent, there are various software platforms and programming languages to support agent-based modeling simulation. The most and commonly used ABM platforms are Swarm in Objective-C, Java Swarm, MASON in Java, NetLogo in its own programming language, Repast Java, AnyLogic in Java, Repast HPC in C++ and Repast Simphony.

In recent years, agent-based modeling simulation widely applied in the traffic and transportation systems. Agents could represent drivers, vehicles, signals, cities, blocks, households, sensors, pedestrians, or other traffic participants who are explicitly presented as active, heterogeneous entities in an environment such as road network, service area and other kind of environment. Under such environment, agent exhibit arbitrary complex information processing and decision making. Their behavior especially which can result in simulated movement, can be visualized, monitored, and validated at individual level, leading to new possibility for analyzing, exploring and illustrating traffic phenomena. A general introduction for easily understanding the concept of agent-based model simulation can be found in Epstein (2007), Gilbert (2007), Klugl and Bazzan (2012).

Though many studies have been reported to adopt agent-based model approach to traffic and transportation systems for modeling and simulation individual's behavior or a unit's behavior under specific environment, there is still very few studies to apply agent-based model approach for modeling individual's or unit's behavior under the environment of road network or service area and then to evaluate or measure the effectiveness of traffic systems such as navigation information systems in the environment. Jiaqi et al. (2012) adopted agent-based modeling simulation approach to model and simulate the traffic system of one-lane highway and a single intersection, with and without Cooperative adaptive cruise control (CACC) technology. But the factor of complicated driver behavior and drivers' interaction were not considered in the research of Jiaqi et al. (2012). Application in other field, Spencer and Scott (2008) evaluated the impact of different emergency department (ED) physician schedules on the time patients wait for their initial physician evaluation. They also presented the details relating to the construction of their modeling tool and evaluated whether or not modeling tool is accurate for modeling waiting times.

In this thesis, from the parking guidance information (PGI) system management perspective, agents can be applied to represent the characteristics of drivers which are autonomy, collaboration, reactivity and intelligent. Agent can operate without direct intervention of humans and other. Besides, in some extent, agents' activity reflects its own will and can represent the random and variety of drivers in the real world. This feature helps to implement the management system contain automated drivers and PGI system. Based on feature of agent which is described above, we applied agent-based modeling as an evaluation approach to model drivers' parking choice behavior under the system with and without PGI. For the cases of with PGI system and without PGI system, from an individual view, agents' parking choice behavior follows different parking choice model which can reflect drivers' feature of intelligent, interactive, random, variety and so on. In addition, after simulated a set of agents parking choice behavior of with and without PGI system, each individual agent's searching time, lost agent number can be quantified and summarized as evaluation index to measure whether the time cost (searching time) is reduced or the economic effect (lost agent) is positive by comparing the result from two agent-based modeling simulation of with PGI and without PGI. Moreover, the comparison result can also be used to justify whether setting PGI system is necessary and the improvement effect.

1.2 Research aim

As mentioned at the end of section 1.1.1, maximizing the effectiveness of real-time information system is a key issue which is need to be solved for achieving the goal of reducing congestion, reducing carbon emission, enabling traffic to flow more smoothly and other benefits. This thesis presents an economic evaluation of a parking guidance information system. To maximize the effectiveness of real-time parking guidance information system, we need to firstly collect information on drivers' parking choice behavior in response to dynamic PGI signs in the service area. Then, we need to analyze and find out how the drivers response to the information shown on dynamic PGI signs and developed suitable parking choice model which can predict and describe drivers' behavior properly under the influence of different types of dynamic PGI signs. Moreover, incorporate the parking choice model in agent-based model simulation to study the benefits of using PGI system.

This thesis develops a new agent-based simulation model to evaluate the economic effect of parking guidance information system by comparing and simulating the drivers' behavior with and without the influence of PGI system. In the practical level, this new measure method is applied in a case study, and also the flexibility of this new methodology has been discussed. Based on above analysis, the aims of this thesis can be separated as two parts, both theoretical level and practical level.

1.2.1 Aim at theoretical level

The main aims of the theoretical part of this research are:

- Compare and analyze drivers' behavior response under the influence of different scenarios of with PGI and without PGI. For the scenario of with PGI there are two types of displayed information – ECF information and ASL information. For the scenario of without PGI, there is only one type of displayed information – Null information.
- Based on data and behavior analysis result, summarize the attributes or factors which are more likely to affect drivers' parking choice behavior.
- The development of model structure follows the traditional random choice process and the s the dynamic transition probability of sequential activities process.
- The development of a framework for sequential parking choice model
- The study of agent-based model (ABM) simulation applied in the evaluation of PGI system by developing two projects of with PGI and without PGI; Economic evaluation results of "Lost Agent" and "Searching Time" are not traditional economic evaluation indexes, but still can be applied to measure the economic effects of PGI system.

1.2.2 Aim at practical level

The main aims of applied part of this research are:

- Build the databases of parking choice behavior under the influence of PGI system which is provided for analyzing the impact of PGI system on drivers parking behavior and identify what displayed type significantly influence drivers parking behavior.
- Estimate the parameter of multi-nominal discrete choice model of with PGI and without PGI and use the parameter estimation result into multi-agent simulation.
- The development of a framework and simulation for the joint modeling of the multinomial discrete parking choice model in a parking area with multi-agent model, queuing theory and GIS.
- The development of framework and simulation for the joint modeling of sequential parking choice model with PGI and without PGI in a parking area with multi-agent model, queuing theory and GIS.
- Evaluate the economic effectiveness of PGI system by compare the multi-agent simulation results of developing two Repast projects of with PGI and without PGI. Multi-nominal parking choice model is adopted to perform drivers' parking choice behavior in the two projects.

1.3 Outline of the thesis

To give a general overview of the structure of this thesis, the main contents which presented in each chapter are shown in the follow:

- Chapter 2 – presents a review of economic evaluation of information systems through the aspects of: 1) review on the impacts of traffic information on drivers' behavior; 2) review on modeling drivers' behavior under the effect of information system; 3) review on economic evaluation of traffic information system. In the section 2.4, after the review of existing work, we discuss the reason and feasibility of adopting agent-based model simulation as economic evaluation approach.
- Chapter 3 – analyzes the effect of PGI system on drivers' behavior through the aspects: 1) whether or not consider the observed individual parking route data; 2) parking guidance information displayed types –providing occupancy status of each block as showing Empty, Congest and Full (ECF) information and showing number of available space and location (ASL) information of each block by PGI signs.
- Chapter 4 – models driver behavior by adopting multi-nominal discrete choice model under the effect of without PGI (null information) and with PGI (ECF information and ASL information).
- Chapter 5 – presents a framework of drivers' sequential parking choice behavior model.
- Chapter 6 – adopts multi-agent modeling simulation methodology to evaluate the effectiveness of PGI by developing agent-based model simulation of with PGI and without PGI. Estimated result of number of lost agent and average searching time are used and seen as two economic indexes to evaluate and measure the effectiveness of PGI system.
- Chapter 7 – conclusions.

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2 Literature review on economic evaluation of information system

2.1 Introduction

The review presented in this chapter is separated into three parts: 1) review on effect of traffic information system on drivers' behavior, see section 2.2; 2) review on economic evaluation of information system, see section 2.3; 3) review on economic evaluation of traffic information system, see section 2.4. In the section 2.4, after the review of former research of applying general methodology in the economic evaluation of traffic information system, we discuss the reason of adopting agent-based model simulation methodology as a solution for economic evaluation in this thesis.

2.2 Review on traffic information on drivers' behavioral impacts

Drivers' behavioral change related with the provision of traffic information. Many existed studies give us a variety of insights into the impact of the provision of various types of information (route navigation, parking guidance, descriptive information, etc.) spread by varied types of media (internet, text-message, car navigation, Variable Message Signs, dynamic parking guidance signs, Smartphone, etc.) on multiple choices (departure time, parking space, travel route or mode, etc.) in some travel situations (pre- or in-trip, business trip, recreational trip, rest break, etc.). Many travel demand studies either explicitly or implicitly frame a traveler's decision to acquire travel information and/or to change behavior as a result of acquired information as a cost-benefit decision. Schofer et al. (1993) dicussed key behavioral issues in the evaluation of traveler responses to in-vehicle information systems by conducting stated preference methods and observation of revealed behavior in laboratory simulations and field tests with various degrees of control and complexity. Bonsall (2001) discussed what type of uncertainties likely to afflict traveler and under in which circumstances they are likely be affected. Yang and Meng (2001) determined the saturation market penetration level and the time path of growth to reach stationary equilibrium by the information benefit derived from ATIS and ATIS service charge. Golledge (2002) presented comments on both demand and supply areas of behavioral travel modeling based on key aspects of ITS dynamics advanced traveler information system. Khattak et al. (2003) explicated the effect of information attributes, individual characteristics and travel context on individuals' use of and willingness to pay for travel information by estimating a random-effects negative binomial regression model. Denant-Boèmont and Petiot (2003) applied experimental method to observe information value in dynamic choice setting by focusing on sequential transport choice in a context of increasing information by comparing two information messages which are offered one after the other and the second giving more information. Srinivasan and Mahmassani (2003) proposed the dynamic kernel logit (DKL) framework and applied it to model route-switching dynamic based on data from interactive simulator experiments for observing effects in route switching dynamics under advanced traveler information systems (ATIS). Sun et al. (2005) conducted numerical simulation to illustrate the system and to derive theoretical implication from the model which represented the impact of information and decisions on the full activity-travel pattern. Arentze and Timmermans (2005a) formulated and developed a more general theory and model for the trip choice under conditions of uncertainty and learning based on a Bayesian model of mental maps and belief updating. Chorus et al. (2006a) presents a review of contemporary conceptual ideas and empirical findings on the use of travel information and their effects on travelers' choices, besides, integrates behavioral determinants such as the role of decision strategies with manifest determinants such as trip contexts and socio-economic variables into a coherent framework of information acquisition and its effect on travelers' perceptions.

2.3 Review on modeling drivers' behavior under effect of information system

Since the first automotive navigation system has been created at the earliest of 80s, many researchers have studied the drivers' response and choice behavior under different type's real-time information, such as variable message signs, radio traffic information (Richard 1996), or under special case, traffic congestion situation, or congested in a traffic corridor (Moshe 1992; Hani 1991). The empirical analysis will first collect data by conducting survey, mail survey, telephone survey, questionnaire and other survey method, and then summarize the factors which are more likely to influence drivers' behavior applying binary Logit model, multinomial Logit model on the basis of discrete choice model. Caplice and Mahmassani (1992) applied binary Logit model to explain different commuters' response and listening propensity to radio traffic report based on survey data. Khattak et al. (1993) analyzed drivers' diversion and return choices related with the implementation of Road Transport Information (RTI). Khandker (2009) presented a joint discrete-continuous model by adopting a multinomial Logit model for mode choice and a continuous time hazard model for trip timing, allows for unrestricted correlation between the unobserved factors influencing these two decisions.

Some researchers focus on applying advanced data, the data is divided into two types –stated preference (SP) data and revealed preference (RP) data. The approach of obtaining above two types of data including: mail survey, telephone survey and other surveys of field survey, interactive route choice simulators, and so on. Yang (1993) applied neural network concept to model drivers' route choice under advanced in Road Transport Information (RTI) environment based on data collected from learning experiment using interactive computer simulation. Mohamed A. Abdel-aty, Ryuichi Kitamura, Paul P. Jovanis (1997) model commuters' route choice applied binary Logit model include the effect of traffic information by utilizing data collected from two stated preference survey techniques. They found that both expected travel time and variation in travel time influence route choice. Peter Bonsall. Ian Palmer (2004) analyzed the effect of PGI information on route choice and car park choice of variables such as price, walking time and drive distance from data collected using the PARKIT parking choice simulator to simulate the drivers' decision making process. And they found out the initial expectation of probable wait time has a significant influence, besides, PGI has more influence on females' than males' expectation. Eran(2008) analyzed the combined effects of information and experience on route choice decisions in a simulated environment by conducting an experiment under advanced travel information system(ATIS).

Other researcher efforts focus on the model methodology to analyze driver's route choice behavior under information effect. Kiyoshi Kobayashi (1990) presented a framework for traffic equilibrium with incomplete information and developed route choice model under incomplete information by applying rational expectation equilibrium. Jou (2001) formulated a joint model for route and departure time decisions with and without pre-trip information based on Probit model form. BJ Waterson (2001) developed driver parking choice models (both during the journey and pre–trip) and the implementation of these models in the existing network traffic simulation model RGCONTRAM, then quantified the effects of the PGI system on both the drivers seeking available parking spaces and the parking stall itself. Russel G. Thompson (2001) presented a behavioral model of parking choice incorporating drivers perceptions of waiting times at car parks based on PGI signs. Srinivas Peeta and Jeong W. Yu (2004) proposed a seamless framework to incorporate the day-to-day and within-day dynamic of driver route choice decisions under real-time information provision by adapting a hybrid probabilistic-possibilistic model. Their study explained Hybrid route choice model can be applied to capture driver behavior dynamics, and the associated prediction accuracy such as the phenomena of inertia, compliance, delusion, freezing, and perception update under information provision.

2.4 Review on economic evaluation of traffic information system

2.4.1 Existing work

Generally, many researches are conducted related to impact evaluation for traffic navigation information through the aspects of system function and operation function, the main approaches and methodology are: 1) identify the impact of traffic navigation information and their improvement of related traffic situation, 2) identify the effect of traffic navigation information on users and their influence on individual cost; 3) identify the impact of traffic navigation information and their improvement on environmental consideration. Academic researchers think the identification of benefits is the key content of impact evaluation for traffic information system. The benefit of its impact and influence of traffic information system are shown after application, and then economic evaluation of traffic information system should be based on the technology evaluation and stress to identify its direct and indirect benefit.

In the many former researches, though the research are different widely in the adopted methodology or approach, applied theory and description of choice-strategies but in common of using the information system for alternative generation or assessment. And the main purpose is to frame such process under the effect of traffic information system as a cost-benefit decision and achieve the goal of maximization of benefits or explore or evaluate behavior process under certain information system to meet such goal. The costs of information acquisition are a function of price and usability of the information service and characteristics of travel situation. That may refer to a great number of tangible and intangible costs, such as monetary costs, time, effort, irritation, attention and the risk of forgoing and already found alternative. Such researches can be proved above statement. Simon (1978a) gave a clue that economics tends to emphasize a particular form of rationality – maximizing behavior. Other researches which illustrated the above statement can also be found in Weibull (1978), Shugan (1980) and Richardson (1982).

The economic evaluation of traffic information system mainly include the approach of field investigation, mathematic statistic method, cost-benefit analysis method, simulation method, system approach and networks analysis approach etc. Tarry and Graham (1995) evaluated the benefit of VMS system by adopting field investigation approach as a case study of freeway in Britain. Sengupta and Hongola (1998) examined the potential benefits of travel time saving of applying ATIS by establishing relationship between traffic management variables. Juan Zhicai (2001) evaluated the socio-economic impacts of ITS by combining the cost-benefit analysis method, AHP (Analytical Hierarchy Process) and DEA (Data Envelopment Analysis). Jinan Piao (2001) evaluated the effect of VMS by adopting the approaches of network modeling and field measurements, and found that incident severity, incident location, incident duration, VMS duration and traffic demands can influence the effects of VMS significantly. Except above mentioned approach, with the developing of platform and programming language of agent-based modeling simulation, more and more researchers attempted to adopt this approach in the field of transportation analysis.

2.4.2 Agent-based modeling simulation as a solution

Traffic information system plays a significant influence in drivers' decision making process aim at guiding user to a less congested route from the economic view. Many researchers focused on evaluating the information system from the economic view or environmental view. It means they have to tackle two main problems: how to describe drivers' behavior under the effect of information system; and which methodology can be applied to evaluate the information system. Kiyoshi(1995) measured the economic values of information systems for route navigation by adopting rational expectations equilibrium to describe drivers' behavior and three kinds of information systems are compared by using two economic benefit evaluation methodologies, expected consumer surplus and option price. Other researchers evaluated the effect of information system from the view of cost benefit performing analysis (Iris, 1994; Aristotelis, 2004; Yang, 2008). Ericsson (2006) measured the economic values of real-time information system from the environment view who presented a methodology in analyzing the potential for reducing fuel consumption and thus the emission of CO_2 for real time information from probe vehicles.

A number of writers have evaluated the effect of information system in route navigation and developed related choice model. Felix Caicedo (2010) developed a demand assignment model to evaluate the benefits of manipulating information with the objective of reducing the time and distance involved in finding a parking place; including the walking distance involved. Bekhor (2006) evaluated the effectiveness of Advanced Traveler Information System (ATIS) by discussing choice set generation and route choice model estimation for large-scale urban networks in Boston.

Recent years, many researchers making effort on applying Agent-based modeling and simulation into the field of transportation as a microscopic simulation approach to modeling complicated system. For exploring route choice behavior under traveler information, Meignan (2007) presented a bus network simulation tool and adopt a multi-agent approach to describe the global system operation as behaviors of numerous autonomous entities such as buses and travelers. For route navigation in the field of transport, the application of agent-based modeling (ABM) can be classified into four categories.

First, evaluate parking policies and land use with agent-based model of parking process. Such as, Benenson (2008) presented an agent-based model – PARKAGENT to simulate the behavior of each driver in a spatially explicit environment for exploring the impact of additional parking supply in a residential area with a shortage of parking places. Dieussaert (2009) provided an agent-based modeling simulation tool which can be applied in parking policy to simulate the local parking situation in changed circumstances.

Second, ABM is cooperated with transportation management or traffic assignment to improve traffic congestion problem. For example, Adler (2002) proposed an approach to manage roadway network congestion problem based on cooperative multi-agent-based principled negotiation between agents which represent network manager, information service providers and drivers equipped with route guidance systems. Logi (2002) described a new multi-agent modeling simulation approach to automatic decision support to Traffic Operations Center operators for multi-jurisdictional management of incidents on integrated freeway and arterial networks. Martens (2010) proposed a non-spatial model of parking search and an explicit geosimulation model of the parking process called PARKAGENT and compared the above two models' outcome to analyze the phenomena of cruising for parking. Lin (2008) developed a conceptual framework and explored practical integration of activity-based modeling and dynamic traffic assignment. Caicedo(2009) explored the advantages and the potential available to a parking facility operators from manipulating the information received from the PARC system.

Third, quantify the environmental cost with ABM of parking search process which can be found in the following researches. Oscar (2010) formalized and parameterized a detailed milti-agent model for production of transport fuels and fuels bends to improve traditional least-cost optimization models. Liya (2013) developed a novel agent-based transportation model of a university campus focus on vehicle-related travel and the explicitly associated parking search process and quantified the environment cost of wasted fuel and increased emissions. Felix (2010) developed a demand assignment model to evaluate the benefits of manipulating information with the objective of reducing the time and distances involved in finding a parking-place; including the walking distances involved.

Fourth, assess drivers' decision making process by presenting an agent-based modeling framework. Rossetti (2000) presented an agent-based model of DRACULA to represent the uncertainty of human behavior. Waraich (2012) represent an agent-based model which focus on parking choice and capture individual valuation of time and differences in taste.

Traffic and transportation systems consist of many autonomous and intelligent entities, such as man-driven vehicles, signal lights, and variable information signs, Agent-based modeling provided a suitable way to model and simulation traffic system since they offer an intuitive way to describe every autonomous entity on the individual level. It is a sophisticated task to determine the strategic activity drivers' route choice behavior and information navigation system which can be solved by agent-based modeling simulation. It is an extension to assess the effect of traffic information system on drivers' choice behavior by applying such approach. Combining with field investigation, mathematic statistic method, effect of parking guidance information analysis, and road networks analysis, agent-behavior parameters can be determined and defined in the drivers' behavior model interface of agent-based modeling simulation. In addition, the strategic layer describe drivers response to the dynamic information on traffic system by applied the analysis result of effect of traffic information system, the movement of individual agent and result can be simulated by agent-based modeling simulation approach. Moreover, the evaluation can be conducted based on the result of individual agent's response to different dynamic information systems.

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3 Information effect on drivers' parking choice behavior

3.1 Introduction

3.1.1 Approach to analyze behavioral impacts of variable parking guidance information

To provide an insight into how drivers response to real-time traffic information, generally, there are two approaches: Revealed Preference (RP) and Stated Preference (SP). RP data, reflecting actual drivers' choice under the real-time information based upon diaries of actual trips reports in the field studies. Studies based on RP data can be found in the following researches. Emmerink et al. (1996) analyzed the impact of both radio traffic information and variable message sign information on route choice behavior based on an extensive survey held among road users by adopting data from the EC drive II project BATT. Polydoropoulou and Ben-Akiva (1998) explored the complex mechanisms governing users' response to the provision of advanced traveler information system (ATIS) traffic information. Hato et al. (1999) explicated driver behavior in acquiring and using traffic information in an environment with multiple sources of information, the RP data on driver behavior were collected and used in model validation. Chatterjee and McDonald (2004) analyzed drivers' reactions to VMS and the impacts of VMS on road network efficiency and results are reported for four different types of traffic information: incident messages, route guidance information, continuous information describing the traffic state on a major route, and travel time information.

Though SP data (including data from travel simulators), questionnaires have been conducted to study drivers response with information by giving a series hypothetical scenarios to be evaluated. In the recent studies, SP approach has been extensively applied in the empirical research. Khattak et al. (1993) examined short-term commuter response to unexpected (incident-induced) congestion and investigated factors which may influence diversion from the regular route and return to the regular route after diversion. Chen and Mahmassani (1993) examined the behavioral processes underlying commuter decisions on route diversions en route and day-to-day departure time and route choices as influenced of the provision of real-time traffic information by conducting a set of new simulator experiments. Koutsopoulos et al. (1994) described a PC-based driving simulator for collecting relevant data in a controlled environment and calibrated a new class of route choice model in the presence of information base on fuzzy concepts. Bonsall and Palmer (2004) discussed the incorporation of choice models into a network assignment model from data collected by using the PARKIT parking choice simulator which can provide an experimental environment in drivers' choice under the influence of different levels of parking-stock knowledge monitoring.

In this thesis, instead of conducting questionnaire surveys or simulator experiments, we adopted the RP data by using the combination of advanced technology of communicating between magnetic field sensor and variable message signs. RP data, reflecting parking choice actually made in the actual environment. Arrival time and departure time of each vehicle parked at each space, and the time of changing information and the content of information on each VMS can be obtained according to the advanced technology of communicating between magnetic field sensor located at each space and variable message signs in the parking area. Then, we can estimated the time each driver enter into the parking area and what content shown on the VMS the driver could be received and influenced the final parked space. To explicitly understand drivers' parking behavior under real-time parking guidance information, the experiment can be divided into two parts. First part of experiment is to explore drivers' response (final parked space) to VMS in a parking area environment without knowing each driver's parking route. Second part of experiment is to explore drivers' response to VMS in a parking area environment with knowing each driver's parking route.

3.1.2 Experiments design

Takayuki and Yamamoto (2012) presented the evaluation of applying magnetic field sensor into vehicle detection in the Shimizu Parking area. Based on the advanced magnetic field sensor, the vehicle detection result of each space can feedback to the PGI system, then the occupancy status of each space can be summarized and shown on each information board. As mentioned above, in this thesis, SP data is adopted for explicitly explore drivers' parking behavior response to VMS. And two periods experiments were conducted during the year 2012 and 2013. Then the following part is the introduction of the detail and aims of two parts of experiment.

The first part of experiment can be divided into two periods: 1)14th April 2012 ~ 14th June 2012; 2) ^{7th} September 2012 ~ 19th September 2012. And over 200 thousands driver, total sample number N=239037 were recorded during the above two periods. After eliminating the sample date of 14th April 2012, 14th June 2012, 7th September 2012 and 19th September 2012 which recorded hours is not 24 hours, the total sample number is N=233269. For this part, it is assumed under perfect information that all the drivers received information of all alternatives just after they entering into the parking area, and then make a parking decision. For considering one information display type, the empty, congested and full (ECF) information, since the Shin-tomei expressway (where Shimizu parking area located in) is begun to use with the open of road link on 14th April 2012, to give enough time for the study area to be well known and increase traffic volume, we use the sample data of 7th September 2012 ~ 19th September 2012 in the second period of first part experiment for analyzing the effect of (ECF) information on drivers' final destination without receiving the parking route data. The analysis for the first part of experiment aim at founding some characteristics such as arrival peak date, arrival peak hour, arrival time distribution, parking duration time distribution, departure time distribution, and the effect of dynamic parking guidance information provide each block's occupancy status of empty, congested and full under the situation of without knowing the drivers' parking route, and only acquiring the data of their final parked space.

The second part of experiment can also be divided into two periods: 1) 9th June 2013 (9:00 ~ 15:00), and total sample number N=672; 2) 23rd June 2013 (9:00 ~ 16:00), and total sample number N=879. For this part, we also give an assumption it is perfect information, but according to the additional parking route sample data, drivers' behavior probability be influenced by not only one variable parking guidance message sign which can be seen just after entering into the parking area. To analyze the effect of different display types of PGI system on drivers' parking route and the destination of parked space, the second part experiment were conducted under the guidance of three different types of display: 1) express the occupancy status of each block by showing the empty, congested and full (ECF) information; 2) express the occupancy status of each block by showing the number of available space and location (ASL) information; 3) null (Null) information. On the 9th June, the experiment was conducted from 9:00 ~ 15:00, visual parking guidance information signs showed the occupancy status of each block by showing the empty, congested and full (ECF) information, see figure 3.5; On the 23rd June, the experiment was conducted from 9:00 to 16:00, for time of 9:00 ~ 10:00, 13:00 ~ 14:00 and 15:00 ~ 16:00 , visual parking guidance information signs showed null (Null) information, see figure 3.6; for time 10:00 ~ 13:00, visual parking guidance information signs showed the occupancy status of each block by showing the number of available space and location (ASL) information, see figure 3.7; for time 14:00 ~15:00, visual parking guidance information signs showed the occupancy status of each block by showing the empty, congested and full (ECF) information, see figure 3.5. The analysis of the second part of the experiment is aim at founding the effect of different types of display of parking guidance information on drivers' destination of parked space, parking route, and then determining the main factors which affect drivers' parking behavior obviously. And the result will help to determine the variable of parking choice model in the next chapter. The thesis presented the findings of the study and discussed the implication of these finding for further work in Japan and other study sites.

3.1.3 Outline of this chapter

In this chapter, firstly generally introduce the background of case study area, parking guidance information (PGI) system, and the research area, the outline of this chapter. In the section 3.3, describe the available data sample, experiment for collecting RP data, and how to match the individual parking data, route data with guidance information data, summarized data bases. In the section 3.4, data has been analyzed through the aspects of arrival frequency, occupancy rate, parking choice probability based on the total data bases. In the section 3.5, the detail of displayed type of main dynamic parking guidance information signs are described and showing guidance content on PGI signs are also listed and categorized in this part. In the section 3.6, without matching with observed individual parking route data, drivers parking choice behavior under the effect of both ECF information and ASL information are explored though the functional view of different PGI signs. In the section 3.7, firstly the significance of walking distance factor on drivers' parking choice behavior is analyzed. And then to explicitly explore the impact of both ECF information and ASL information on drivers parking choice behavior, the further analysis is conducted after considered the characteristics of observed result of individual parking route data and weakened the influence of walking distance factor.

3.2 Background of Shimizu parking area

3.2.1 Case study site description

The study area is Shimizu parking area located in the Shin-tomei expressway, operated by Central Nippon Expressway Company of Japan which is begun to use with the open of road link between Mikkabi JCT (Junction) and Gotemba JCT (Junction) on 14th April 2012 see Figure3.1. The upstream of Shimizu parking area is for the drivers who are heading to Tokyo direction. The downstream of Shimizu parking area is for the drivers who are heading to Nagoya direction. The map of Shimizu parking area is shown in the figure 3.2. The spaces are classified into large-size vehicle space, small-size vehicle space, both of small and large size vehicle space, bus space, handicap space for disable person. There are total 18 guidance information boards in the Shimizu parking area, and 12 guidance information boards in the upstream of Shimizu parking area, 6 guidance information boards in the downstream of Shimizu parking area. Moreover, there are total 25 blocks in the parking area including all types of parking spaces. The location of all guidance information boards and the blocks are shown in the figure 3.3. The research object in this paper is upstream of Shimizu parking, in another word, drivers who are heading to Tokyo direction.

Figure 3.1: Location of new open road link and Shimizu PA

Figure 3.2: Map of Shimizu parking area

3.2.2 Parking guidance information (PGI) system

In the study area of Shimizu parking area, sensors were set up at each space which can sense whether the space is occupied or not and record the type of vehicle, arrival time and departure time of each vehicle, then feedback to the PGI system. PGI system collected the dynamic result of each sensor and display on the message signs dynamically. Figure 3.3 shows the location and display means of each information board in the Shimizu parking area and the location of each parking row which we define as parking block. Table 3.1 shows the list of each parking guidance boards and the location numbers are corresponding with the location numbers in the figure 3.3. Table 3.2 and 3.3 shows the detail of each block of upstream and downstream of Shimizu parking area respectively and corresponding with the location numbers in the figure 3.3

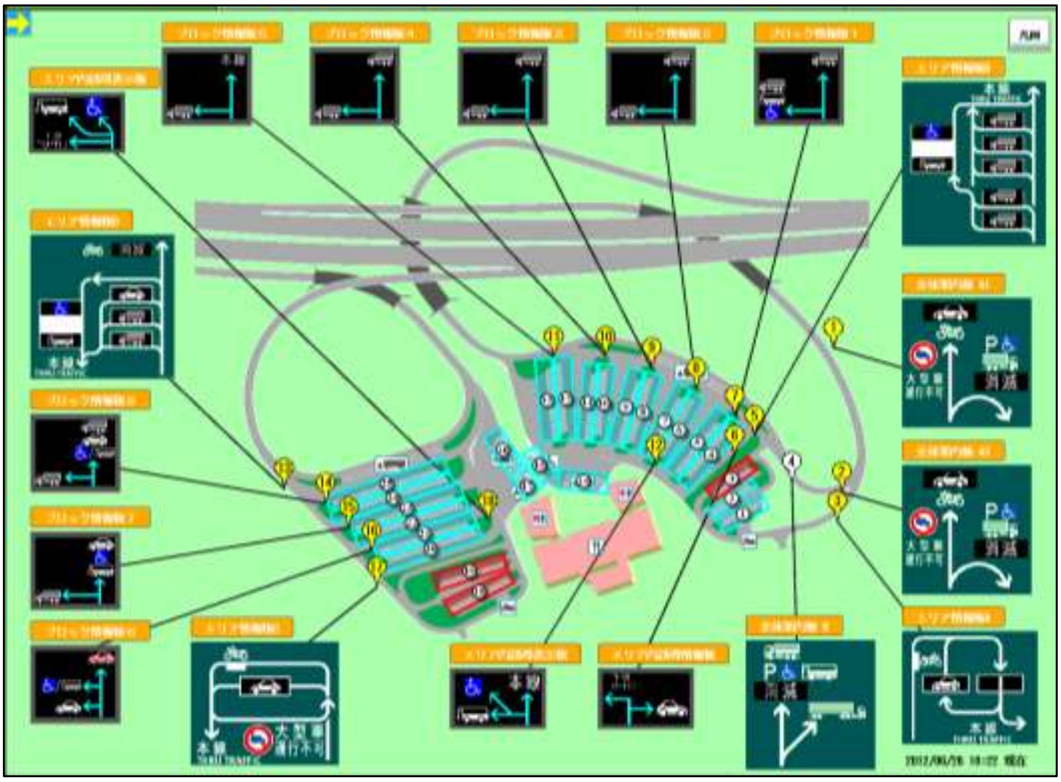


Figure 3.3: The location of all the guidance information boards in the Shimizu parking area

Table 3.1: List of parking guidance information boards

No.	Name	Location in Fig.2.3	Direction
1	Entire board A1	1	
2	Entire board A2	2	
3	Parking area information board A	3	Upstream
4	Entire board B	4	
5	Parking area information board B	5	
6	Parking area guide board	6	

7	Block information board 1	7	
8	Block information board 2	8	
9	Block information board 3	9	
10	Block information board 4	10	
11	Block information board 5	11	
12	Parking area guide board	12	
13	Parking area information board D	13	Downstream
14	Block information board 8	14	
15	Block information board 7	15	
16	Block information board 6	16	
17	Parking area information board C	17	
18	Parking area guide board	18	

Table 3.2: The detail of parking block of upstream

ID	Name	Type of vehicle	Number of space	Direction	Location in Fig.1.4
1	A block	Small	12	upstream	1
2	B block	small	13		2
3	C block	small	12		3
4	D block	both	12		4
5	E block	Both	12		5
6	F block	both	12		6
7	G block	both	12		7
8	H block	both	12		8
9	I block	both	12		9
10	J block	large	12		10
11	K block	large	12		11
12	L block	large	13		12
13	M block	large	13		13
14	N block	bus	8		14
15	O block	Handicap	3		15
Total			170		

Table 3.3: The detail of parking block of downstream

ID	Name	Type of vehicle	Number of space	Direction	Location in Fig.1.4
1	A block	small	18	Downstream	18
2	B block	small	18		19
3	C block	both	20		20
4	D block	both	20		21
5	E block	both	22		22

6	F block	both	22	23
7	G block	large	24	24
8	H block	large	24	25
9	I block	bus	8	16
10	J block	Handicap	3	17
Total			179	

3.2.3 Research area

To simplified the study area and investigate the drivers' parking behavior deeply in the limited time, in this thesis, we only focus on the upstream (drivers who heading to Tokyo) of Shimizu parking area as case study area. And the upstream of Shimizu parking area and the location of dynamic parking guidance information signs is shown in the figure 3.4. As described in the former section, the experiment can be divided into two parts. The first part was conducting during two periods: 1)14th April 2012 ~ 14th June 2012; 2) 7th September 2012 ~ 19th September 2012. And, the parking guidance information during the above periods was only displayed in one style, as shown in the figure 3.5. The second part was conducting during two periods: 1) 9th June 2013 (9:00 ~ 15:00); 2) 23rd June 2013 (9:00 ~ 16:00). And the parking guidance information during the period of 9th June 2013 (9:00 ~ 15:00) was only displayed in one style, as shown in the figure 3.5; the parking guidance information during the period of 23rd June 2013 (9:00 ~ 10:00, 13:00 ~ 14:00, 15:00 ~ 16:00) was displayed in the style as shown in the figure 3.6; the parking guidance information during the period of 23rd June (10:00 ~ 13:00) was displayed in the styled as shown in the figure 3.7; the parking guidance information during the period of 23rd June 2013 (14:00 ~ 15:00) was displayed in the style as also shown in the figure 3.5.

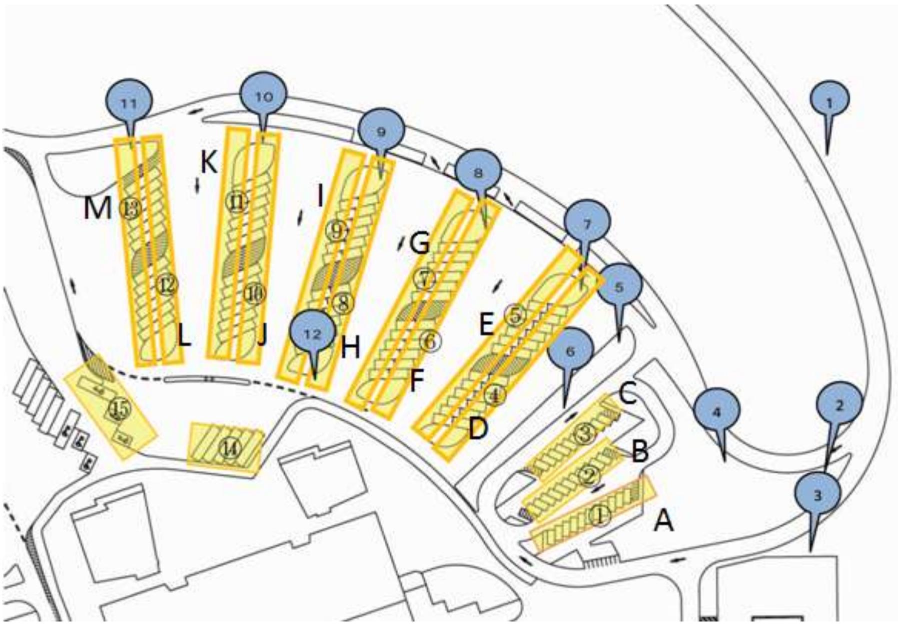


Figure 3.4: The study area of upstream and location of parking guidance information boards

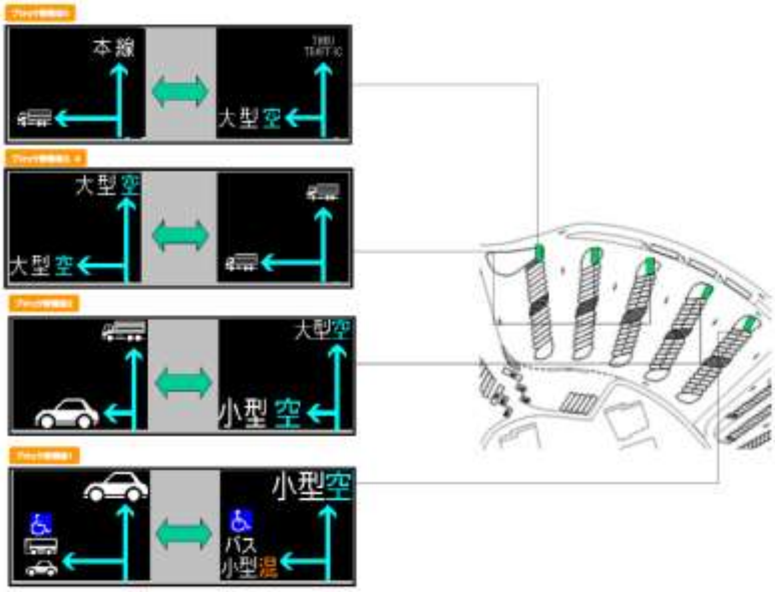


Figure 3.5: Empty, congests, full (ECF) information and type of vehicle display example

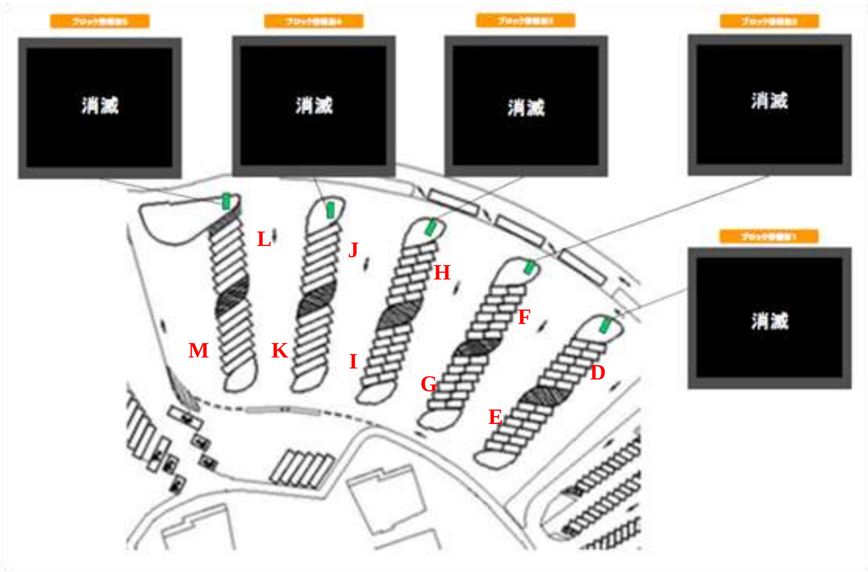


Figure 3.6: Null information display example

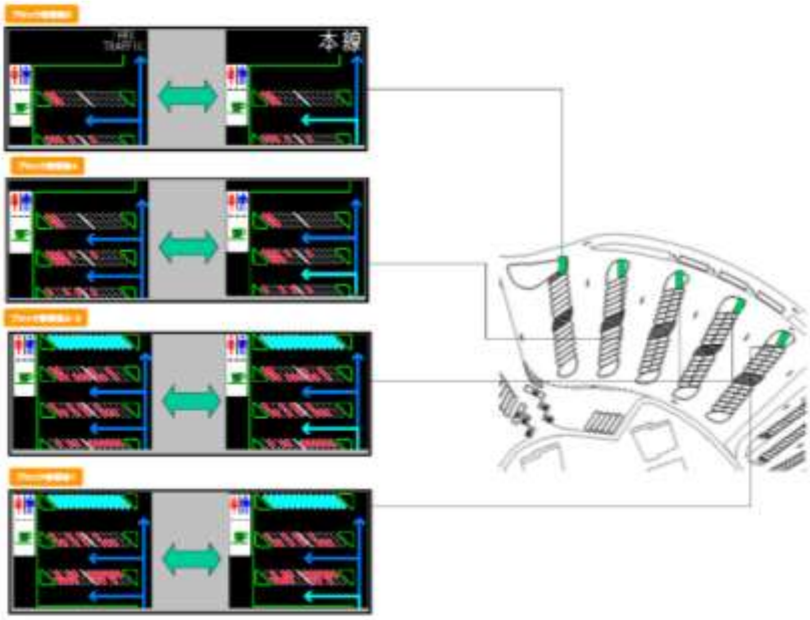


Figure 3.7: Available space and location (ASL) information display example

3.3 Data collection

In this part, the available data sample is introduced and separate by two parts of the experiment. Besides, for the two parts of experiment, how to match parking guidance information data with individual vehicle data is also briefly introduced. After matched with parking guidance information data with individual vehicle data, the final database is also introduced in this part.

3.3.1 Available data sample

For the first part of the experiment, the detail of available data file, sample number, type of showing information on dynamic parking guidance information signs and main content of the data is shown in the table 3.4. For the second part of the experiment, the detail of available data file, sample number, type of showing information on dynamic parking guidance information signs and main content of the data is shown in the table 3.5.

Table 3.4: The detail of available data of first part of the experiment

ID	File name	Sample number	Info. type	Main content
1	20120414 ~ 20120618 PGI signs data	355414	ECF info.	Included recorded date from 14th April 2012 ~ 18th June 2012 information varying time and guidance information of signs No.1 ~ No.18 of both upstream and downstream
2	20120414 ~ 20120618	432935	ECF info.	Included recorded date from 14th April 2012 ~18th June 2012 parked space arrival time, departure

	individual vehicle parking data			time, ID, block name and type of vehicle of upstream (block A ~ O)and downstream (block A ~ J)
3	20120414 ~20120618 occupancy rate	58409	ECF info.	Included recorded date from 14th April 2012 ~ 18th June 2012 the occupancy rate of total parking area of upstream
4	20120414 ~ 20120618 block occupancy rate	771023	ECF info.	Included recorded date from 14th April 2012 ~ 18th June 2012 the occupancy rate of each parking block of upstream and downstream
5	20120908 ~ 20120919 PGI signs data	66931	ECF info.	Included recorded date from 8thSeptember 2012 ~ 19th September 2012 information varying time and guidance information of signs No.1 ~ No.18 of both upstream and downstream
6	20120908 ~ 20120919 individual vehicle parking data	73472	ECF info.	Included recorded date from 8th September 2012 ~19th September 2012 parked space arrival time, departure time, ID, block name and type of vehicle of upstream (block A ~ O)and downstream (block A ~ J)
7	20120908 ~ 20120919 occupancy rate	11083	ECF info.	Included recorded date from 8th September 2012 00:00:27 ~ 19th September 2012 23:59:55 the occupancy rate of total parking area of upstream
8	20120908 ~ 20120919 block occupancy rate	119628	ECF info.	Included recorded date from 8th September 2012 ~ 19th September 2012 the occupancy rate of each parking block of upstream and downstream

Table 3.5: The detail of available data of second part of the experiment

ID	File name	Sample number	Info. type	Main content
1	20130609 PGI signs data	1370		Included information varying time and guidance information of signs No.1 ~ No.18 of both upstream and downstream
2	20130609 individual vehicle parking data	983	ECF info.	Included parked space arrival time, departure time, ID, block name and type of vehicle of upstream
3	20130609 parking route record data	745		Included investigated point arrival time, parking route, final parked block, type of vehicle of upstream
4	20130609 occupancy rate	319		Included recorded time from 8:00 ~ 15:00 the occupancy rate of total parking area of upstream
5	20130623individual vehicle parking data	907	ECF info. /ASL info.	Included parked space arrival time, departure time, ID, block name and

			/Null info.	type of vehicle of upstream
6	20130623parking route record data	845		Included investigated point arrival time, parking route, final parked block, type of vehicle of upstream
7	20130623occupancy rate	289		Included recorded time from 9:00 ~ 16:00 the occupancy rate of total parking area of upstream

3.3.2 Data matching and PGI signs

In this part, individual vehicle parking data and PGI signs data of the experiment have been matched in the first part of experiment, and in the second part of experiment, the individual vehicle parking data, PGI signs data and parking route record data have been matched. According to the investigation video, we observed searching time from vehicle appeared at the green star point (as shown in the figure 3.8) till drivers parked at destination block successfully. Because of the limitation of video screen, we can only observed the drivers, whose destination block is D, E, F, G, H, and the average searching time from green star point to each destination block is shown in the figure 3.8 as follow.

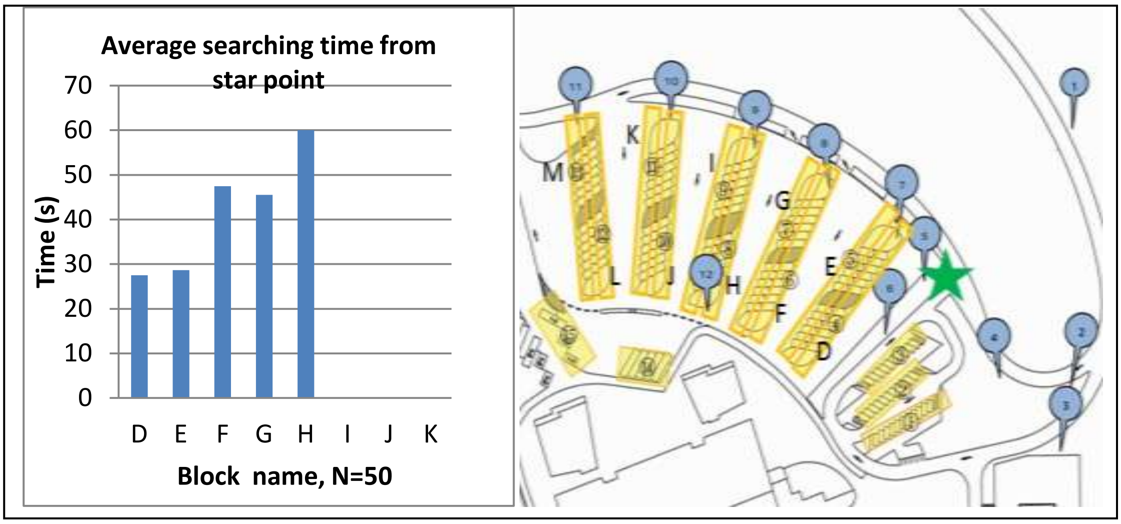


Figure 3.8: Average searching time from star point to selected block

As we can see from the above figure, the average searching time from the point to each destination block, according to the difference of distance, is approximately 30 s ~ 60 s. In the two parts of experiment, we mainly analyzing the effect of parking area Information board B (see figure 3.9) which location in 5 and the effect of block information board 1 (see figure 3.10) which location in 7. In this thesis, we assumed before appeared at the green star point, drivers could see the dynamic parking guidance information board, moreover, according to the video observed result of average searching time from point to destination block, we assumed space arrival time is around 60 s ~ 90 s latter than the time driver could see and receive guidance information displayed on the dynamic PGI signs. And the assumption can be applied in both the two parts of the experiment.

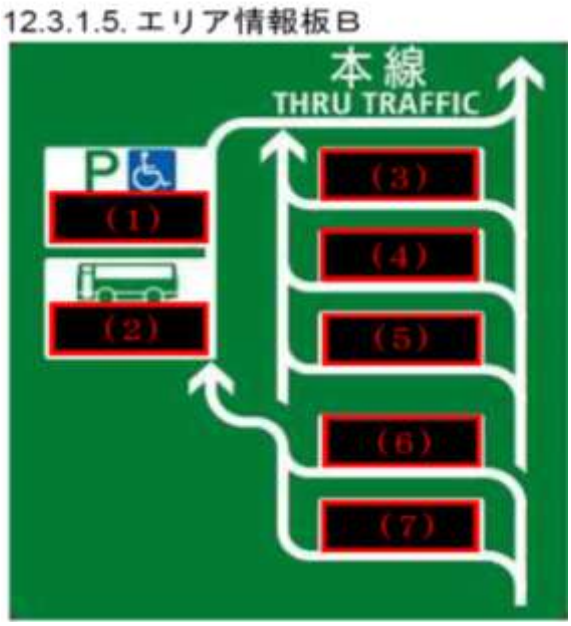


Figure 3.9: Parking area Information board B location in location 5

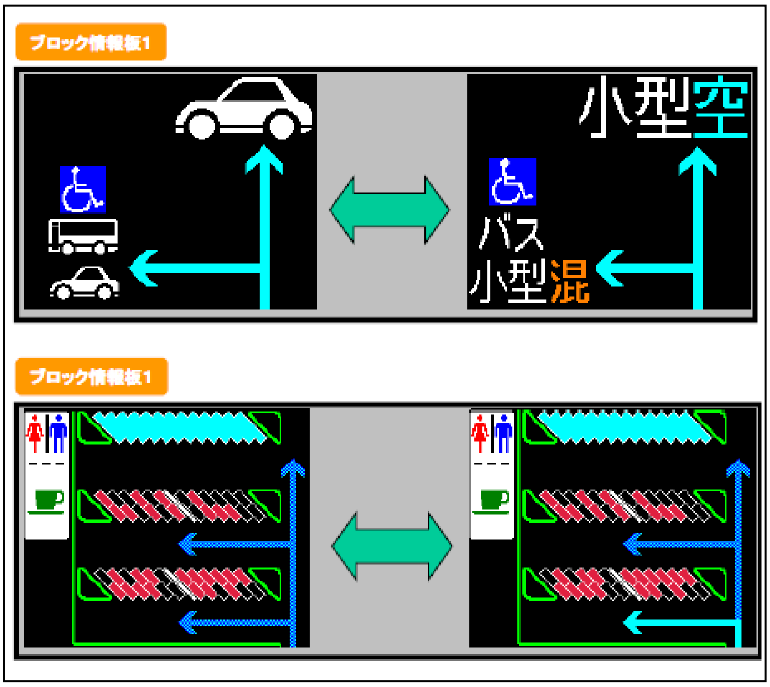


Figure 3.10: Block information board 1

3.3.3 Database

In this thesis, we have conducted two parts of experiment, so there are two types of database. The first database without the drivers' parking route information based on the matched data of the individual vehicle parking data and PGI signs data during first part of experiment, see figure 3.11. The second database with drivers' parking route information based on the matched data of the individual vehicle parking data, PGI signs data and parking route record data during second part of experiment see figure 3.12.

	A	B	C	D	E	F	G	H	I
1	Information about sample			block information 1			block information 2		
2	CarID	Car type	Date	informatio	PassTime	directior	block information	PassTime	directio
3	1	小型	2012/9/8	LC_LC	0:02:04	up	LF_LE	0:02:07	up
4	2	小型	2012/9/8	LC_LC	0:03:25	up	LF_LE	0:03:28	up
5	3	大型	2012/9/8	LC_LC	0:04:59	up	LF_LE	0:05:02	up
6	4	小型	2012/9/8	LC_LC	0:05:32	left	0	0	C
7	5	小型	2012/9/8	LC_LC	0:05:33	up	LF_LE	0:05:36	up
8	6	小型	2012/9/8	LC_LC	0:05:53	left	0	0	C
9	7	小型	2012/9/8	LF_LE	0:07:46	up	LF_LE	0:07:49	up
10	8	大型	2012/9/8	LF_LE	0:08:14	up	LF_LE	0:08:17	up
11	9	大型	2012/9/8	LF_LC	0:09:41	up	LF_LC	0:09:44	up
12	10	大型	2012/9/8	LC_LC	0:11:58	left	0	0	C
13	11	小型	2012/9/8	LF_LC	0:12:43	up	0	0:12:46	left
14	12	大型	2012/9/8	LF_LC	0:13:33	up	LF_LC	0:13:36	left
15	13	小型	2012/9/8	LF_LC	0:16:55	up	0	0:16:58	left
16	14	大型	2012/9/8	LF_LC	0:19:01	up	LF_LC	0:19:04	up
17	15	大型	2012/9/8	LF_LC	0:20:56	up	LF_LC	0:20:59	up
18	16	小型	2012/9/8	LF_LC	0:21:08	up	LF_LC	0:21:11	up
19	17	大型	2012/9/8	LF_LC	0:24:42	left	0	0	C
20	18	大型	2012/9/8	SC_SBC	0:27:12	up	SF_SLC	0:27:15	up
21	19	小型	2012/9/8	SC_SBC	0:28:01	up	SF_SLC	0:28:04	up
22	20	小型	2012/9/8	SC_SBC	0:28:09	up	SF_SLC	0:28:12	up
23	21	小型	2012/9/8	SC_SBC	0:32:35	up	SF_SLC	0:32:38	up
24	22	大型	2012/9/8	SC_SBC	0:35:12	up	SF_SLC	0:35:15	up
25	23	大型	2012/9/8	SC_SBC	0:36:54	up	SF_SLC	0:36:57	up
26	24	大型	2012/9/8	SC_SBC	0:41:35	up	SF_SLC	0:41:38	left
27	25	小型	2012/9/8	SC_SBC	0:42:05	up	0	0:42:08	left

0908 0909 0910 0911 0912 0913 0914 0915 0916 0917 0918 0919 Sheet1 more than 6

J	K	L	M	N	O	P	Q	R	S
block information 3			block information 4			Parked lot			
block information	PassTime	directio	block information	PassTime	directior	ID	arrival	depature	rate
LF_LE	0:02:10	up	LC_LE	0:02:13	up	K ブロック 10	0:02:36	5:38:32	79
0	0:03:31	left	0	0	0	G ブロック 11	0:03:51	0:42:55	79
LF_LE	0:05:05	up	LC_LE	0:05:08	left	J ブロック 3	0:05:28	0:09:50	79
0	0	0	0	0	0	D ブロック 1	0:05:52	0:06:01	79
0	0:05:39	left	0	0	0	G ブロック 12	0:05:59	0:31:41	79
0	0	0	0	0	0	D ブロック 1	0:06:13	3:39:59	79
LF_LE	0:07:52	up	LC_LE	0:07:55	up	L ブロック 12	0:08:18	0:09:43	79
LF_LE	0:08:20	up	LC_LC	0:08:23	up	L ブロック 4	0:08:46	0:30:08	79
LF_LC	0:09:47	up	LC_LC	0:09:50	up	L ブロック 3	0:10:13	2:51:32	79
0	0	0	0	0	0	D ブロック 3	0:12:18	4:05:38	79
0	0	0	0	0	0	K ブロック 4	0:13:06	0:25:42	79
0	0	0	0	0	0	F ブロック 5	0:13:56	0:45:38	79
0	0	0	0	0	0	E ブロック 10	0:17:18	2:06:51	79
LF_LC	0:19:07	up	LC_LC	0:19:10	left	J ブロック 2	0:19:30	0:51:13	79
LF_LC	0:21:02	up	LC_LC	0:21:05	left	J ブロック 3	0:21:25	1:12:45	79
LF_LC	0:21:14	up	LC_LC	0:21:17	up	L ブロック 7	0:21:40	0:30:39	79
0	0	0	0	0	0	D ブロック 6	0:25:02	0:58:17	79
SF_SLC	0:27:18	up	SC_SLC	0:27:21	up	L ブロック 5	0:27:44	4:05:51	79
SF_SLC	0:28:07	up	SC_SLC	0:28:10	up	L ブロック 11	0:28:33	3:40:47	79
SF_SLC	0:28:15	up		0:28:18	left	I ブロック 2	0:28:38	0:46:36	79
0	0:32:41	left	0	0	0	G ブロック 12	0:33:01	0:43:34	79
SF_SLC	0:35:18	up	SC_SLC	0:35:21	left	J ブロック 6	0:35:41	1:00:15	79
SF_SLC	0:37:00	up	SC_SLC	0:37:03	left	J ブロック 5	0:37:23	1:11:14	79
0	0	0	0	0	0	F ブロック 7	0:41:58	3:42:18	79
0	0	0	0	0	0	K ブロック 4	0:42:28	1:02:06	79

Figure 3.11: Database of matching individual vehicle parking data and PGI signs data

Notes: "PassTime" – the time pass by the block information board; "block information" – showing information when the car just passed by corresponded block information board; "direction" – driving direction of turning left or head straight at the block information board; "CarID" – ID of vehicle; "ID" – ID of chosen space (including block name and space No.); "arrival" – arrival time of parked space; "departure" – departure time of parked space; "LE" – occupancy status of large size vehicle is empty; "LC" – occupancy status of large size vehicle is congest; "LF" – occupancy status of large size vehicle is full; "SE" – occupancy status of small size vehicle is empty; "SC" – occupancy status of small size vehicle is congest; "SF" – occupancy status of small size vehicle is full; "_" – separate sign of leftwards arrow and upwards arrow on information board, e.g., “LF_LC” means that leftwards arrow is showing large size vehicle is full and upwards arrow is showing large size vehicle is congested.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	NO.	時間	車種	直進車はC列		D1	D2	E2	E1	F2	F1	G2	G1	H2	H1	I2	I1	J2	J1
96	95	10:14:10	小型		1	1	2	○	3										
97	96	10:15:25	小型		1	1	○												
98	97	10:16:07	小型		1	1	2	3	4	5		○	6						
99	98	10:18:07	小型		1	1			3		4	○	5						
100	99	10:19:18	小型		1	1	○												
101	100	10:20:18	小型	○	1	1	2	3		4		5		6		○			
102	101	10:21:45	小型		1	1	○												
103	102	10:23:32	小型		1	○													
104	103	10:24:03	小型		1	1	○												
105	104	10:24:36	小型		1	1			2	○									
106	105	10:24:40	小型		1	1	2	○		3									
107	106	10:25:03	小型		1	1	○												
108	107	10:26:04	小型		1	1	2	3		4		5		○					
109	108	10:26:36	小型		1	1			2		3		○						

	A	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
1	NO.	K2	K1	L2	L1	M2	M1	選択	誘導種類	PassABC	AT	DT	備考	駐車率
96	95							E	マス誘導	N	10:16:55	10:38:07		44
97	96							D	マス誘導	N	10:17:48	10:25:25		41
98	97							G	マス誘導	N	10:19:41	10:19:41		33
99	98							G	マス誘導	N	10:20:41	10:20:41		43
100	99							D	マス誘導	P	10:21:41	10:31:21		41
101	100							I	マス誘導	P	10:23:04	10:59:37		35
102	101							D	マス誘導	P	10:24:16	11:21:24		45
103	102							D	マス誘導	P	10:25:52	10:26:20		39
104	103							D	マス誘導	N	10:26:24	10:43:20		30
105	104							F	マス誘導	N	10:27:01	10:31:23		43
106	105							E	マス誘導	P	10:26:20	10:26:29		40
107	106							D	マス誘導	N	10:26:48	10:27:07		39
108	107							H	マス誘導	N	10:28:52	11:02:20		38
109	108							G	マス誘導	P	10:28:40	10:32:23		43

	A	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP
1	NO.	空有数D	空有数E	空有数F	空有数G	空有数H	空有数I	空有数J	空有数K	空有数L	空有数M
96	95	4	2	7	6	7	4	10	8	10	9
97	96	5	6	7	6	7	4	9	8	10	9
98	97	4	6	9	7	9	6	10	9	10	10
99	98	5	2	6	6	8	7	10	8	10	7
100	99	4	4	7	6	8	6	9	8	10	9
101	100	4	5	7	9	8	6	10	9	10	10
102	101	1	4	6	6	7	4	9	9	10	10
103	102	5	6	7	6	8	5	9	8	10	9
104	103	7	5	10	8	10	7	10	8	10	9
105	104	4	2	7	4	10	5	10	8	10	9
106	105	4	4	7	6	9	5	10	8	10	9
107	106	4	5	8	6	8	6	9	8	10	9
108	107	5	3	7	8	7	5	10	10	10	10
109	108	4	2	8	4	9	5	10	8	10	9

Figure 3.12: Database of matching individual vehicle parking data, PGI signs data and parking route record data

Notes: “No.” – No. of vehicle; “AT” – arrival time of parked space; “DT” – departure time of parked space; “PassABC” – whether or not pass ABC block. “D” ~ “M” – block name and number means the order of passed corresponded block.

3.4 Data analysis

3.4.1 Arrival frequency analysis

As we known in the section 3.1.2, the experiment is divided into two parts, the first part of the experiment if during 14th April 2012 ~ 14th June 2012 and 7th September 2012 ~ 19th September 2012, total sample number is 239037 vehicles. After eliminated the sample date of 14th April 2012, 14th June 2012, 7th September 2012 and 19th September 2012, which the investigated period is not the full 24 hours, and then the total sample number of vehicles is 233269. The number of arrival vehicles of the whole sample date is shown in the figure 3.13, and the number of arrival vehicles dividing by the type of date is shown in the figure 3.14. The average number of arrival vehicles dividing by the type of date is shown in the figure 3.15. According to the actual data, the type of date is divided into six types: holiday, weekday, weekend, and one day after holiday (ODAH), one day after weekend (ODAW) and one day before weekend (ODBW).

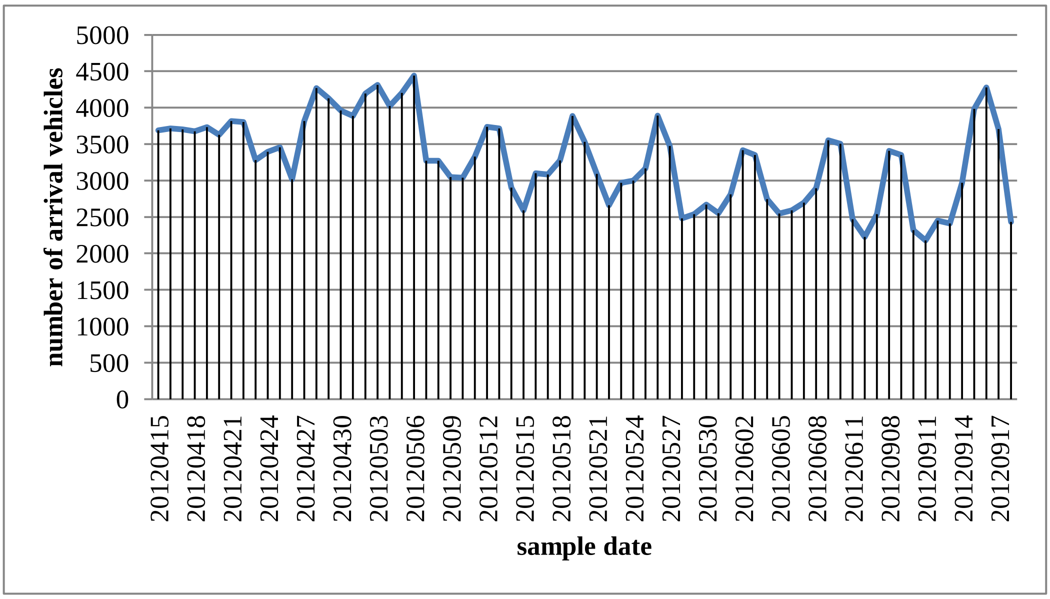


Figure 3.13: Number of arrival vehicles by sample date

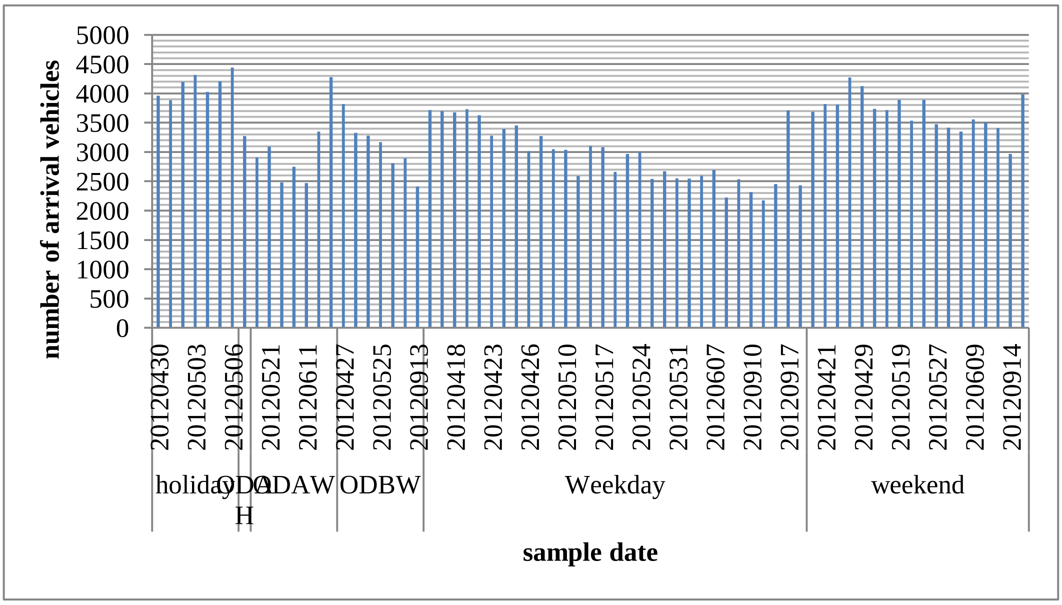


Figure 3.14: Number of arrival vehicle by type of date

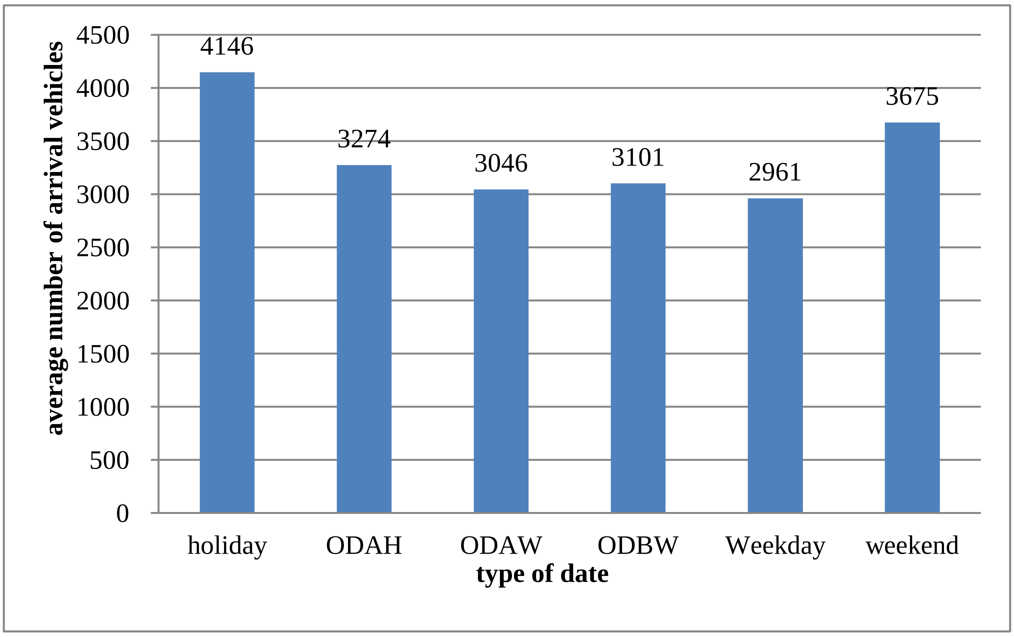


Figure 3.15: Average number of arrival vehicle by type of date

As described in the figure 3.13, from the date of 15th April 2012 to the date of 18th September 2012, there are total 71 days. The highest number of arrival vehicle in one day is happened on 6th May 2012 and the value is 4439 vehicle/day. The lowest number of arrival vehicle in one day is happened on 12th September 2012 and the value is 2452 vehicle/day. As can been seen in the figure 3.14 and figure 3.15, though the study area is begun to use with the open of road link on 14th April 2012, because of the coming Golden week, the number of arrival vehicle of during 15th April 2012 ~ 6th May 2012 generally over 3500 vehicles/day. The highest average arrival traffic volume is on the holiday which is 4146 vehicles/day; the lowest average arrival traffic volume is on the weekday which is 2961 vehicles/day. Besides, based on observing the original PGI signs' data during 14th April 2012 ~ 14th June 2012, we known most of information shown on the PGI signs only guiding drivers type of vehicle and rarely guiding the occupancy information. So, we focus on the period during 7th September 2012 ~ 19th September 2012 for the second part of the experiment. Besides, we known most of information have shown on the PGI signs during 14th April 2012 ~ 14th June 2012 provided information of type of vehicle only. Then, in the later section, the data of small-size vehicle during 7th September 2012 ~ 19th September 2012 is used for analyzing occupancy rate.

3.4.2 Occupancy rate analysis

Before exploring the information's effect on drivers' behavior, the occupancy rate of the study period need to be analyzed and pointed out whether the influence of drivers' parking choice behavior under congested and uncongested situations is different. Since the two experiments were conducted, the occupancy rate of first part experiment during 7th September 2012 ~ 19th September 2012 and second part experiment on 9th June 2013, 23rd June 2013 is compared. The average occupancy rate of total sample date from 8th September 2012 to 19th September 2012, sample date on 8th September 2012, sample data on 11th September 2012, sample data on 17th

September 2012, sample data on 9th June 2013 and sample data on 23rd June 2013 is shown in the figure 3.16, figure 3.17, figure 3.18, figure 3.19, figure 3.20 and figure 3.21 respectively.

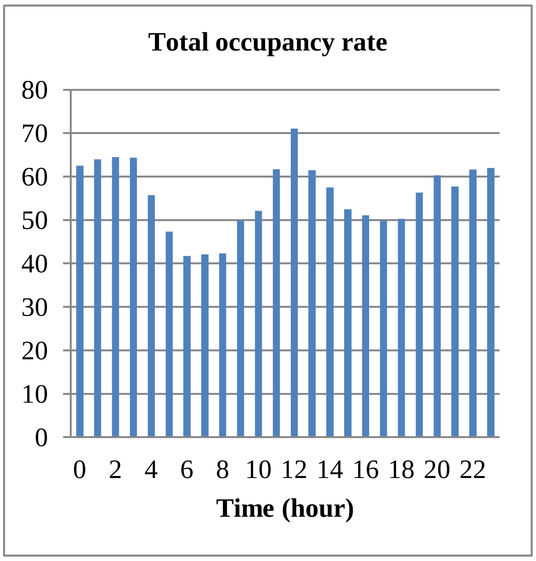


Figure 3.16: Occupancy rate of 8th ~ 19th Sep

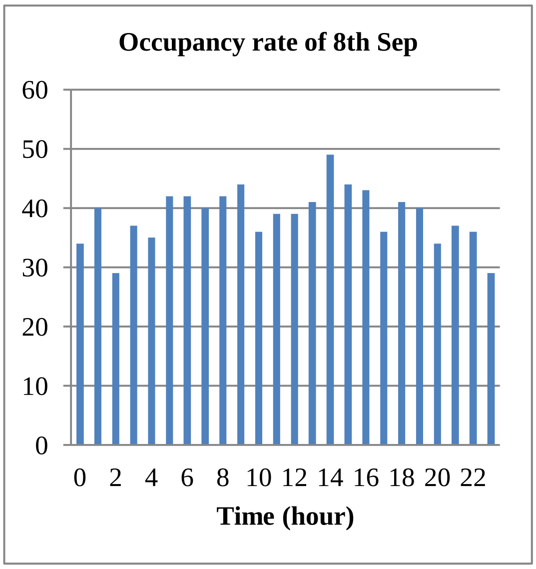


Figure 3.17: Occupancy rate of 8th Sep

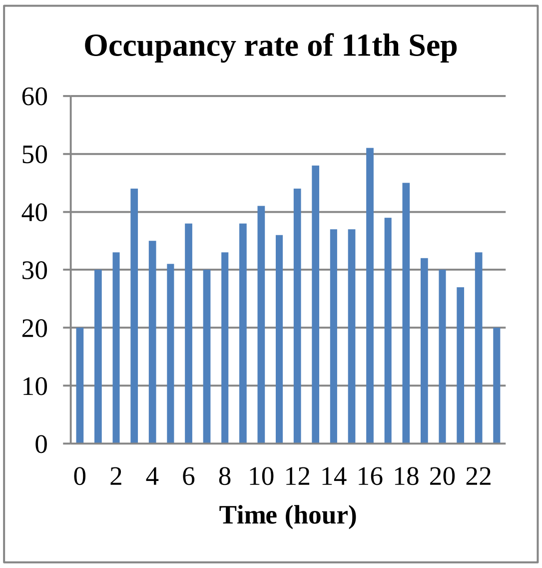


Figure 3.18: Occupancy rate of 11th Sep

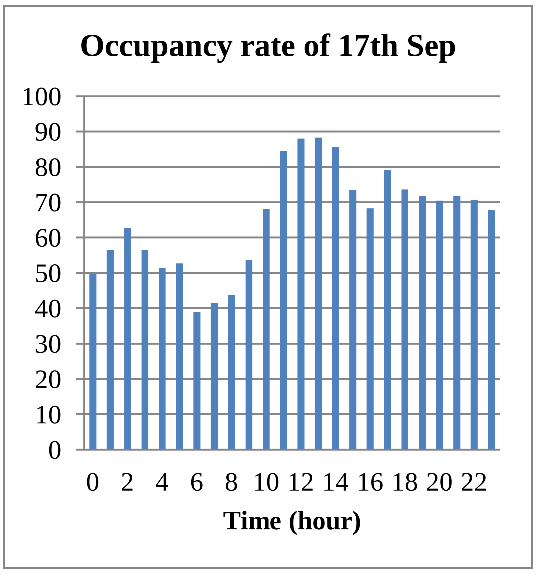


Figure 3.19: Occupancy rate of 17th Sep

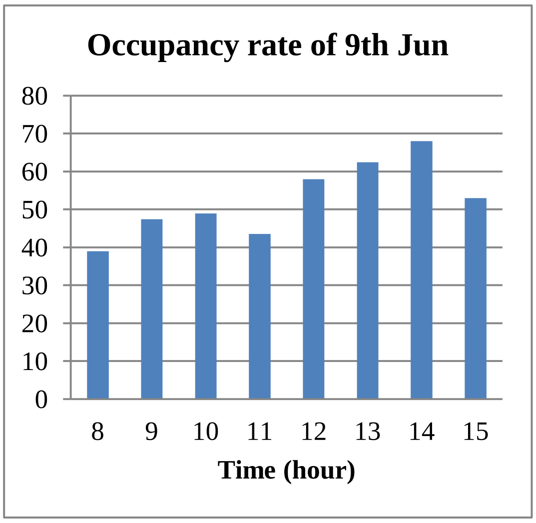


Figure 3.20: Occupancy rate of 9th Jun

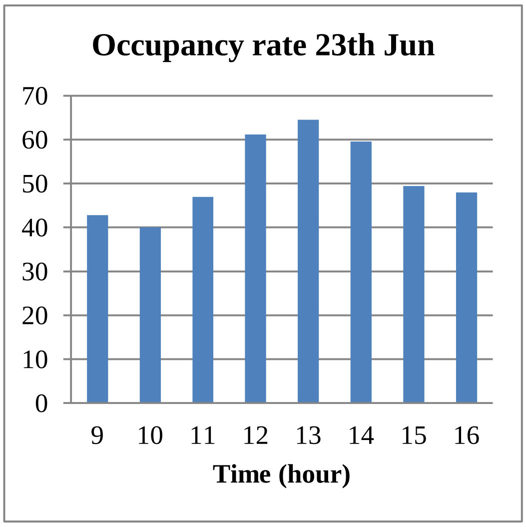


Figure 3.21: Occupancy rate of 23rd Jun

As we can see from above figures, the highest occupancy rate of almost all of the observed data is appeared during the time 12 hour ~ 14 hour. It is obviously that there is a noon peak in the study parking area. As shown in the figure 3.16, 3.18 and 3.19, the lowest occupancy rate is appeared during the time 5 hour ~ 8 hour. Only on the day of 17th September 2012 (see Figure 3.19), the occupancy rate of the whole parking area is above 80% during 11 hour ~ 14 hour. For other sample days which are shown in the above figures, the occupancy rate is varying around 50%, and then we can analyze the information effect by dividing occupancy rate into two situations: above 50% and below 50% to explore the effect of parking guidance information under more congested situation and less uncongested situation.

3.5 Parking guidance information

Before exploring drivers' response to the effect of parking guidance information, the schemes of displaying information need to be explained. There are three schemes conducted on two parts of experiment: 1) ECF information parking area information board B and block information board 1, 2, 3 and 4 during 8th Sep ~ 19th Sep 2012; 2) ECF information of parking area information board B and block information board 1 on 9th June 2013 and 23rd June 2013 (14:00 ~ 15:00); 3) ASL information of block information board 1, 2, 3 and 4 on 23rd June 2013 (10:00 ~ 13:00); 4) Null information of block information board 1, 2, 3 and 4 on 23rd June 2013 (9:00 ~ 10:00, 13:00 ~ 14:00 and 15:00 ~ 16:00).

3.5.1 ECF information of blocks

For the first experiment during 8th Sep ~ 19th Sep, there is only one type of parking guidance information – ECF information and without knowing drivers' parking route. Then we give an assumption that after entered into the area and till parked at destination block, all the drivers drive through the main parking lane and through block information boards which located in the front of the preferred block. The expected parking route and ECF information shown on each block information board depicted in Figure 3.22.

As shown in the figure 3.22, each block information board can only guide the occupancy status of current row and further rows. For the block information board 1, information on the leftwards arrow provided the occupancy status of block D and E, and the upwards arrow provided the occupancy status of block F to block M. For the block information board 2, information on the leftwards arrow provided the occupancy status of block F and G, and the upwards arrow provided the occupancy status of block H to block M. For the block information board 3, information on the leftwards arrow provided the occupancy status of block H and I, and the upwards arrow provided the occupancy status of block J to M. For the block information board 4, information on the leftwards arrow provided the occupancy status of block J and K, and the upwards arrow provided the occupancy status of block L and M. Because in our assumption it is forbidden to turn around and drive back, if drivers passed by block information board 4, that means their preferred block is either L or M. No matter what information shown on block information board 5 (occupancy status of block L and M), driver who passed by block information board 4 will choose to park at block L and M. So in this thesis, during sample date the 8th Sep ~ 19th Sep 2012, we only consider the ECF information effect of block information board 1, 2, 3 and 4. Then the ECF information of block information board 1, 2, 3 and 4 is depicted in the Table 3.6.

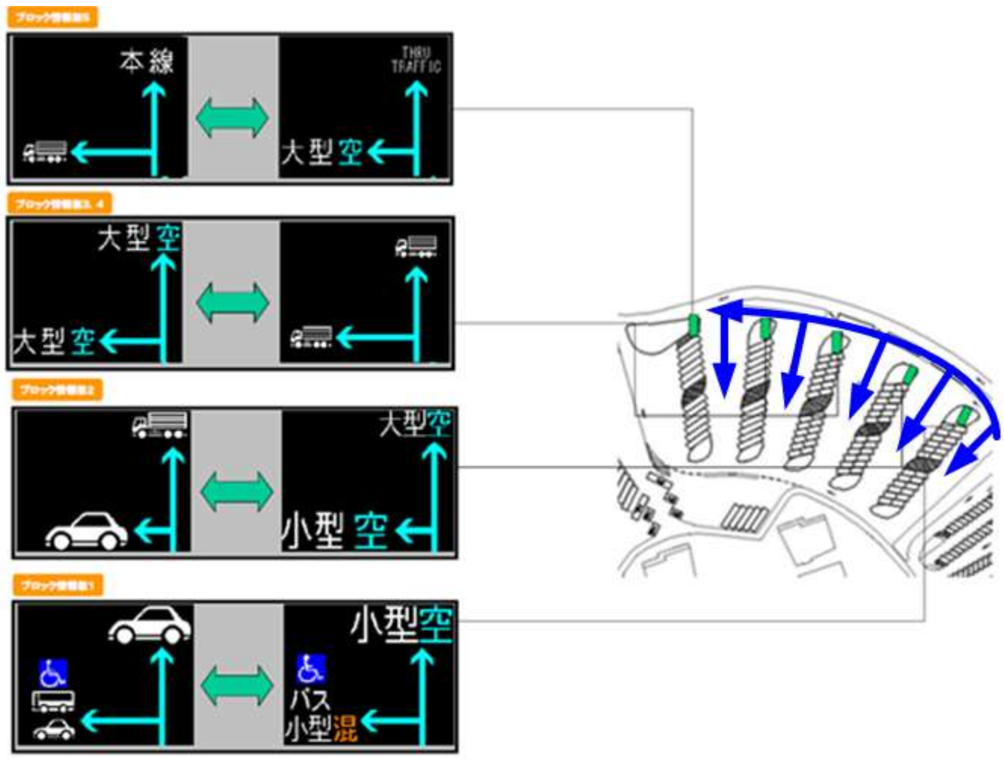


Figure 3.22: Expected parking route and block ECF information

Table 3.6: ECF information of block information board 1, 2, 3 and 4

ID	Info.	Priority	Sample number			
			Block Info. Board 1	Block Info. Board 2	Block Info. Board 3	Block Info. Board 4

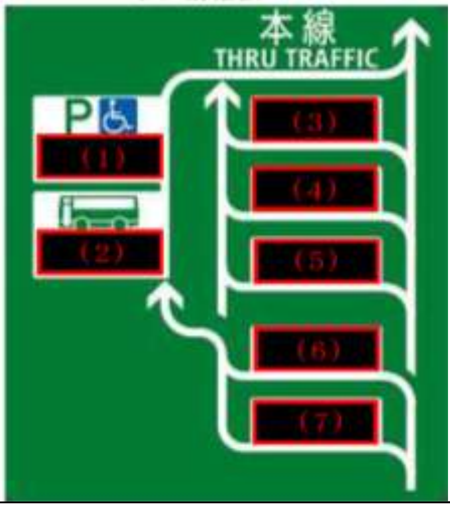
1	L:SE/U:LC	Leftwards	5	26	128	332
2	L:LE/U:LC		51	-	-	87
3	L:LC/U:LF		67	64	84	137
4	L:SLC/U:SF		-	-	-	41
5	L:SE/U:LE	None	1157	917	2615	1595
6	L:SC/U:SC		36	67	69	129
7	L:SC/U:SLC		325	330	426	599
8	L:SF/U:SF		-	-	-	29
9	L:SF/U:SLF		749	819	834	869
10	L:LE/U:LE		704	893	1581	935
11	L:LC/U:LC		408	339	356	468
12	L:LF/U:LF		80	144	213	222
13	L:SLC/U:SC		-	-	36	228
14	L:SC/U:SE	Upwards	205	281	582	630
15	L:SC/U:SLE		2625	2770	2363	1391
16	L:SF/U:SE		1147	1084	793	317
17	L:SF/U:SC		868	791	792	718
18	L:SF/U:SLE		3889	3221	870	340
19	L:SF/U:SLC		1569	1476	1151	743
20	L:LC/U:LE		1327	1797	627	857
21	L:LF/U:LE		535	438	222	134
22	L:LF/U:LC		522	542	411	324
23	L:SLC/U:SE		-	-	-	33
24	Total		16269	15999	14153	11158

Notes: "L:" – leftwards arrow on information signs; "U:" – upwards arrow on information signs; "LE" – occupancy status of large size vehicle is empty; "LC" – occupancy status of large size vehicle is congest; "LF" – occupancy status of large size vehicle is full; "SE" – occupancy status of small size vehicle is empty; "SC" – occupancy status of small size vehicle is congest; "SF" – occupancy status of small size vehicle is full; "SLE" – occupancy status of small and large size vehicle is empty; "SLC" –occupancy status of small and large size vehicle is congest; "SLF" –occupancy status of small and large size vehicle is full; "Priority" – we defined the occupancy status of empty is prior than congest and full; and the occupancy status of congest is prior than full. If the information of one direction is prior than another direction, in another word, navigation information aim at guiding drivers to the blocks which are less congested, then the priority is the direction which guiding the occupancy status of blocks are less congested.

3.5.2 ECF information of parking area and block

For the second part of experiment on 9th June 2013 during 9:00 ~ 15:00 and on 23rd June 2013 during 14:00 ~15:00, there is only one type of parking guidance information – ECF information and with receiving drivers' parking route. Because of lacking the parking guidance information signs' data on 23rd June 2013 during 14:00 ~15:00, in this thesis, to analyze the ECF parking guidance information impact on drivers' behavior, only the data on 9th June 2013 during 9:00 ~

15:00 has been adopted. We assume that after entered into the area, drivers could see information of all the blocks which shown on the area information board B. The area information board B and parking guidance of blocks by each window can be seen in figure 3.23. The ECF parking guidance information on each window of parking area information board B is shown in Table 3.7.



Window No.	Block
Third Window	L, M
Fourth Window	J, K
Fifth Window	H, I
Sixth Window	F, G
Seventh Window	D, E

Figure 3.23: Area information board B and guided blocks of each window

Table 3.7: ECF information on parking area information board B

ID	Third Window	Fourth Window	Fifth Window	Sixth Window	Seventh Window	Number of sample	Group
1	L E	LE	LE	SC	LE	3	
2	LE	LE	SE	LC	SE	6	1
3	LE	LE	SE	SC	LE	3	
4	LE	LE	SE	LF	LE	9	
5	LE	LE	SE	LF	SE	2	2
6	LE	LE	SE	SF	SE	5	
7	LE	SE	SC	SE	LC	4	
8	LE	LE	LC	SE	SC	17	3
9	LE	LE	LC	LE	LC	4	
10	LE	LE	LE	SE	SC	17	
11	LE	LE	LE	SE	LC	3	4
12	LE	LE	SE	SE	LC	8	
13	LE	SE	SC	SE	LF	2	5
14	LE	LE	LC	SE	SF	27	
15	LE	LE	LE	SC	LF	4	
16	LE	LE	LE	SC	SF	13	6
17	LE	LE	SE	SC	SF	16	

18	LE	LE	LE	LC	LF	29	
19	LE	LE	LE	LC	SF	83	
20	LE	LE	LE	SC	LC	10	7
21	LE	LE	LE	SC	SC	9	
22	LE	LE	SE	LC	SC	3	
23	LE	LE	SE	SC	LC	43	
24	LE	LE	SE	SC	SC	7	
25	LE	LE	LC	SC	SF	1	8
26	LE	SE	SC	SC	SF	67	
27	LE	LE	LC	LC	LF	14	
28	LE	LE	LC	SC	LC	2	9
29	LE	LE	LC	SC	SC	2	
30	S・LE	SC	SC	SC	SF	21	10
31	LE	LC	SC	SC	SF	2	
32	LE	LE	SC	SF	SF	3	11
33	LE	SE	SC	SF	SF	60	
34	LE	LE	LE	LF	SF	20	12
35	LE	LE	SE	SF	SF	28	
36	LE	SE	SF	SF	SF	6	13
37	S・LE	SC	SF	SC	SF	5	14
38	S・LE	SC	SC	SF	SF	40	15
39	S・LE	SC	SF	SF	SF	45	16
40	LE	LC	SE	SC	SF	2	17
41	LE	LC	SE	SF	SF	5	18
42	S・LE	SF	SF	SC	SF	2	19
43	S・LE	SF	SF	SF	SF	10	20
44	LE	LE	LC	SC	SE	3	21
45	LE	LE	SE	SC	―	7	22
46	Total			672			

Notes: “LE” – occupancy status of large size vehicle is empty; “LC” – occupancy status of large size vehicle is congest; “LF” – occupancy status of large size vehicle is full; “S・LE” – occupancy status of small and large size vehicle is empty; “SE” – occupancy status of small size vehicle is empty; “SC” – occupancy status of small size vehicle is congest; “SF” – occupancy status of small size vehicle is full; “―” – no information shown on this window.

Note that we combined drivers’ parking route data with individual vehicle parking data and PGI signs data, as can be seen in figure 3.8 of section 3.3.2, drivers who arrived at the green star point can also see the information shown on the block information board 1.To give a clearly impression of drivers' response to ECF information during 9:00 ~ 15:00 of second part of experiment on 9th June 2013, the ECF information on block information board 1 is also presented as list in the Table 3.8.

Table 3.8: ECF information of block information board 1

No	Info.	Priority	Sample number
1	L:-/U:-	-	172
2	L:LC/U:LE	Upwards	6
3	L:SC/U:SLE		65
4	L:SF/U:SLE		98
5	L:SF/SC		19
6	L:LE/U:LE	None	8
7	L:SL/U:SE		208
8	L:SE/U:LE		40
Total		616	

3.5.3 ASL information of blocks

For the second part of experiment during 10:00 ~ 13:00 on 23rd June 2013, there is only one type of parking guidance information – ASL information, we assume drivers can obtain ASL information of all alternative blocks when arrive at star point. As shown in the figure 3.24, for the ASL information, the occupancy status can be distinguished by colors of space, red – indicate that the space is occupied, otherwise it not.

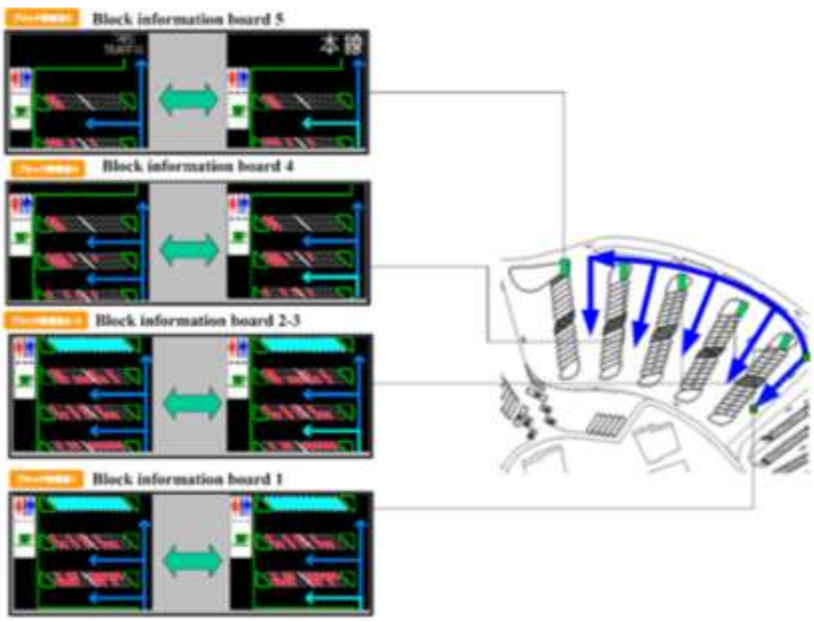


Figure 3.24: Expected parking route and block ASL information

3.6 Impacts of information on drivers' behavior without observed parking route data

As mentioned in the former section, the experiment can be divided into two parts, only in the second part of the experiment, individual driver's parking route has been observed, but both parts of the experiment have been conducted under the effect the ECF parking guidance information. In this section, firstly, parking choice probability of all the samples data divided by null information, ECF information and ASL information is analyzed. Then effect of ECF information on drivers' parking choice behavior are compared and analyzed when ECF information are shown by different PGI signs (parking area information board B and block information board 1, 2, 3 and 4). Moreover, drivers' parking choice behavior analysis under the effect of different type of parking guidance information, ECF information and ASL information, in the same part of the experiment have also been presented. Additionally, in this section, expected drivers' parking routes under ECF information and ASL information are separately same with the drawn routes which shown in figure 3.22 and in figure 3.24.

3.6.1 Parking choice probability

To give a detailed understanding of drivers' response to the impact of information, it is instructive to compare ratio of selecting different blocks of both the two parts of experiment without considering the effect of parking guidance information. As explained, the ratio of block choosing can be categorized as three different information types: 1) drivers' receiving the parking guidance information as displayed of type of vehicle attached with Empty, Congest and Full (ECF) information, such as the observed data from 8th September ~ 19th September 2012, observed data on 9th June 2013 and observed data on 14:00 ~15:00 of 23rd June 2013; 2) drivers' receiving null parking guidance information, such as the observed data on 9:00 ~ 10:00, 13:00 ~ 14:00 and 15:00 ~ 16:00 of 23rd June 2013; 3) drivers receiving the parking guidance information as displayed of whether each space is available and the location, Available Space and Location (ASL) information, such as on 10:00 ~ 15:00 of 23rd June 2013.

As shown in the figure 3.4 in the section 3.2.3, in the upstream of study area, block A, B and C are separated from block D, E, F, G, H, I, J, K, L and M into an independent zone by planting configuration. Therefore, in this thesis, our research objects of parking choice alternatives are block D, E, F, G, H, I, J, K, L and M, each block (row) has 12 available parking spaces. Then the number of total available parking spaces from block D to block M is 120.

For the first type, ECF information, the total effective sample number from 8th September ~ 19th September 2012 (only small-size of vehicle) is 16784, the choice frequency of block D to M under the effect of ECF information on 19th September 2012 is shown in figure 3.25; and the sample number on 9th June 2013 is 672 (including both large and small-size of vehicle), the choice frequency of block D to M under the effect of ECF information on 9th June 2013 is shown in figure 3.26; and the sample number on 14:00 ~15:00 of 23rd June 2013 is 146 (including both large and small-size of vehicle), the ratio of choosing block D to M under the effect of ECF information on 23rd June 2013 is shown in figure 3.27. For the second type, null information, the sample number on 9:00 ~ 10:00, 13:00 ~ 14:00 and 15:00 ~ 16:00 of 23rd June 2013 is 353 (including both large and small-size of vehicle), the choice frequency of D to M under the effect of null information on 23rd June 2013 is shown in figure 3.28. For the third type, ASL information, the sample number is on 10:00 ~ 15:00 of 23rd June 2013 is 389, the ratio of choosing block D to M under effect of ASL information on 23rd June 2013 is shown in figure 3.29.

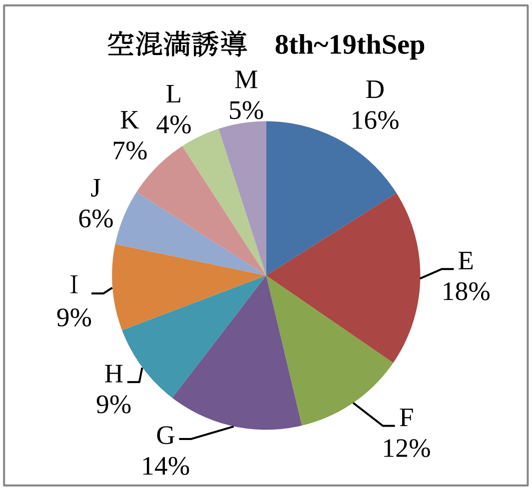


Figure 3.25: Block choice frequency under ECF information, N=16784

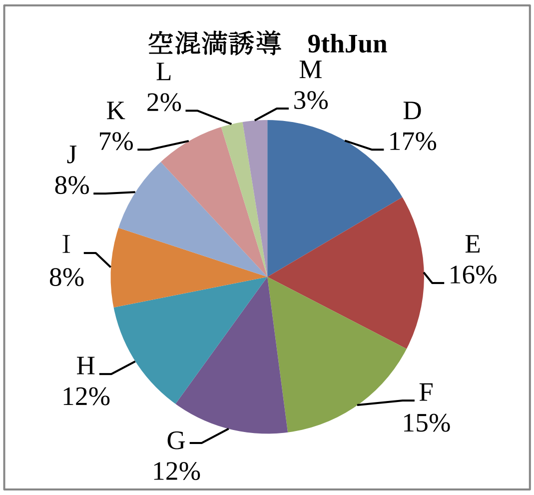


Figure 3.26: Block choice frequency under ECF information, N=672

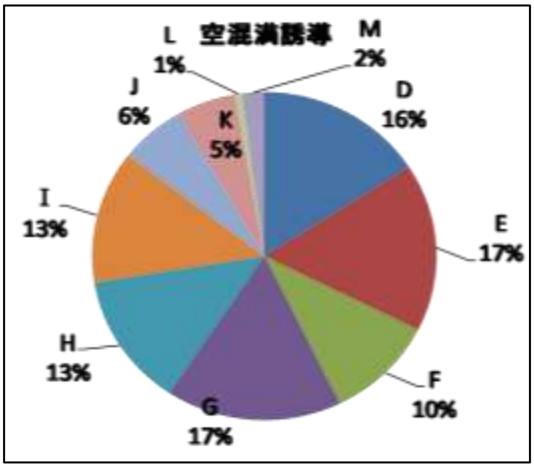


Figure 3.27: Block choice frequency under ECF information, N=146

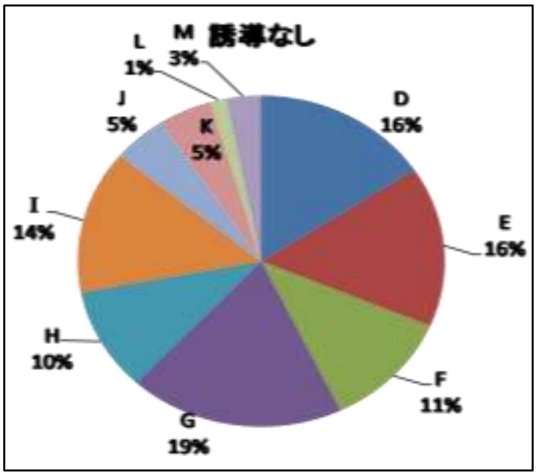


Figure 3.28: Block choice frequency under Null information, N=353

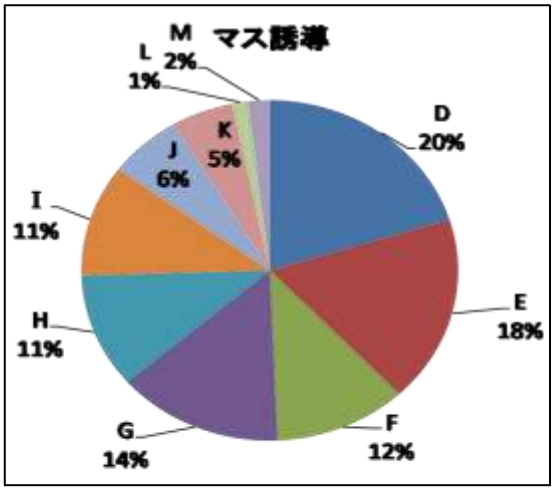


Figure 3.29: Block choice frequency under ASL information, N=380

As can be seen from figure 3.25 to figure 3.29, the total ratio of choosing block D, E, F, G is over 60% which is more than the total ratio of choosing block H, I , J, K, L, M regardless of under any type of parking guidance information. Besides, as shown in figure 3.4 (see section 3.2.3) and figure 3.8 (see section 3.3.2), walking distance from entrance to each parked block increased with the varying of block label from D to M. The result of comparing total ratio of choosing block D, E, F and G with total ratio of choosing block H, I, J, K, L, and M suggests that drivers more likely to park at the blocks (or alternatives) with shorter distance from entrance.

To compare the different parking guidance information in the same day of 23rd June 2013 of figure 3.27, 3.28 and 3.29, the ratio of choosing block D under ASL parking guidance information is 20% which is higher than the both situations of under Null information and ECF information, which are 16%. Besides, the ratio of choosing block E under ASL parking guidance information is 18%, higher than the situation of under Null information, which is 16%, also higher than the situation of under ECF information which is 17%. Moreover, the ratio of choosing block F under ASL parking guidance information is 12%, higher than the situation of under Null information which is 11%, also higher than the situation of under ECF information which is 10%. These findings suggested that drivers more likely to choose former blocks (D, E, F) as long as they known there is available empty space in former blocks according to ASL information guidance.

In addition, the ratio of choosing block G under the effect of null information is 19% which is the highest compare with the ratio of choosing block G under the effect no matter of ECF information or ASL information. This finding suggests that, under the effect of null information, drivers are more likely to choose the block which is not the closest but also not very far from entrance. It is therefore likely that drivers are unwilling to take the risk of parking at the closest blocks without knowing any parking guidance information about occupancy status.

3.6.2 Impacts of blocks' ECF information on drivers' behavior

To give a detailed comparison of provided occupancy status information of leftwards arrow and upwards arrow of each block information board, the functional guidance of leftwards and upwards arrow of each block information sign is summarized in Table 3.9.

Table 3.9: Guiding blocks of each block information board

Direction of arrow on information sign	Occupancy status information of blocks			
	Block information board 1	Block information board 2	Block information board 3	Block information board 4
Leftwards	Block D, E	Block F, G	Block H, I	Block J, K
Upwards	Block F, G, H, I, J, K, L, M	Block H, I, J, K, L, M	Block J, K, L, M	Block L, M

In this section, only drivers' choice of small-size vehicle is analyzed. Then choice frequency of small-size vehicle under the ECF information of total four block information boards is depicted in Figure 3.30. Figure 3.31, 3.32, 3.33 and 3.34 shows the choice frequency of small-size vehicle under the effect of ECF information separated by block information board 1, 2, 3 and 4.

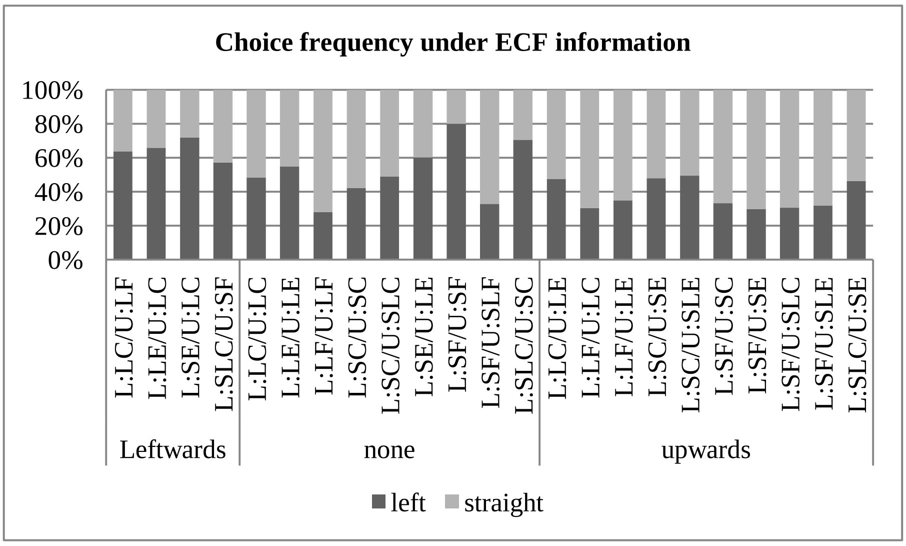


Figure 3.30: Choice frequency under ECF information of four block information boards, N=30813

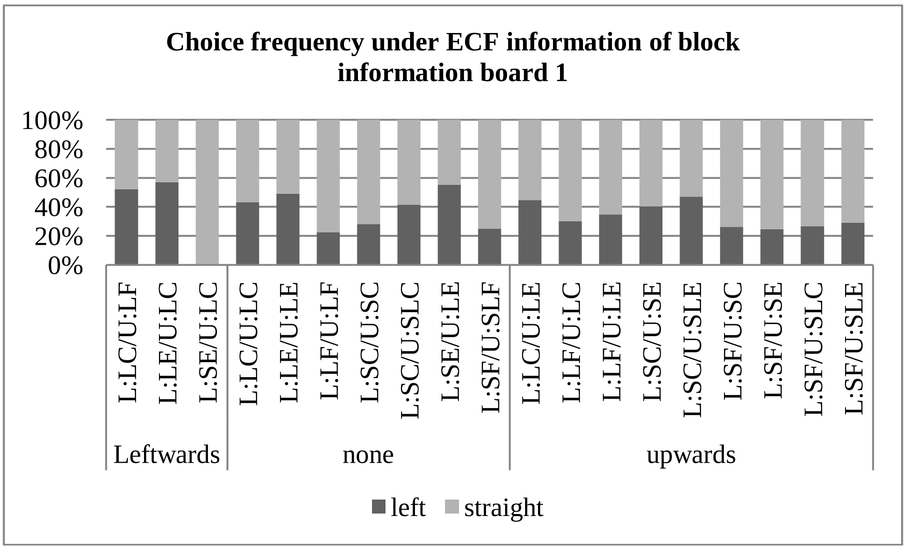


Figure 3.31: Choice frequency under ECF information of block information board 1, N=14053

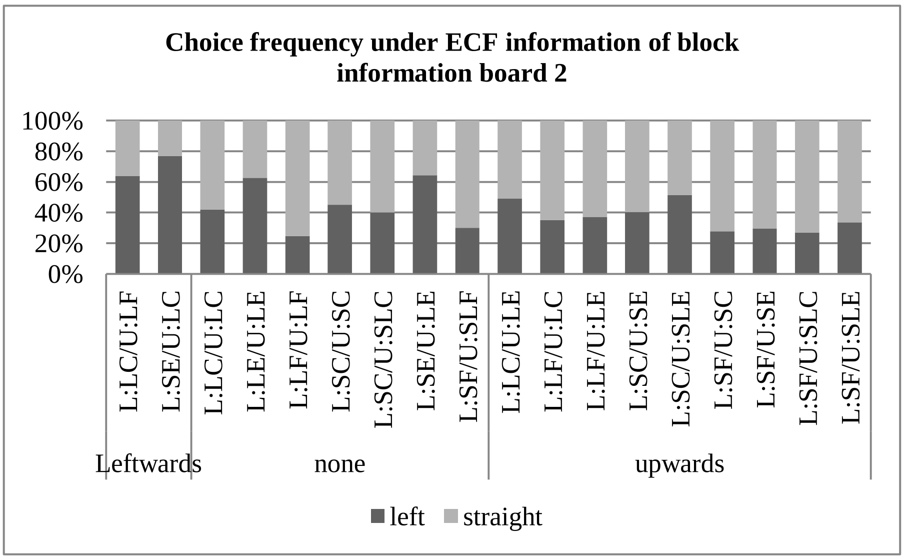


Figure 3.32: Choice frequency under ECF information of block information board 2, N=9089

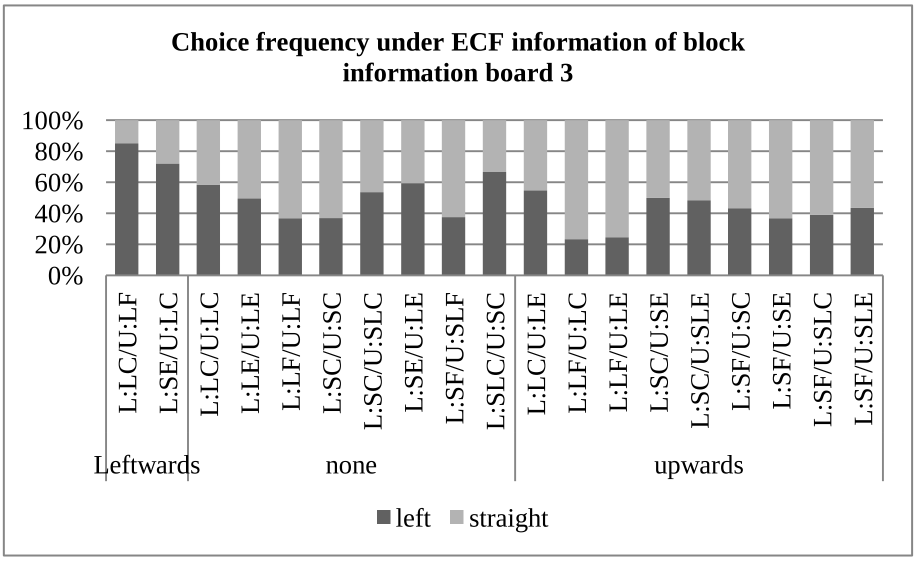


Figure 3.33: Choice frequency under ECF information of block information board 3, N=5153

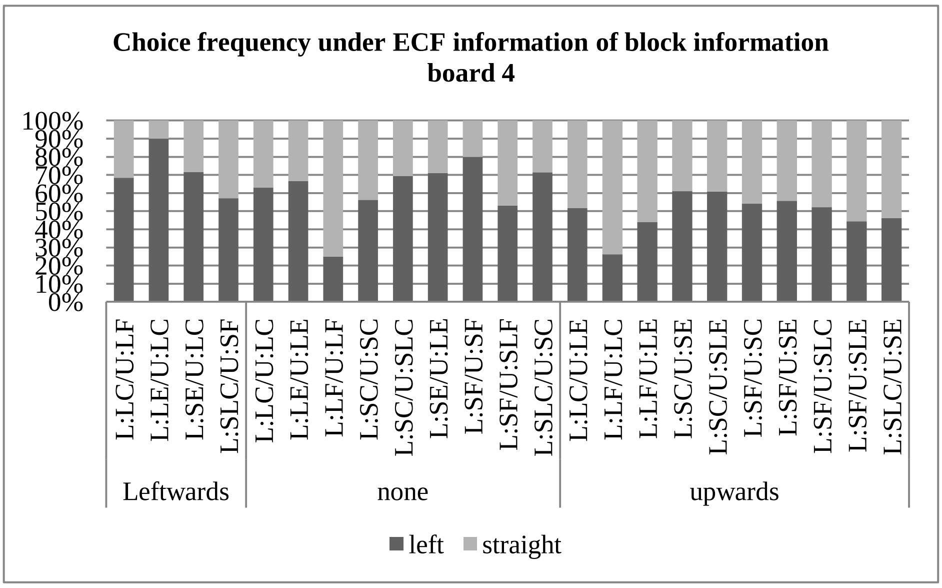


Figure 3.34: Choice frequency under ECF information of block information board 4, N=2518

Notes: "L:" – leftwards arrow on information signs; "U:" – upwards arrow on information signs; "LE" – occupancy status of large size vehicle is empty; "LC" – occupancy status of large size vehicle is congest; "LF" – occupancy status of large size vehicle is full; "SLE" – occupancy status of small and large size vehicle is empty; "SLC" – occupancy status of small and large size vehicle is congest; "SE" – occupancy status of small size vehicle is empty; "SC" – occupancy status of small size vehicle is congest; "SF" – occupancy status of small size vehicle is full; "—" – no information shown on this window.

As we can seen in the figure 3.30, under total four block information boards, for the leftwards priority, almost over 60% of small-size vehicle drivers have turned left and followed information guidance to park at less congested blocks. For the upwards priority, more than 70% small-size vehicle drivers have went straight and followed information guidance to park at less congested blocks under the information of "L:LF/U:LC", "L:LF/U:LE", "L:SF/U:SC", "L:SF/U:SE", "L:SF/U:SLC" and "L:SF/U:SLE"; and only more than 50% drivers have went straight and followed information guidance to park at less congested blocks under the information showing by leftwards arrow which occupancy status of blocks are congested. For the no priority situation, choice frequency of turning left varies from less than 30% to 80%. The result suggests that, drivers more likely to follow information guidance when the occupancy status is displayed by full, and in this situation, more than 70% drivers would follow the guidance of information signs. Otherwise, the effect of ECF information displayed by blocks information boards is not very significant. The reasons are :only over 60% drivers have turned left and followed guidance of information when showing blocks on left direction are less congested; only over 50% drivers have went straight and followed guidance of information when showing the front blocks are less congested especially the situation of information just displaying left side blocks are "congest".

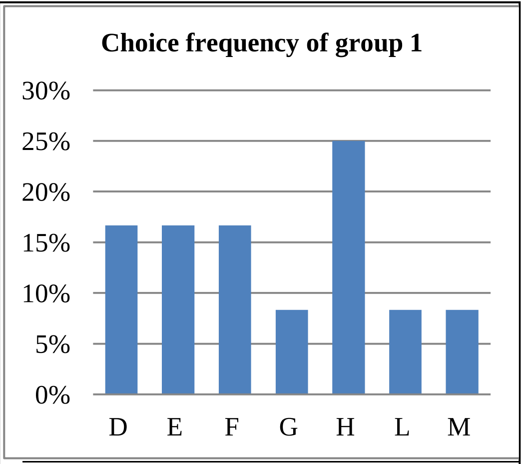
To compare figure 3.31, 3.32, 3.33 and 3.34, with the increasing of number of block information board, the ratios of choosing and parking at left side blocks have been increased when the parking guidance information is just guiding to turn left. It is therefore likely that, under effect of the block information board 1, only the drivers who chosen to park at block D and E can be seen as behavior of turning left, others (who chosen to park at block F, G, H, I, J, K ,L, M) are seen as behavior of going straight. With the varying of number of block information boards, in another word, when drivers have driven further and further, there are always two available blocks on the left side, but the number of remain available blocks in the front direction is less and less. Then, with the varying of number of block information board from 1 to 4, the proportion of drivers who choose to park at left blocks and follow the guidance of information signs has been increased comparing to the decreasing of number of available blocks in the front direction.

3.6.3 Impacts of parking area's ECF information on drivers' behavior

To analyze the effect of the information of all blocks' occupancy status which are provided in the same time, some information sample shown on the parking area information board B are adopted. The detail of displayed parking guidance information on each window and guided blocks of each window can be found in figure 3.25 (see section 3.5.2) and table 3.7 (see section 3.5.2). To simply the comparison, according to the similarity of parking guidance information, displayed information types are categorized into 22 groups. In this section, only drivers parking choice behavior under effect the ECF information displayed type group of No. 1, 3, 5, 6, 7,8, 11,12, 15 and 16 (see Table 3.7 in section 3.5.2) are summarized and compared. The results are shown in the figure 3.35, 3.36, 3.37, 3.38, 3.39, 3.40, 3.41, 3.42, 3.43 and 3.44 respectively. And the corresponding blocks of each window of area information board B guided block is listed in Table 3.10 as follow which also shown in the figure 3.25.

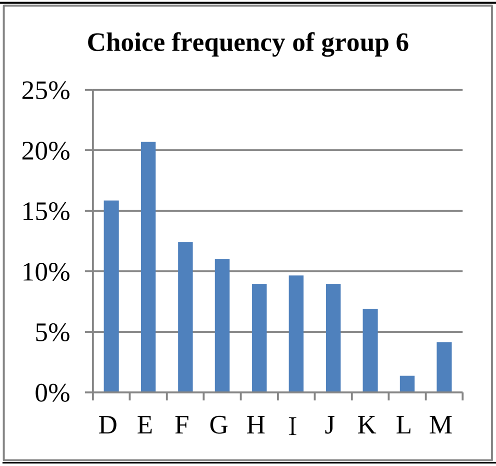
Table 3.10: Corresponding blocks of each window of area information board B

NO.	W7	W6	W5	W4	W3
Blocks	D, E	F, G	H, I	J, K	L, M



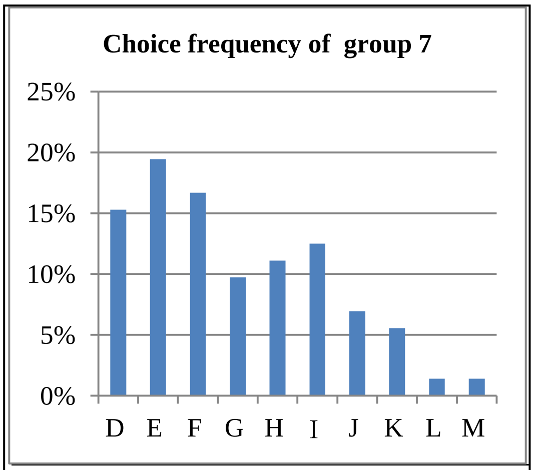
W7	W6	W5	W4	W3
E	C	E	E	E

Figure 3.35: Choice frequency of group 1, N=12



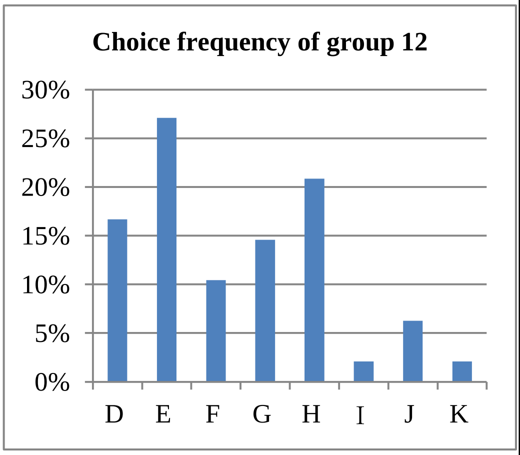
W7	W6	W5	W4	W3
F	C	E	E	E

Figure 3.36: Choice frequency of group 6, N=145



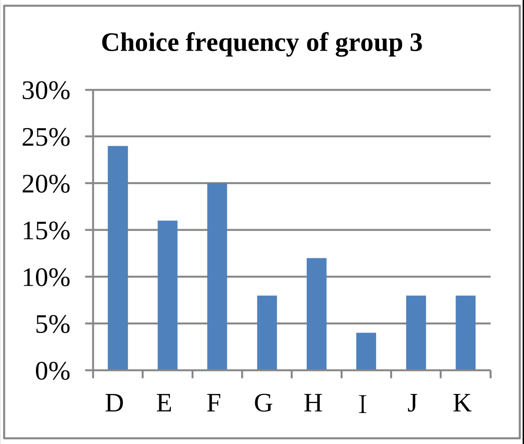
W7	W6	W5	W4	W3
C	C	E	E	E

Figure 3.37: Choice frequency of group 7, N=72



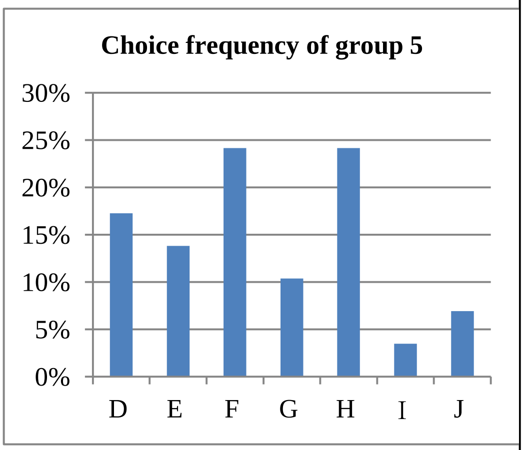
W7	W6	W5	W4	W3
F	F	E	E	E

Figure 3.38: Choice frequency of group 12, N=48



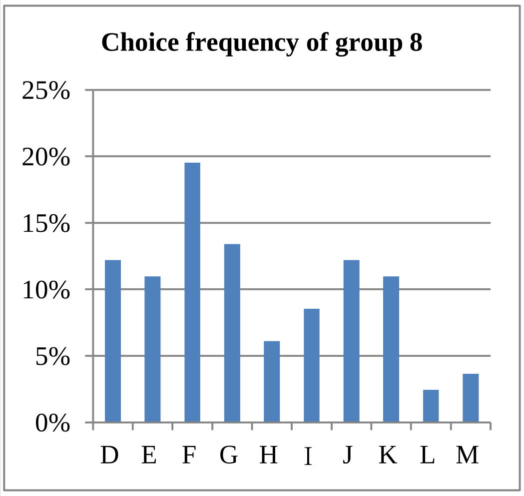
W7	W6	W5	W4	W3
C	E	C	E	E

Figure 3.39: Choice frequency of group 3, N=25



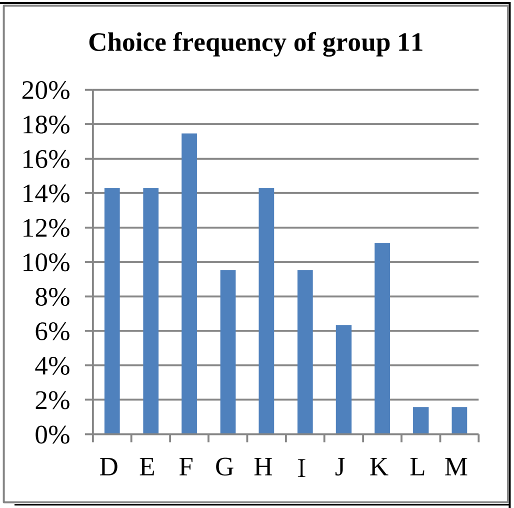
W7	W6	W5	W4	W3
F	E	C	E	E

Figure 3.40: Choice frequency of group 5, N=29



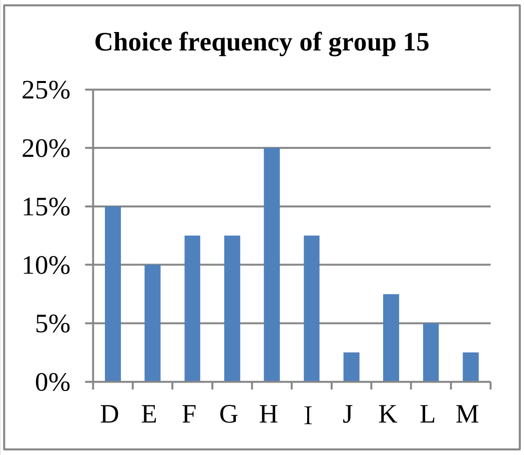
W7	W6	W5	W4	W3
F	C	C	E	E

Figure 3.41: Choice frequency of group 8, N=82



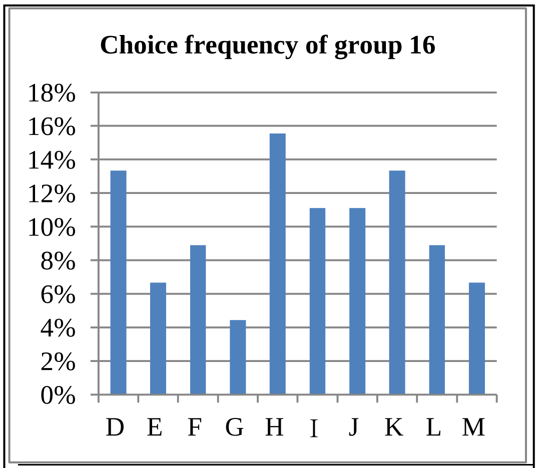
W7	W6	W5	W4	W3
F	F	C	E	E

Figure 3.42: Choice frequency of group 11, N=63



W7	W6	W5	W4	W3
F	F	C	C	E

Figure 3.43: Choice frequency of group 15, N=40



W7	W6	W5	W4	W3
F	F	F	C	E

Figure 3.44: Choice frequency of group 16, N=45

Notes: “W7” – seventh window of area information board B; “W6” – sixth window of area information board B; “W5” – fifth window of area information board B; “W4” – fourth window of area information board B; “W3” – third window of area information board B; “E” – occupancy status is empty regardless the type of vehicle; “C” – occupancy status is congested regardless the type of vehicle; “F” – occupancy status is full regardless the type of vehicle.

Figure 3.35, 3.36 and 3.37 have presented the block choice frequency of showing same information on window 6 (“congest”), window 5(“empty”), window 4 (“empty”), window 3 (“empty”) and different information on window 7 (“empty” in figure 3.37, “congest” in figure

3.36 and “full” in figure 3.37), the choice frequency of block D is 16% in figure 3.35, 16% in figure 3.36 and 15% in figure 3.37; the choice frequency of block E is 16% in figure 3.35, 21% in figure 3.36 and 19% in figure 3.37. It shows that even the occupancy status of block D and E shows “empty”, the ratio of selecting of block D, and E is not obviously higher than the ratio when shows “congest” or “full”. On the converse, when the displayed information on window 7 is “empty”, the ratio of selecting E is the lowest compare with the situations of showing “congest” and “full”.

See figure 3.37 and 3.38, when the information on window 3, 4 and 5 is same and displayed “empty”, the information on window 6 and 7 is “congest” in figure 3.37, “full” in 3.38, but the choice frequency of block is not obviously showing under guidance of information, the ratio of selecting block D in both figure 3.37 and 3.38 almost same, the ratio of selecting block E in figure 3.38 even higher than the ratio shown in figure 3.37. The percentage of choosing to park at block H in figure 3.38 is 21% higher than the data in figure 3.37. It may suggest the selection of block H is following the guidance of information but, according to the percentage of from block the selection from I to M is not higher in figure 3.38 comparing to 3.37, it cannot suggest that parking choice behavior follow the guidance to park at less congested blocks when window 7 and 6 shows “full” others shows “empty”.

Figure 3.39 and 3.40 present the block choice frequency of showing same information on window 6 (“empty”), window 5(“congest”), window 4 (“empty”), window 3 (“empty”) and different information on window 7 (“congest” in figure 3.39 and “full” in figure 3.40). In figure 3.39, the ratio of choosing block D is 24% and block E is 16% which are larger than the ratio of choosing block D equal to 17% and block E 14% in figure 3.40. It is therefore likely that driver who did follow the guidance of displayed ECF information on window 7 are more likely to park at block D and E especially under less congested situation.

Comparing figure 3.40, 3.41 and 3.42, the showing information is same on window 7(full), window 5(“congest”), window 4 (“empty”), window 3 (“empty”) and different on window 6 (“empty in figure 3.40, “congest” in figure 3.41 and “full” in figure 3.42), the ratio of selecting block F in figure 3.40 is 24%, 19% in figure 3.41 and 17% in figure 3.42; the ratio of selecting block G is 10% in figure 3.40, 13% in figure 3.41 and 9% in figure 3.42. As described that the displayed information on window 6 provides the occupancy status of block F and G. For the choice frequency of block F, when window 6 shows “empty”, the ratio of selecting block F is larger than the situation of when window 6 shows “congest” or “full”. It may suggest that drivers’ selection of block F follows the guidance information shown on window 6. But, for the choice frequency of block G, when window 6 shows “empty”, the ratio of selecting block G is even smaller than the ratio of when window 6 shows “congest”. It may suggest that drivers’ selection of block G is not obviously follow the guidance information shown on window 6.

As present in figure 3.43 and figure 3.44, the showing information is same on window 7(“full”), window 6(“full”), window 4 (“congest”), window 3 (“empty”) and different on window 5 (“congest” in figure 3.43, “full” in figure 3.44), the ratio of choosing block H is 20% in figure 3.43, 16% in figure 3.44; the ratio of choosing block I is 12% in figure 3.43, 11% in figure 3.44. The result of choice frequency of block H and I under the displayed information of “congest” is much higher than the ratio of selecting block H and I when showing information of “full” on window 5. It may suggest that, when only the displayed information on window 5 is different, drivers are prefer to park at less congested blocks especially the situation of when the window 7 and window 6 also shows “full”.

The results shown in above 10 figures may suggest that drivers are more likely don’t follow the guidance of ECF information when the total occupancy status of the parking area isn’t congested. The guidance effect of the difference between guidance information of “congest” and “full”; “empty” and “congest” is not very obvious. The guidance effect of difference between guidance information of “empty” and “full” seems much more obvious when most of windows also showing “full”. To summarize the analysis, drivers’ parking choice behavior following the guidance ECF information but seems not very obviously. The reason probability is some drivers are more care about the characteristic of blocks themselves no matter under what guidance information the window displayed on.

3.6.4 Impacts of ASL information on drivers’ behavior

As described in the former experiment design introduction section 3.1.2, during 10:00 ~ 13:00 on 23rd June 2013, visual parking guidance information signs showed the occupancy status of each block by showing ASL information which can be seen in the figure 3.7 (see section 3.2.3). To give a completely impression of the effect of the ASL information, the varying tendency of choice frequency of all blocks with the increasing of number of available space of objective block (from 0 to 12) has been analyzed in this section. Figure 3.45, 3.46, 3.47 and 3.48 presents the result of choice frequency of blocks with varying of number of available space of some blocks.

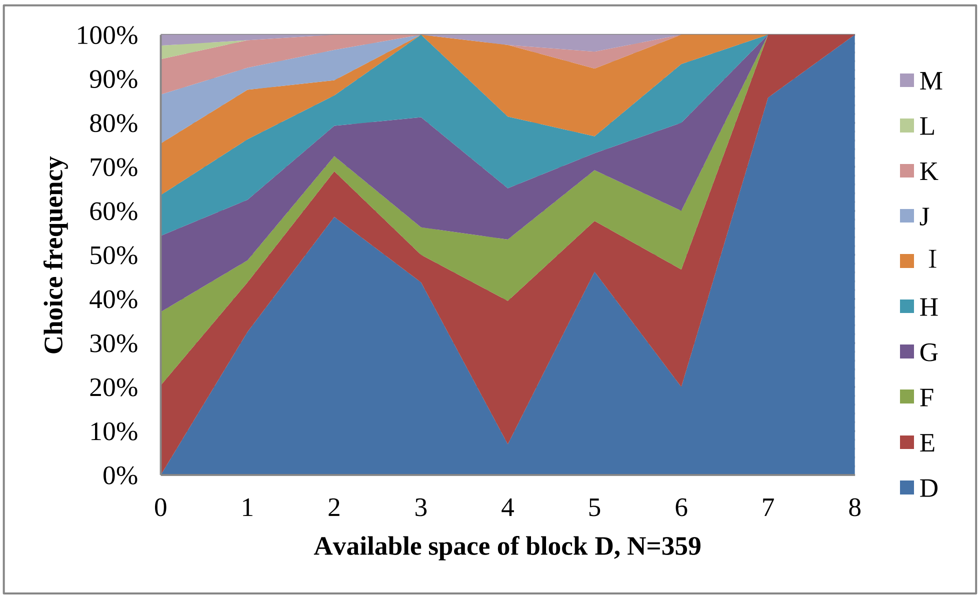


Figure 3.45: Choice frequency of blocks with varying of number of available space of block D

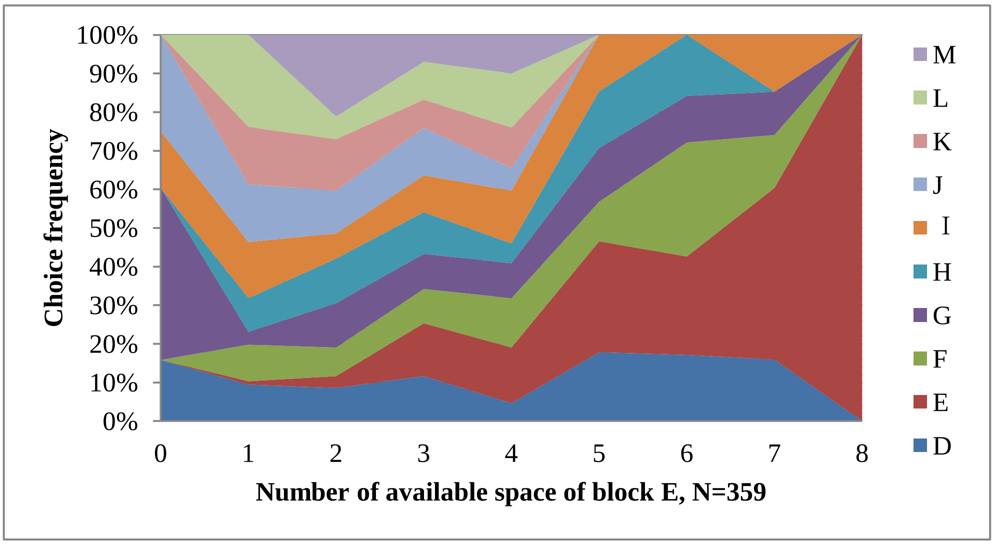


Figure 3.46: Choice frequency of blocks with varying of number of available space of block E

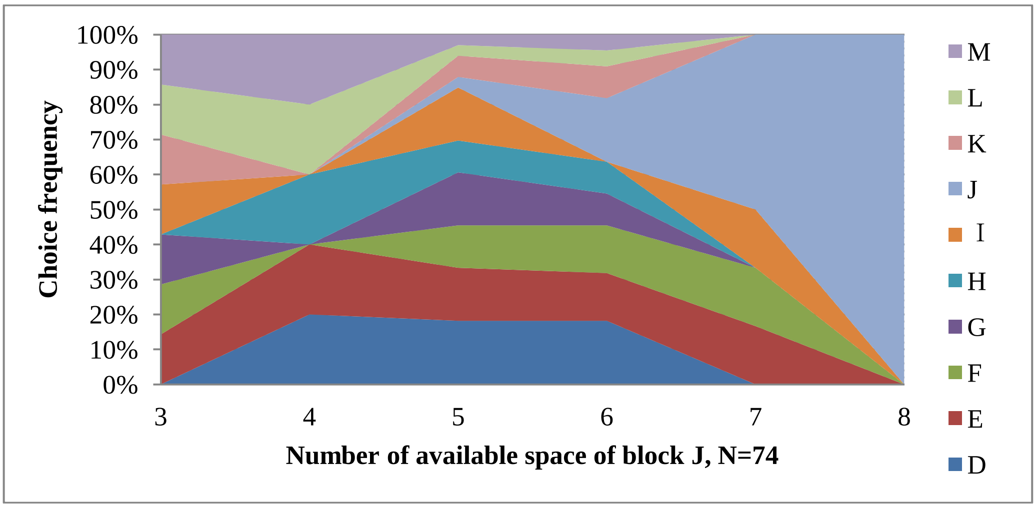


Figure 3.47: Choice frequency of blocks with varying of number of available space of block J occupancy rate is over 60%

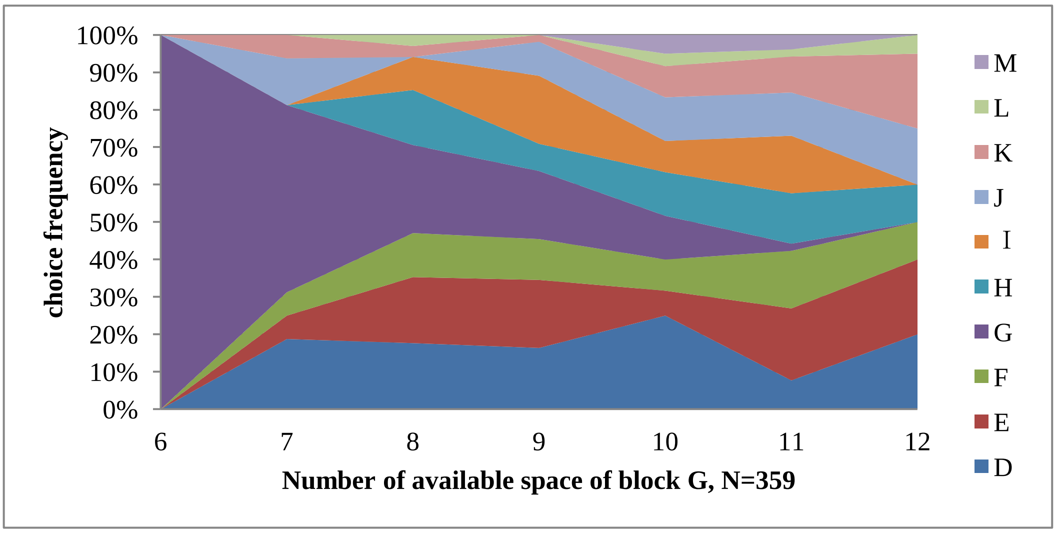


Figure 3.48: Choice frequency of blocks under vary of number of available space of block G

In our expectation, drivers are more likely to choose the uncongested block after received the information about number of available space of preferred blocks. The result has shown in Figure 3.46 suggests that the ratio of selecting block E enhanced with the increasing number of available space of block E vary between 0 and 8. Some cases can meet the expectation and only can be occurred when satisfied some specific conditions. The result has shown in figure 3.47 explains that, only when the occupancy rate of parking area is over 60%, the ratio of selecting block J will be enhanced with the increasing of number of available space of block J from 3 to 8. Some interesting results can also be found in figure 3.48, that the ratio of selecting block G has been reduced with the increasing of number of available space of block G from 6 to 12. And the result has shown in figure 3. 43 suggests that the ratio of selecting block D will show an enhancing tendency with the increasing number of available space of block D vary between 0 to 8, but the ratio of choosing block D decreasing sharply when the number of available space of block D is 4 and 6. The reason of interesting result happened in figure 3.45 and figure 3.48 probably because the difference of characteristics of decision makers, some drivers are more sensitive to the PGI system and willing to make a decision according what information they acquired, but some drivers are less sensitive to the PGI system and willing to make a decision based their own preference and recognition of characteristics of alternatives.

3.7 Impacts of information on drivers’ behavior with parking route data

As mentioned in the former sections, in the second part of experiment, the individual driver’s parking route data have been merged with parking guidance information signs’ data and individual driver’s parking data. In this section, the impact of PGI on drivers’ parking behavior with observed data of individual driver’s parking route will be explored. Besides, the main factors which may obviously influence drivers’ parking choice behavior will also be determined in this section.

3.7.1 The effect of walking distance factor

In the former section 3.4.3, we compared block choice frequency under different displayed type of PGI, ECF information, ASL information and null information situation. The result can be summarized in the Table 3.11 as follow. Then the cumulative choice frequency of each block under different displayed type of PGI is depicted in figure 3.49.

Table 3.11: Choice frequency under different displayed type of PGI

Block	Choice frequency				
	ECF info. a (%)	ECF info. b (%)	ECF info. c (%)	Null info. c (%)	ASL info. c (%)
D	16	17	16	16	20
E	18	16	17	16	18
F	12	15	10	11	12
G	14	12	17	19	14

H	9	12	13	10	11
I	9	8	13	14	11
J	6	8	6	5	6
K	7	7	5	5	5
L	4	2	1	1	1
M	5	3	2	3	2

Notes: a – observed data during 8th ~ 19th Sep 2012; b – observed data on 9th June 2013; c – observed data on 23rd June 2013.

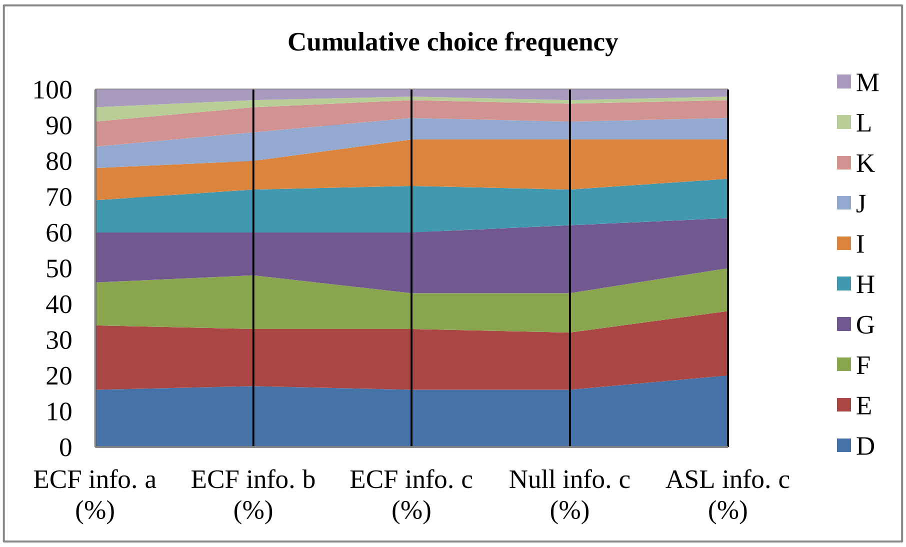


Figure 3.49: Cumulative block choice frequency under different displayed type of PGI

As summarized in the Table 3.11 and figure 3.49, the total ratio of choosing block D, E, F, G, H (about 70%) is much higher than the total ratio of choosing block I, J, K, L, M (about 30%) no matter of under what displayed type of information. As we known in the figure 3.4 in section 3.2.3, block D, E, F, G, H are close to the entrance of parking area compare to block I, J, K, L and M. Besides, the total ratio of selecting former five blocks – D, E, F, G, H is over 70% which is obviously greater than the total ratio of selecting further five blocks – I, J, K, L and M. The most likely thing is that the factor of walking distance form entrance to the preferred block significantly affects drivers' parking choice decision making process no matter under what displayed type of information.

3.7.2 The parking choice probability of whether pass ABC block

According to the individual parking route data, it can be found that many drivers are insensitive to the delivering parking occupancy status information shown on the PGI signs. They would like to drive through the blocks from the closest one to distant one and searching for their preferred block against to the expectation that drivers make a parking decision and drive to their destination block directly after acquired information. As can be seen in the figure 3.4, in the upstream of study area, block A, B and C are separated from block D, E, F, G, H, I, J, K, L and M into an independent zone by planting configuration. The research object of parking alternatives are block D, E, F, G, H, I, J, K, L and M. in this section, after entered into the parking area, drivers' parking route can be divided by whether or not pass block A,B and C, see figure 3.50. The results of drivers' behavior and selection under different displayed information based on the second experiment on June 9th and 23rd of 2013 (three displayed type of information – ECF information, ASL information and Null information) are shown in the figure 3.51, 3.52, 3.53, 3.54, 3.55, 3.56, 3.57 and 3.58 respectively.

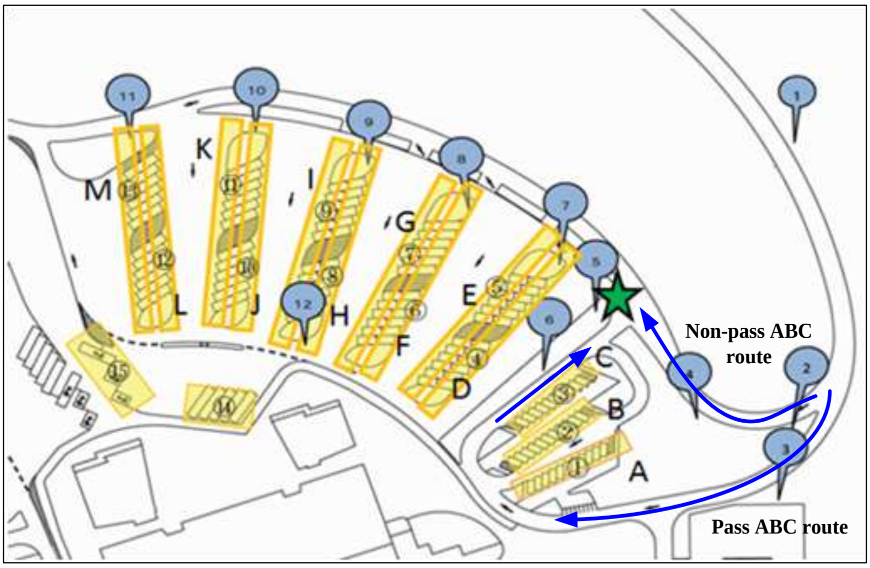


Figure 3.50: Driver behavior from star point dividing by whether pass ABC block

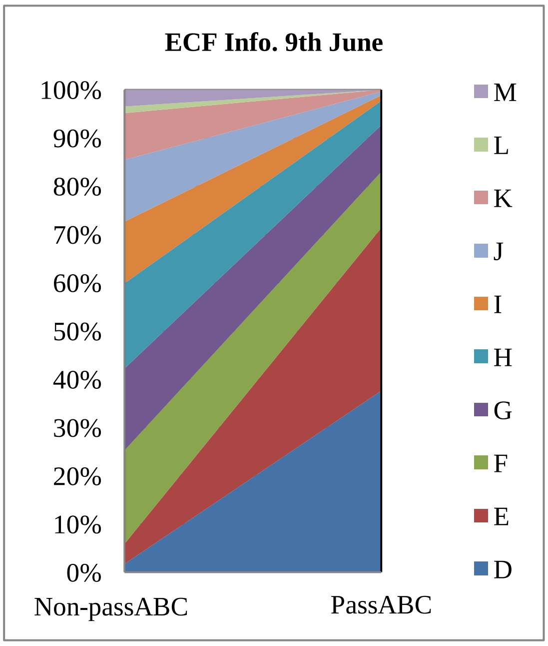


Figure 3.51: Block choice frequency of 9th June under ECF information divided by whether pass ABC block, N=547

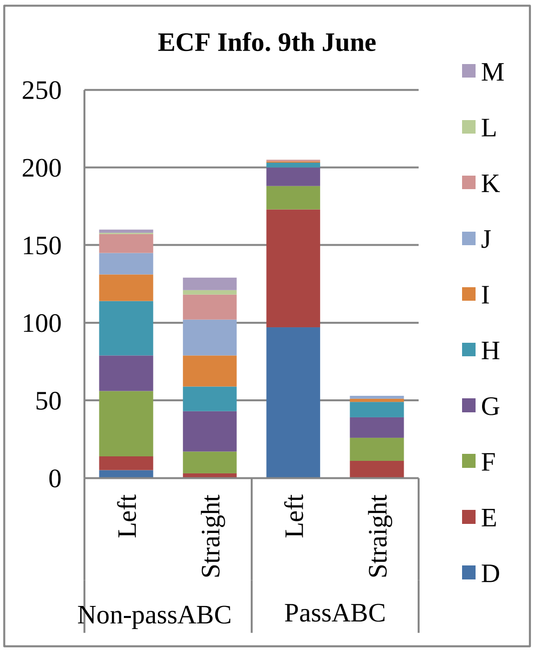


Figure 3.52: Block choice number of 9th June from star point under ECF information divided by whether pass ABC block, N=547

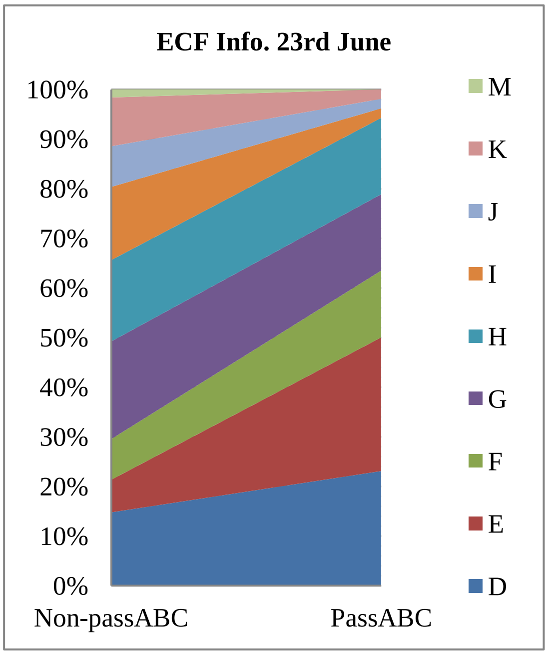


Figure 3.53: Block choice frequency of 23rd June under ECF information divided by whether pass ABC block, N=113

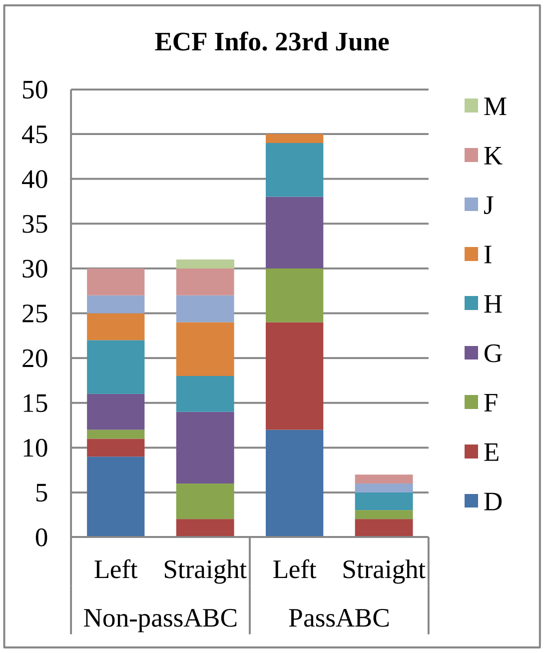


Figure 3.54: Block choice number of 23rd June from star point under ECF information divided by whether pass ABC block, N=113

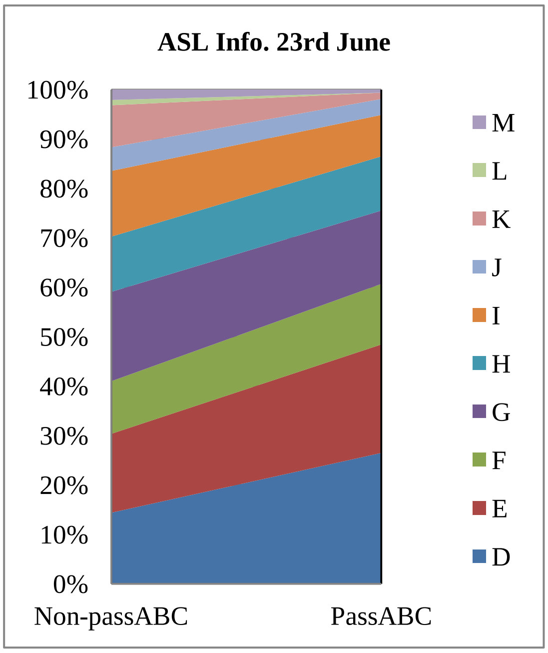


Figure 3.55: Block choice frequency of 23rd June under ASL information divided by whether pass ABC block, N=300

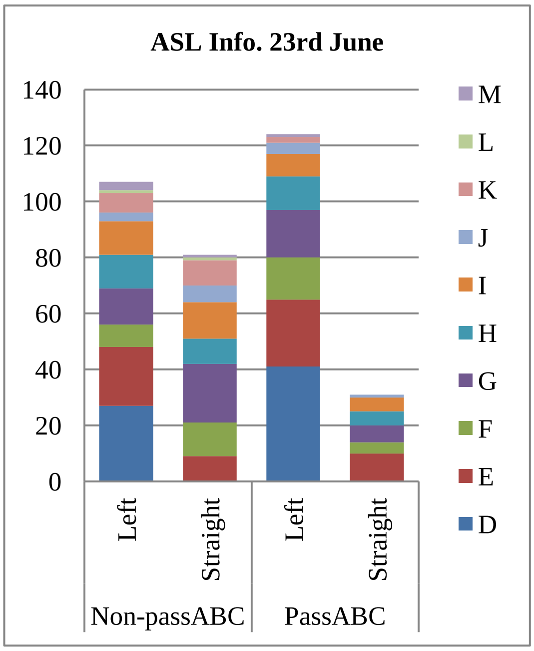


Figure 3.56: Block choice number of 23rd June from star point under 23rd June divided by whether pass ABC block, N=300

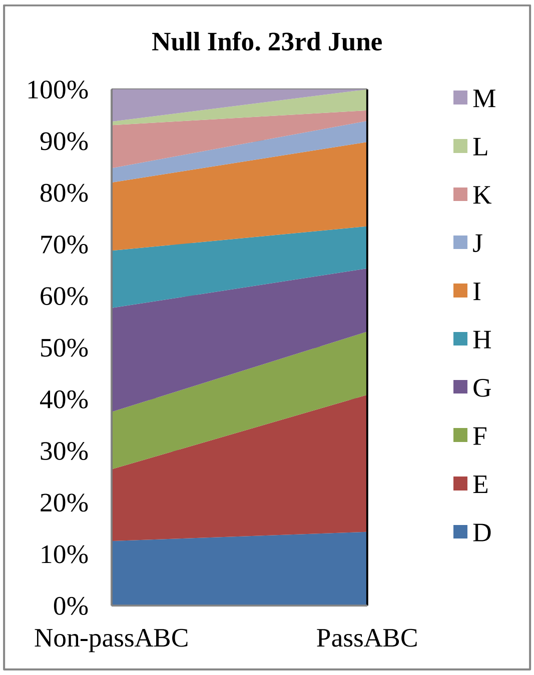


Figure 3.57: Block choice frequency of 23rd June divided by whether pass ABC block, N=193

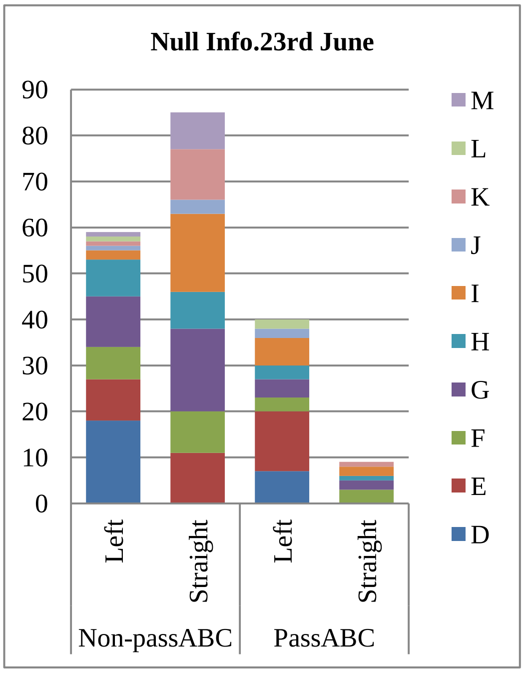


Figure 3.58: Block choice number from star point divided by whether pass ABC block, N=193

Notes: “Non-pass ABC” – drivers who don’t pass A, B and C block; “PassABC” – drivers who pass A, B, and C block; “Left” – drivers’ behavior of turning left at the green star point; “Straight” – drivers’ behavior of going straight at the green star point.

As can be seen in figure 3.51, 3.53 and 3.55, for the drivers who passed A, B and C block, the choice percentages of block D, E are higher than the ratio of drivers who didn't pass A, B and C block under both the effect of ECF information and ASL information. Figure 3.57 shows that under the effect of Null information, for the choice percentage of block D, there isn’t big difference between the drivers who passed and didn’t pass A, B, and C block; only for the ratio of choosing block E, drivers who passed A, B and C block is much higher than drivers who didn’t pass A, B and C block.

Figure 3.52, 3.54, 3.56 and 3.58 suggest that no matter under what kind of displayed information, for the drivers who passed A, B and C block, the ratio of turning left at the green star point (see figure 3.50) is much higher than the ratio of heading straight, but the ratio of choosing each block is different under a variety of displayed type information. And for the drivers who didn't pass A, B and C block, under the effect of ECF information and ASL information, the ratio of turning left at green star point (see figure 3.50) is also higher than the ratio of heading straight but the difference is not as greater as the case of drivers who passed A, B and C block. Besides, under the effect of Null information, the result is opposite with the case of under ECF information and ASL information, that the ratio of heading to straight forwards at green star point is higher than the ratio of heading straight. The results suggest that, drivers who didn’t pass A, B and C blocks under the guidance of null information system, they prefer to park at further blocks such as F, G, H, I blocks may because of considering the high risk of congested status of closed blocks and avoiding the congested risk. Under the different displayed information (ECF information and ASL information) on the same day (June 23rd), for the driver who didn't pass A, B, C blocks, the total ratio of selecting block J, K, L and M is seems no different no matter whether the information is guiding for turning left or heading straight. It may suggest that, the choice of block J, K, L and M is not reflect the response to the guidance information. But, under the null information in figure 3.58, for the driver who didn't pass A, B, C blocks, when the information is guiding for heading to further blocks ("straight"), the total ratio of choosing block J, K, L and M is much higher than information is guiding for turning left, and even greater than under same guidance direction in figure 3.52 (ECF information), figure 3.54 (ECF information) and figure 3.56 (ASL information). For the driver who passed A, B, C blocks, the total ratio of choosing block J, K, L and M is too small to be used for analyzing the behavior response correspond with choice frequency.

Also the total ratio of choosing blocks of D, E, F and G is greater than the total ratio of choosing blocks of H, I, J, K, L and M no matter under what displayed type of information. Especially for the drivers who passed A, B, C blocks and turned left at the star point(see figure 3.50), the highest ratio is appeared on 9th June, and the total ratio of choosing block D, E, F, and G almost is over 90% under the effect of ECF information.

For the drivers who intend to turn left even after passed A, B and C block, they are probably significantly influenced by the factors of characteristics of blocks such as walking distance factor. Then in the next section 3.7.3 and 3.7.4, to highlight the effect of ECF information and ASL information, the effect of dynamic information will be analyzed by except those drivers and only focus on the drivers who seems more sensitive to the PGI system.

3.7.3 The effect of ECF information

According to the analyzed result in the section 3.7.2, is has been known that some drivers are probably significantly influenced by the factors of characteristics of blocks themselves. To explicitly the effect of ECF information simplicity, drivers' response to ECF information of second experiment on the 9th June 2013 will be analyzed. And, for the drivers who passed A, B, C blocks and still intended to turn left at the star point (see figure 3.50) are not considered in this section as has been explained in section 3.7.2 to highlight the effect of ECF information and ASL information on the drivers who seems more sensitive to the information system. As shown in the figure 3.50, for the drivers who chose the route of pass A, B, C blocks may not notice the area information board B which is named as number 5, after entered into zone from block D ~M, they may be more sensitive to the information on the block information board 1 which is defined as number 7 (see figure 3.50). In addition, for the drivers who chose the route of non-pass A, B, C blocks may notice both the area information board B which is named as number 5 and block information board 1 which is named as number 7 (see figure 3.50). As presented in the section 3.5.2, the ECF information shown on parking area information board is listed in Table 3.7 and the ECF information shown on block information board 1 is listed in Table 3.8. To simplify the description, the content of ECF information listed in Table 3.7 and 3.8 will not be relisted in this section. For the drivers who passed A, B and C blocks and not chose to turn left at the star point, their behavior under the ECF information of block information board 1 is shown in the figure 3.59. Moreover, for the drivers who didn't pass A, B and C blocks, their choice behavior under ECF information of block information board 1 is shown in the figure 3.60 and figure 3.61.

Besides, the effect of ECF information displayed on parking guidance information board B will be explored based on drivers who didn't pass A, B, C blocks. The reason is it may difficult for drivers who passed A, B, C blocks to notice the parking area information board B. The summarized results are shown in the figure 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67 respectively. To ensure the sample number is big enough, the ECF information type group number is adopted based on the Table 3.7 in section 3.5.2.

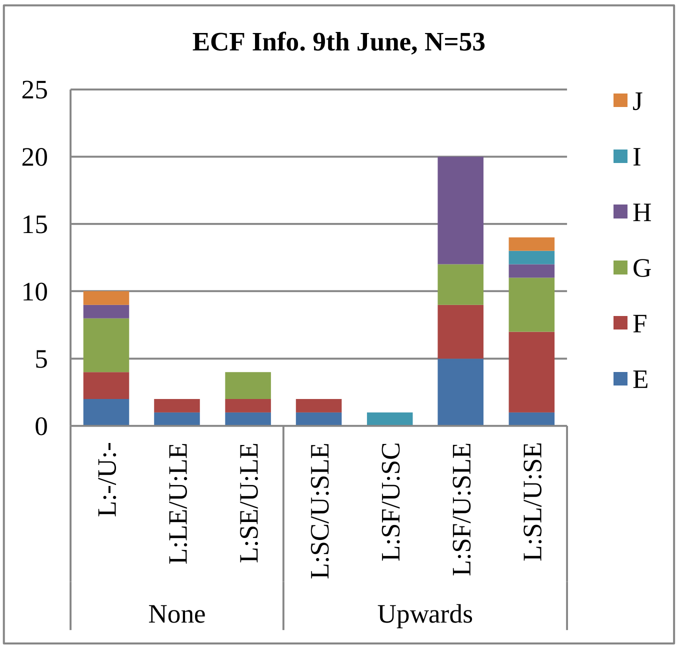


Figure 3.59: Block choice number of drivers who passed ABC blocks and went straight under the effect of ECF information on block information board 1

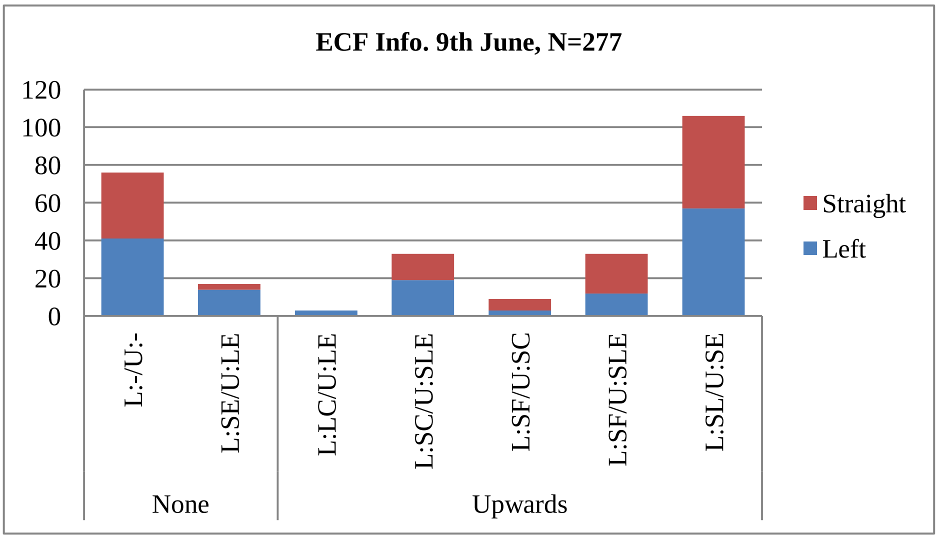


Figure 3.60: Drivers' response at star point for those who didn't pass ABC blocks under the effect of ECF information of block information board 1

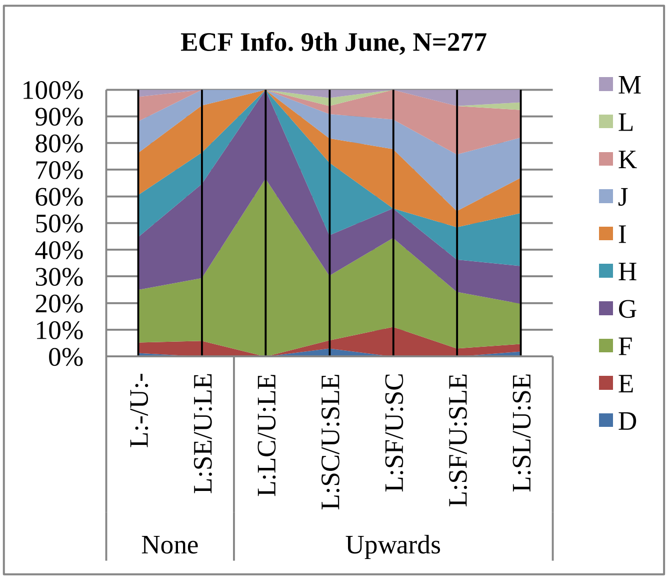
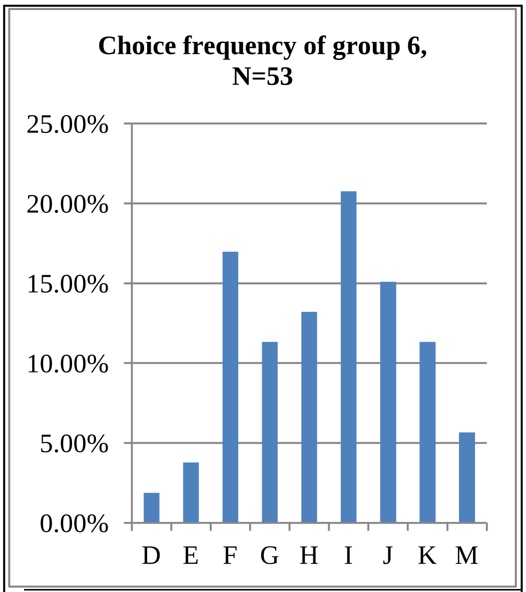


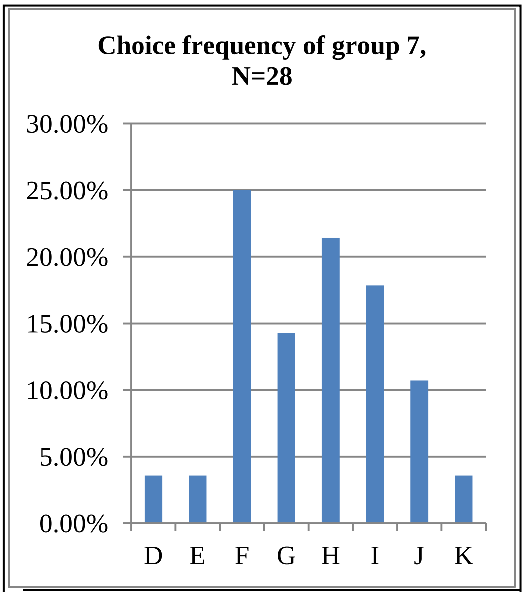
Figure 3.61: Block choice frequency of drivers who didn’t pass ABC blocks under the effect of ECF information of block information board 1

Notes: “L:” – leftwards arrow on information signs; “U:” – upwards arrow on information signs; “SE” – large size vehicle; “S” – small size vehicle; “E” – current occupancy status is empty; “C” – current occupancy status is congest; “F” – current occupancy status is full; “-” – on information shown. “Upwards” – the information of guiding upwards direction is less congested then the leftwards direction; “None” – the information of guiding upwards direction and leftwards direction is same.



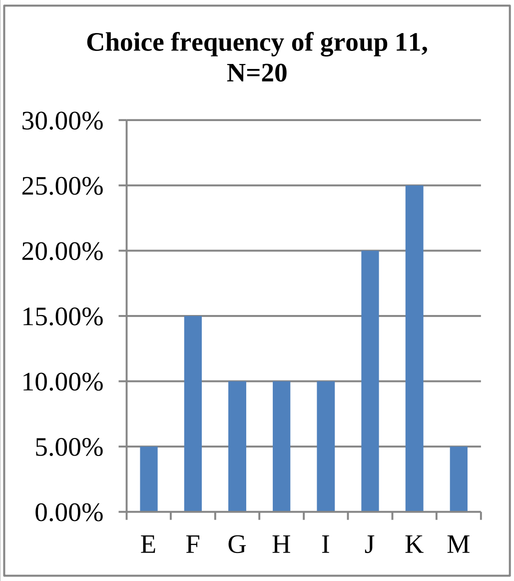
W7	W6	W5	W4	W3
F	C	E	E	E

Figure 3.62: Block choice frequency of drivers who didn’t pass ABC blocks under ECF information of group 6 of parking area information board B



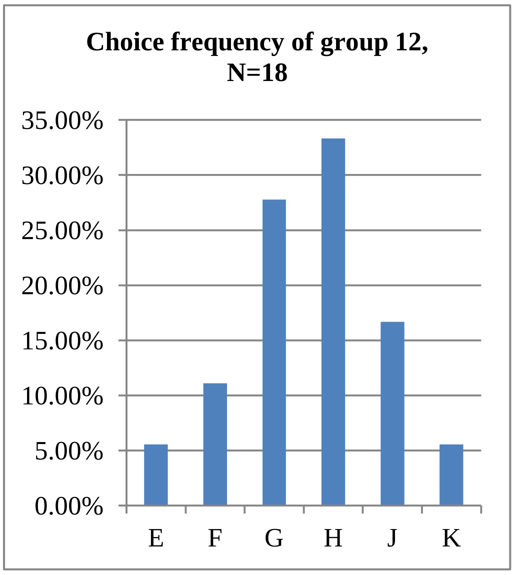
W7	W6	W5	W4	W3
C	C	E	E	E

Figure 3.63: Block choice frequency of drivers who didn’t pass ABC blocks under ECF information of group 7 of parking area information board B



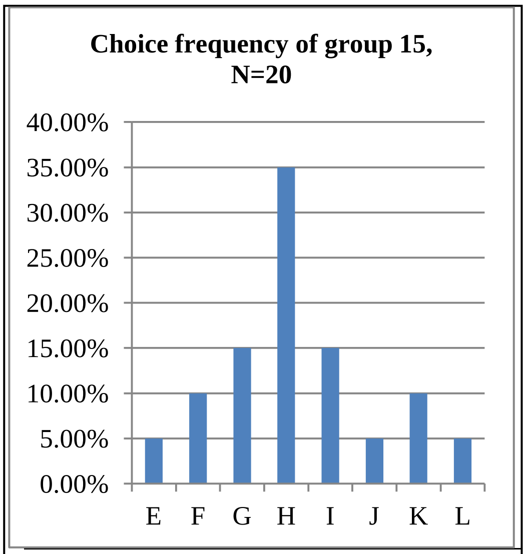
W7	W6	W5	W4	W3
F	F	C	E	E

Figure 3.64: Block choice frequency of drivers who didn't pass ABC blocks under ECF information of group 11 of parking area information board B



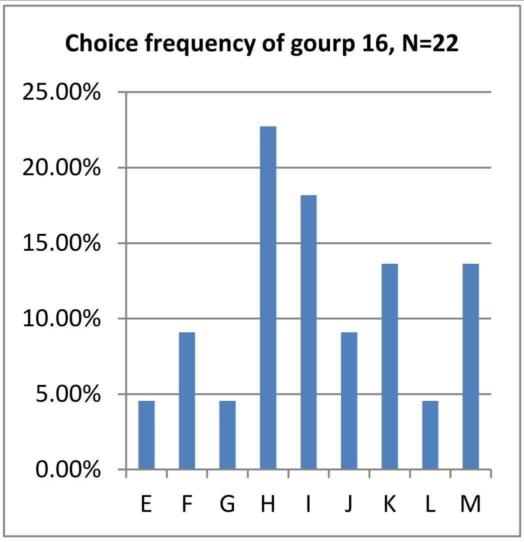
W7	W6	W5	W4	W3
F	F	E	E	E

Figure 3.65: Block choice frequency of drivers who didn't pass ABC blocks under ECF information of group 12 of parking area information board B



W7	W6	W5	W4	W3
F	F	C	C	E

Figure 3.66: Block choice frequency of drivers who didn't pass ABC blocks under ECF information of group 15 of parking area information board B



W7	W6	W5	W4	W3
F	F	F	C	E

Figure 3.67: Block choice frequency of drivers who didn't pass ABC blocks under ECF information of group 16 of parking area information board B

Notes: "L:" – leftwards arrow on information signs; "U:" – upwards arrow on information signs;

"LE" – occupancy status of large size vehicle is empty; "LC" – occupancy status of large size vehicle is congest; "LF" – occupancy status of large size vehicle is full; "SLE" – occupancy status of small and large size vehicle is empty; "SLC" – occupancy status of small and large size vehicle is congest; "SE" – occupancy status of small size vehicle is empty; "SC" – occupancy status of small size vehicle is congest; "SF" – occupancy status of small size vehicle is full; "－" – no information shown on this window.

As shown in the figure 3.59, for drivers who passed A, B and C blocks and went straight at green star point, only under the guidance information of "L: SL/U: SE", the total number of choosing block F, G, H, I, J is much higher than the situation of under guidance information of non-priority. Under effect of other types of guidance information, compared with total ratio of choosing block F, G, H, I and J, the ratio of choosing block E is not obviously different under different the information priority. Besides, figure 3.60 and 3.61 present that, for the drivers who didn't pass A, B, C blocks, they follow the guidance information which providing the occupancy status of one direction is obviously prior (less congested) than another direction, such as the guidance information of "L: SF/ U: SLE" and "L: SE/ U: LE".

As shown in the figures of 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67 of displayed information group of 6, 7, 11, 12, 15, and 16 (the define of information group see table 3.7 in section 3.5.2), for the drivers who didn't pass A, B, C blocks, they have received the guidance information displayed on parking area information board B. Then as summarized in the figure 3.62 and 3.63 (information group 6 and 7), the ratios of choosing further blocks such as F, G, H, I, J, K are much larger, moreover, the ratio of selecting block F of information group 7 is obviously higher than the same ratio of information group 6.

Compare the effect of information group 11 and 12, both the ratios of selecting block J and K are over 20% and larger than ratios of other selections of group 11. Additionally, both the ratios of selecting block G and H are over 25% and much higher than other ratios of selecting other blocks in group 12. The above results indicate that when only window 5 displayed different information and same information ("full") in window 7 and window 6, also same in window 4 and window 3 ("empty"), the ratio of selecting block is obviously different. It is therefore likely that the drivers did follow the information guidance.

Look over the effect of information group 15 and 16, see figure 3.66 and 3.67, the ratio of selecting block H is the almost reach 35% and which is the largest compare with the ratios of selecting other blocks under the effect of information group No.15. Under the effect of information group No.16, the ratio of choosing block H is over 20% and which is still the highest, moreover, the ratios of choosing other blocks are also very high, such as the ratio of choosing block I, K, M ranging from 14% to 18%. It can be attributed that, for the information group No.16, when the information shown on window 7, window 6 and window 5 is same as "full", drivers are more likely to choose further blocks such as block I, K or M compare with the situation of information group No.15. It suggests that drivers significantly follow the information guidance displayed on parking area information board B.

3.7.4 The effect of ASL information

According to the analyzed result in the section 3.7.2, some drivers are probably significantly influenced by the factors of characteristic of blocks. To explore the effect of ASL information simplicity, drivers' behavior response to ASL information will be analyzed in this section based on the data collected from second experiment on the 23rd June 2013. As shown in the figure 3.23 (in section 3.5.2), the number of available space cannot be displayed on the parking area information board B because of the design limitation. Moreover, as shown in the figure 3.25, 3.26, 3.27, 3.28 and 3.29, the percentages of selecting block J, K, L and M are few and nearly remain unchangeable no matter under the effect of what type of displayed information. This suggests that the effect of difference types of displayed information on the drivers' choice behavior of selecting block J, K, L and M is not obvious.

Then, except the choice of block J, K, L and M, the effects of ASL information (displayed information by four block information boards, see figure 3.24) on drivers' behavior is analyzed in this section based on the data collected on 23rd June 2013. To get a deep impression of impacts of PGI on drivers' behavior, the relationship between choice frequency, $\sum y_i(t)$ and the difference of available space between the selected block and the block with maximum empty space at same time, $AS_i(t) - Max\{AS_i(t)\}$ is presented in Figure 3.68. $AS_i(t)$ is defined as the number of available space of selected block i at time t , i denotes the alternative blocks from D to I, $y_i(t)=1$, if block i is chosen otherwise zero.

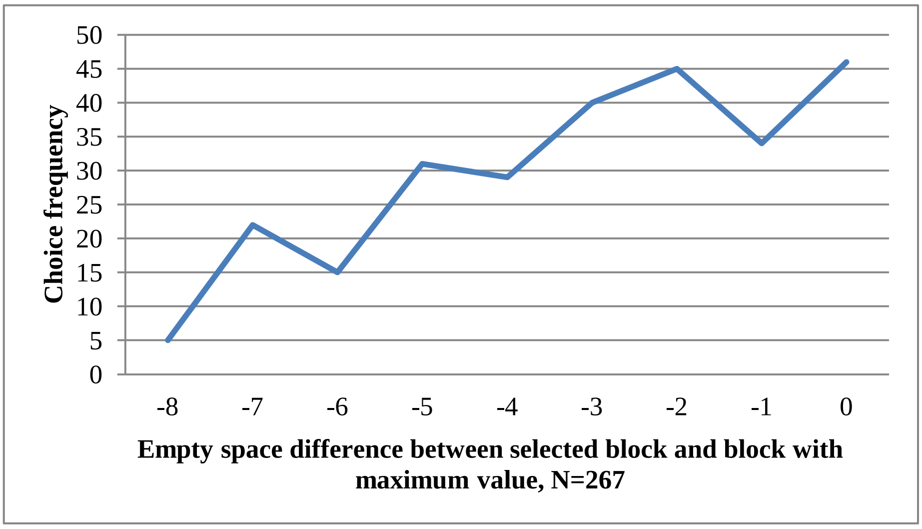


Figure 3.68: Relationship between choice frequency and difference of empty space

The result suggests that, without considering the choice of block J, K, L and M, the block choice frequency has been increased with the reducing of difference of available space between the selected block and the block with maximum empty space. It means that drivers consider the factors of the available space of blocks and its difference with maximum empty space when making a parking decision.

3.8 Conclusion

In this chapter, the effect of parking guidance information on drivers' behavior through the aspects of whether or not considering the observed individual parking route data under different types of displayed information have been analyzed. And then, the main factors which may affect drivers' decision making process are explored and discussed. It has been found that the walking distance factor significantly influence drivers' parking choice under the effect of both ECF information and ASL information. After merged the observed individual parking route data and eliminated the drivers who seems more care about the characteristics of blocks (drivers who turned left at star point even after passed A, B and C blocks), the effect of ECF information and ASL information are analyzed by categorized and summarized different information groups. Then, after eliminated the sample of drivers who turned left at star point even after passed A, B and C blocks, it therefore likely that drivers did follow the guidance of both ECF information and ASL information to find a more uncongested block. On the other hand, for the drivers who didn't pass A, B and C blocks, they are more sensitive to the information displayed on the parking area information board B. Block J, K, L and M are least likely alternatives no matter their occupancy statuses are displayed by what types of information. In the next chapter, the parking choice model will be established based on the result what have been found in this chapter.

3.9 References

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4 Modeling parking choice behavior

4.1 Introduction

In this chapter, firstly the existing work in the field of Birth-Death processes and model structure of discrete choice analysis is presented. With the analyzed result of PGI impact on drivers' parking choice behavior in the chapter 3, the drivers parking choice model with the effect of PGI and without the effect of PGI will be established in this chapter. The discussion in this chapter is structured as follow. After a brief look at the background of Queueing theory, Random utility model, Multinomial logit model and maximum log-likelihood estimation method in the section 4.2, and then queuing theory is adopted to describe drivers' arrival and departure process and estimate the following distribution of arrival and duration interval in section 4.3. In the section 4.4, drivers parking choice models under the effect of null information (without PGI), ECF information (with PGI) and ASL information (with PGI) are presented. The estimated results of above three models are given and compared in section 4.5.

4.2 Background of parking choice model

4.2.1 Background of queueing theory

In the queueing theory, the birth-death process is a special case of continuous-time Markov process and the most fundamental example of a queueing model. There are two types of state transitions – "birth" and "death". "Birth" is defined as the increase of state variable by one; "death" is defined as the decrease of state variable by one. The birth-death process was first developed by W. Feller in 1939 to describe the problem of population growth of stochastic processes. He considered the application of expected birth and death rates among other examples and defined the birth and death rates were constant value and could be any specified functions of the time t.

When a birth occurs, the process goes from state n to n+1. When a death occurs, the process goes from state n to state n-1. The process is specified by birth rate $\{\lambda_i\}_{i=0\ldots\infty}$ and death rates $\{\mu_i\}_{i=0\ldots\infty}$.

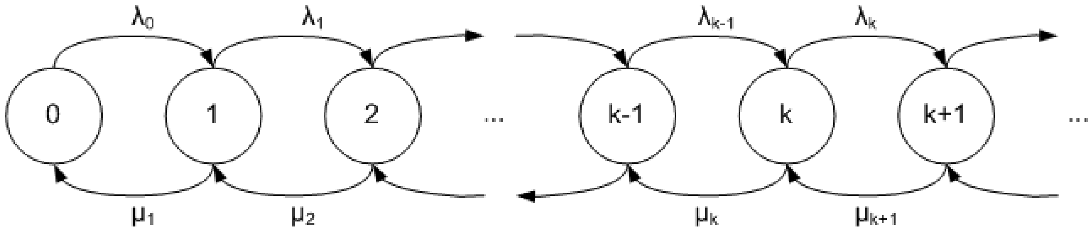

Figure 4.1: Birth and death process[3)]

For the steady-state distribution, the birth-death process can be expressed as follow,

$$P_i = \frac{\lambda_0 \cdots \lambda_{i-1}}{\mu_1 \cdots \mu_i} P_0, \quad i = 1, 2, \cdots, \quad P_0^{-1} = 1 + \sum_{i=1}^{\infty} \frac{\lambda_0 \cdots \lambda_{i-1}}{\mu_1 \cdots \mu_i} \tag{4.1}$$

In probability theory, a passion process is a continuous-time process; a simplest example of a birth-death process which counts the number of events and the time that these events occur in a given time interval. The time between each pair of consecutive events has an exponential distribution with parameter λ and each of these inter-arrival times is assumed to be independent of other inter-arrival times. Besides, the service time (duration time) has an exponential distribution with parameter μ and each of these duration times is assumed to be also independent of other duration times. And the probability density function of exponential distribution is

$$f(\lambda, t) = \lambda e^{-\lambda t} \tag{4.2}$$

Many researchers made effort in finding condition expressed in transition probability of Markov process with continuous path functions. Chung (1955) examined the relation of the continuity properties of the paths of Markov process. In dealing with continuous state spaces, karlin (1957 and 1959), Ray (1956) found that analytic conditions has been possible to describe large classes of process whose path functions are continuous in the interior of the space.

Markov chain model have been apply for determine transition probabilities in many field such as for determining infrastructure hazard transition probability, e.g. Mishalani's (2002) and Kobayashi (2011) or traffic assignment model, e.g. Hazelton (2002). All of the above researches are based on an assumption of constant transition probabilities.

In this paper, queuing theory is applied to describe the arrival and departure probability of drivers, besides, the sequential parking choice activities is based on the assumption of dynamic transition probabilities.

4.2.2 Background of Random utility model

Random utility models attached with a subset of the class of probabilistic choice models, was firstly developed by psychologists who attempt to characterize observed inconsistencies in patterns of individual behavior. Then, Block and Marshak (1960) gave a systematic definition of random utility model as follow:

Let α *be a finite set of alternatives,* T *be a finite population of decision makers and let* $\in^c$ *mean 'is chosen from'. Then choice is consistent with a random utility model is there exist real valued random variables* U_{at} *, all* $a \in \alpha$ *,* $t \in T$ *such that* $\Pr_t\left(a \in^c C'\right) = \Pr\left(U_{at} \geq U_{a't}, a' \in C'\right)$ *for all alternatives* $a \in C$*, all non-null choice sets* $C \subset \alpha$ *and all decision makers* $t \in T$.

Later, McFadden (1968) developed econometric representation of maximizing behavior based on such models. In his formulation, utilities are treated as random variables not to reflect a lack of rationality in the decision maker but to reflect a lack of information regarding the characteristic of alternatives and decision makers. Random utility models assume the decision maker has a perfect discrimination capability. However, the incomplete information is assumed in the research, so the uncertainty must be taken into account. Manski (1977) identified four different sources of uncertainty: unobserved alternative attributes; unobserved individual characteristics (also called "unobserved taste variations"); measurement errors; and proxy, or instrumental, variables.

The utility is modeled as a random variable in order to reflect this uncertainty. More specifically, the utility that individual n associates with alternative i in the choice set C_n is given by

$$U_{in} = V_{in} + \varepsilon_{in} \tag{4.3}$$

Where, V_{in} is the deterministic (or systematic) part of the utility, and ε_{in} is the random term, capturing the uncertainty. The alternative with the highest utility is chosen. Therefore, the probability that alternative i is chosen by decision-maker n from choice set C_n is

$$P(i \mid C_n) = P\left[U_{in} \geq U_{jn}, \forall j \in C_n\right] = P\left[U_{in} = \max_{j \in C_n} U_{jn}\right] \tag{4.4}$$

Many potential models can be applied to derive the random parts of the utility function. The most popular are Logit model and Probit model. The main models belong to Logit family is the Multinomial Logit model, the Nested Logit model, the Cross-Nested model and the Generalized Extreme Value model. In this thesis, we adopted the Multinomial Logit model to describe drivers' behavior under the effect of PGI in chapter 4. The background of Multinomial Logit model is introduced in 4.2.3. The background of Multinomial Probit model is introduced in 5.2.2.

4.2.3 Background of multinomial logit model

The Multinomial Logit (MNL) model is the most basic and widely used model forms of discrete choice mode. Discrete choice models belonging to the family of Random Utility Models (RUM) which have been in many field of social scientists such as transportation choices, housing choices, health economics, and marketing choices. The Logit formula was first derived by Luce (1959) and Marschak (1960), Luce stated the probability of selecting one item over many items which is not affected by the presence of absence of other items and such selection can be called as"independence from irrelevant alternatives"; Marschak (1960) presented the constrain of binary choice and showed that the model is consistent with utility maximization. The model within the Logit family is based on a probability distribution function of maximum of a series of random variable, introduced by Gumbel (1958). McFadden (1974) firstly discussed the estimation of conditional logit model and its statistical properties and implied the use of the type I extreme value (Gumbel) distribution for unobserved part of the utility into Logit formula.

There are also numerous approaches leading to the derivation of the Logit choice probabilities. Domencich and Mcfadden (1975), Ben-Akiva and Lerman (1985) derived Logit choice probability by using the properties of the Gumbel distribution. Train (2003) derived the Logit choice probability by using explicit integration of the multivariate cumulative distribution of the different error term. But the most common approach was developed by McFadden (1974), using integration of the first derivative of the multivariate cumulative distribution of the error term over the range of possible value of other error terms. The MNL choice probability for alternative i and decision maker n is given by

$$P_n\left(i\right)=\frac{e^{V_{i,n}}}{\sum_{j=1}^{I}e^{V_{j,n}}} \tag{4.5}$$

Where, the choice probabilities' calculation is not related with the error terms. The assumption of iid errors is essential to the derivation of Logit model and which can also be called "independent and identically distributed random utility" models (IIDRU) by Manski (1977). After then, the behavior of the MNL model is strictly followed the assumption of independence from irrelevant alternatives (IIA), the ratio of the choice probability of MNL for two different alternative is independent of the attributes or even existence of other alternatives. That means the change in the probability of a given alternative draw equally from the probabilities of all the other alternatives in the choice set. There are many researches who fours on criticizing the effects of the IIA property (Hausman and Wise, 1978), critiquing the Luce' use of the IIA assumption (Tversky, 1972), arguing with some justification that IIA property should rather be called independence of relevant alternatives property or independence among alternatives property (Debreu, 1960).

Logit and Probit are two main formulas for the choice probabilities. Many other models are generated based on standard Logit and Probit model such as Mixed Logit and GEV family which includes Nested Logit, Paired Combinatorial Logit and generalized Next Logit. Chernoff and Zacks (1964) propose a special case of this general model in which there is a constant probability of change at each time point (not dependent on the history of change points). Peeta (2004) presented a new link-nested Logit model which is derived as a particular case of the generalized extreme-value class of discrete choice model. Frejinger (2007) justified the use of original path size formulation among the deterministic correlations of the IIA assumption on the random terms in a multinomial Logit model.

For applying Logit model to describe route choice behavior, Peter (1998) presented a new link-nested logit model which is derived as a particular case of the generalized-extreme-value class of discrete choice model. Ben-Akiva (1999) presented the alternative discrete choice model forms of Logit, Nested Logit, Generalized Extreme Value and Probit, Hybrid Logit and the Latent Class choice model, then elaborated on the applications of these models to short term travel decision. Dugundji (2005) described and illustrated the interdependencies in discrete choice based on an empirical application to mode choice through use of mixed generalized extreme value (GEV) model structure.

4.2.4 Background of maximum log-likelihood estimation

Maximum likelihood estimation is the most popular general purpose method for obtaining estimating a distribution from a finite sample, which is proposed by Fisher (1922) to state that the desired probability distribution is the one that makes the observed data "most likely" which means to find the value of parameter vector to maximize the likelihood function. Cramér (1946) presented a unique consistent root to the likelihood equation under standard regularity conditions, then Tarone and Gruenhage (1975) extended and indicated that root is consistent in case of several roots applying multi-dimensional generalization. Wald (1949) firstly selected the root leading to the maximum likelihood value and established consistency of global maximize of the likelihood under some conditions. Then Kiefer and Wolfowitz (1956) noticed that for some Gaussian mixtures, the global maximize of the likelihood is not always true.

In practice, a search for all roots corresponding to local maximization may take the considerable time and the found value is not guarantee under searching all local maximize. Barnett (1966) gave an example of unbounded number of roots. To solve above problem, De Haan (1981) proposed a p-confidence interval of the maximum likelihood value, Markatou et al, (1998) proposed a random staring point method to construct automatically bootstrap in a reasonable search region. Heyde (1997) and Heyde and Morton (1998) proposed to apply a goodness-of-fit criterion for selecting the best root or picking the root which the Hessian of the log-likelihood behave asymptotically.

Combined with former research result, the definition of maximize the likelihood function is shown as follow,

Let $X^{(1)},\ldots,X^{(n)}$ *be sampled iid from a distribution with a parameter* θ *that lies in a set* Θ. *The maximum likelihood estimator (MLE) is the* $\theta \in \Theta$, *that maximizes the likelihood function*

$$L(\theta)=L\left(\theta \mid X^{(1)},\ldots,X^{(n)}\right)=p_\theta\left(X^{(1)},\ldots,X^{(n)}\right)=\prod_{i=1}^{n} p_\theta\left(X^{(i)}\right) \tag{4.6}$$

Where p *above is the density function if* X *is continuous and the mass function if* X *is discrete. In practice it is often more convenient to work with the logarithm of the likelihood function, called the Log-likelihood:*

$$\ln L(\theta)=\ln L\left(\theta \mid X^{(1)},\ldots,X^{(n)}\right)=\sum_{i=1}^{n}\ln p_\theta\left(X^{(i)}\right) \tag{4.7}$$

Indeed, $\hat{\theta}$ *estimates the expected log-likelihood of a single observation in the model. The method of maximum likelihood estimates by finding a value of* θ *that maximizes* $\hat{\ell}(\theta \mid x)$. *This method of estimation defines maximum-likelihood estimation (MLE).*

Maximum likelihood estimation is widely used in many statistical models such as linear models and generalized linear models; exploratory and confirmatory factor analysis; structural equation modeling; many situations in the context of hypothesis testing and confidence interval formation; discrete choice models and curve fitting. For the field application, maximum likelihood estimation is widespread in communication systems; psychometrics; econometrics; time-delay of arrival in acoustic or electromagnetic detection; magnetic resonance imaging; data modeling in nuclear and particle physics and so on.

4.3 Distribution of data arrival and departure rates

As mentioned in the section 3.4.1, the number of arrival vehicle from the date of 15th April 2012 to the date of 18th September 2012, total 71 days are analyzed. To give a clearly impression of levels of parking arrival, departure and parking congestion, there sample date with highest, medium and lowest number of arrival vehicle are used for analyzing the performance of congestion status in the peak date, medium peak date and non-peak date. The total number of arrival vehicle on the date of 6th May 2012 (highest number), 27th May 2012 (medium number) and 12th September 2012 (lowest number) is 4439 vehicle/ day, 3473 vehicle/day and 2452 vehicle/day respectively. Then the model description and model summary of arrival time interval, duration time interval of date 6th May 2012 (highest number), 27th May 2012 (medium number) and 12th September 2012 (lowest number) is summarized in the Table 4.1. The models' regression estimation between choice frequency and arrival time interval of date 6th May 2012 (highest number), 27th May 2012 (medium number) and 12th September 2012 (lowest number) is shown in the figure 4.1, 4.3 and 4.5 respectively. Then the models' regression estimation between choice frequency and duration time interval of date 6th May 2012 (highest number), 27th May 2012 (medium number) and 12th September 2012 (lowest number) is shown in the figure 4.2, 4.4 and 4.6 respectively.

Table 4.1: Model description and exponential model summary

	N	R Square	Std. Error of the Estimate	Coefficient	T value	Sig.
AT Interval [a]	4439	.811	.840	-.900	-17.570	.000
DT Interval [a]	4439	.574	1.175	-.941	-14.695	.000
AT Interval [b]	3473	.497	1.083	-.705	-13.049	.000
DT Interval [b]	3473	.690	1.681	-.831	-21.087	.000
AT Interval [c]	2452	.817	.907	-.595	-29.977	.000
DT Interval [c]	2452	.861	1.334	--.861	-22.550	.000

Note: a – sample date of 6th May 2012 (highest number); b – sample date of 27th May 2012 (medium number); c – sample date of 12th September 2012 (lowest number); AT – arrival time; DT – duration time

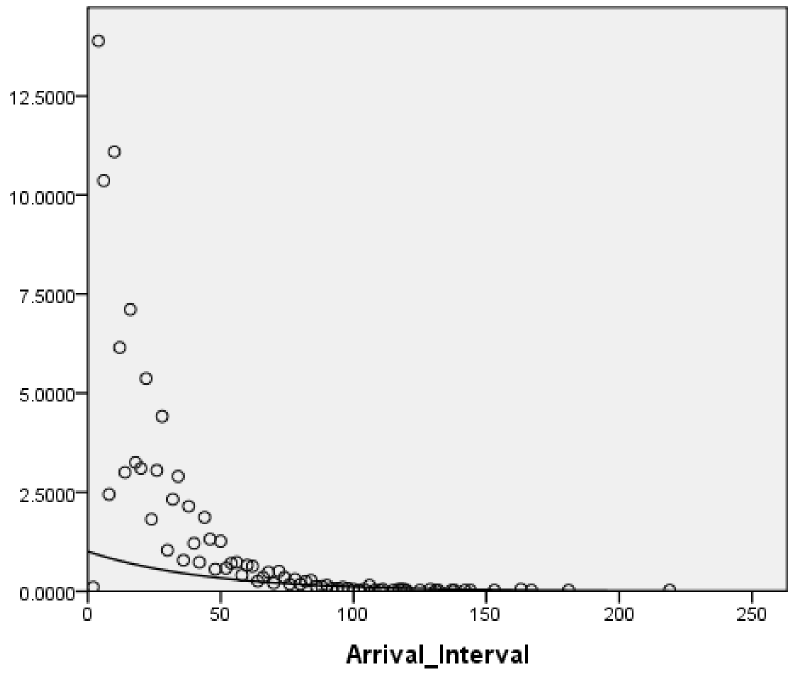

Figure 4.2: Curve estimation between choice percentage and arrival time interval on 6th May 2012

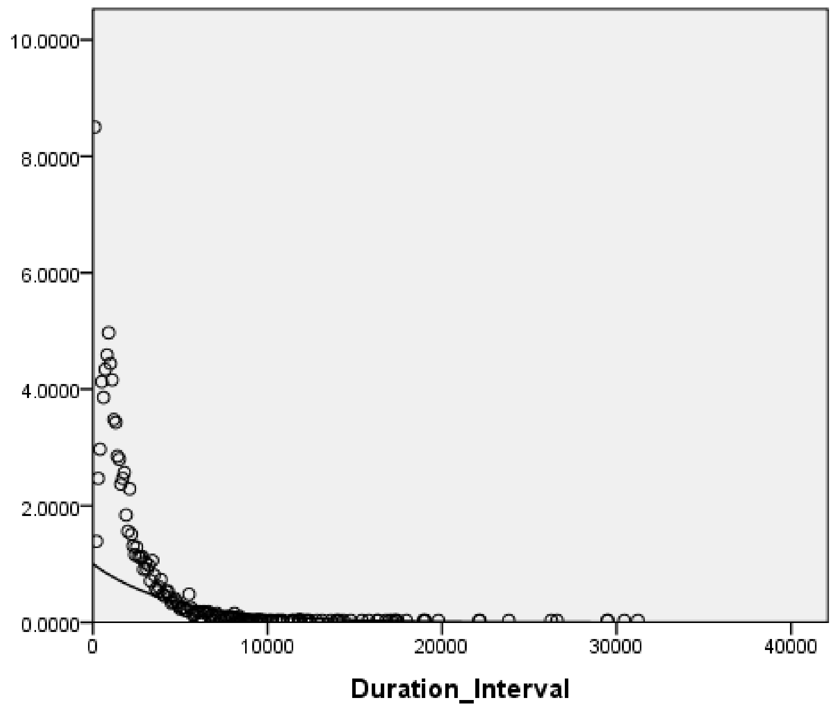

Figure 4.3: Curve estimation between choice percentage and duration time interval on 6th May 2012

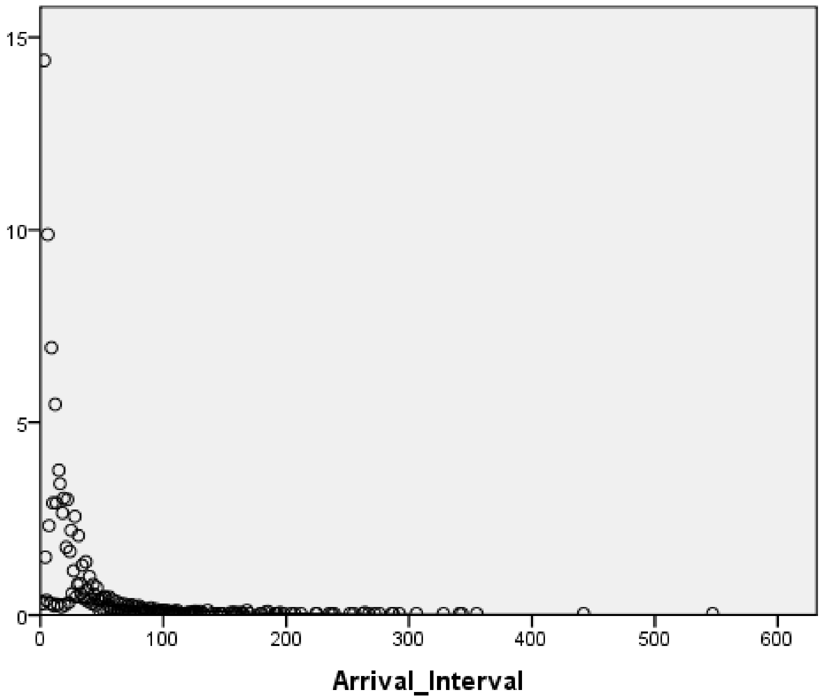

Figure 4.4: Curve estimation between choice percentage and arrival time interval on 27th May 2012

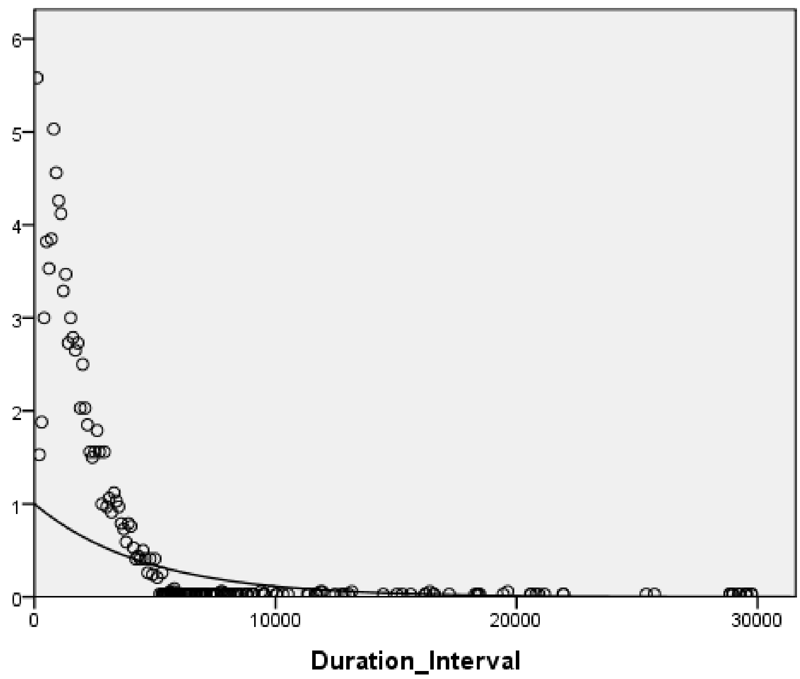

Figure 4.5: Curve estimation between choice percentage and duration time interval on 27th May 2012

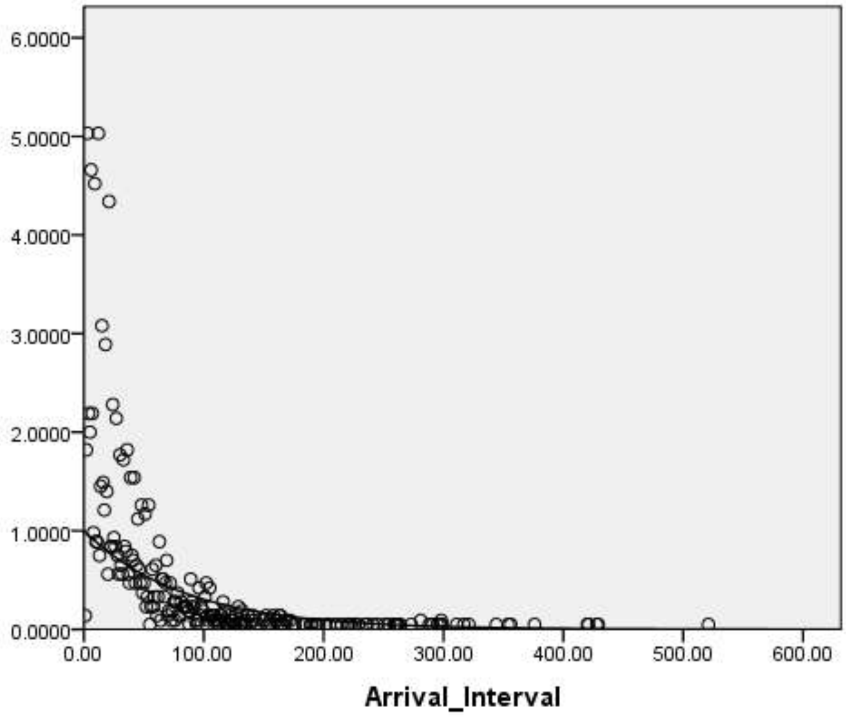

Figure 4.6: Curve estimation between choice percentage and arrival time interval on 12th September 2012

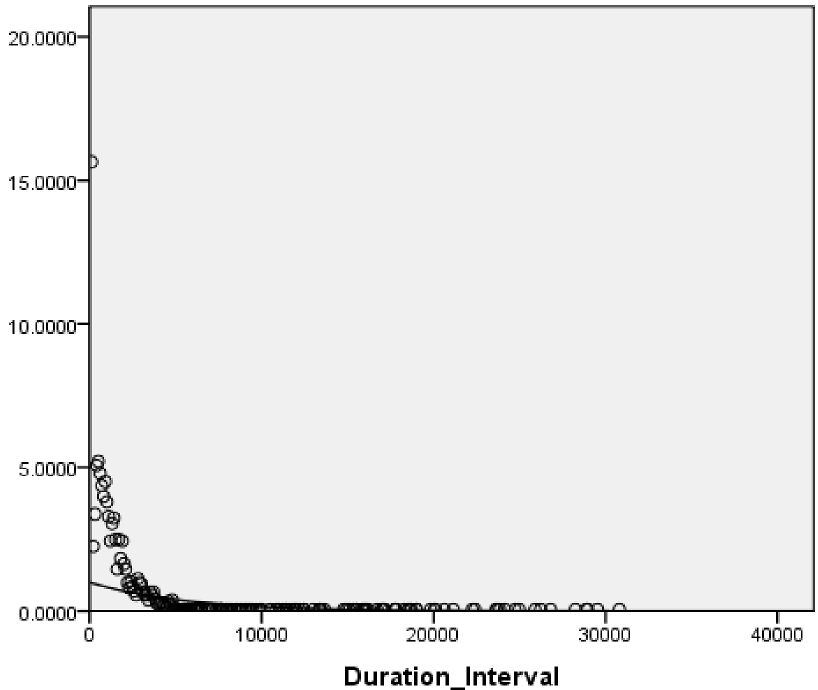

Figure 4.7: Curve estimation between choice percentage and duration time interval on 12th September 2012

4.4 Parking choice model with information and without information

4.4.1 General frame work

In a parking area, there are I alternatives for driver to make a parking decision, or we can say there are I rows of parking spaces. In this paper, each row of parking spaces can be seen as a parking block, which denotes as one alternative. After entered into the parking area, drivers could receive the information related to the occupancy status of each block which is displayed on the PGI signs, and make a decision according to driver's own preference and understanding based on acquisition from PGI. In this thesis, Multinomial Logit (MNL) model is applied to describe drivers parking choice behavior under both with PGI and without PGI cases, simplified parking choice behavior with PGI and without PGI is shown in the figure 4.8.

In this thesis, according to the classification of displayed type of information: null information, ECF information, and ASL information, null information case can be considered as without PGI; both ECF information and ASL information are belonging to the situations of with PGI. As we found in the chapter 3, drivers' response may be different even under the same displayed type of information, for the drivers who passed A, B, and C blocks are more sensitive to the characteristics of alternatives themselves; for the drivers who didn't pass A, B, and C blocks more prefer to follow the guidance of showing content on PGI signs. As mentioned in the chapter 3, only the second experiment which conducted on 9th June 2013 and 23rd June 2013 has been recorded individual parking route data. Then in this chapter, the experiment data of both 9th June 2013 and 23rd June 2013 are used to estimate the parameter of parking choice model.

To explore effect of different displayed of parking guidance information on drivers, in this chapter, we analyze the impacts of null information (without PGI), ECF information (with PGI), and ASL information (with PGI) on drivers who didn't pass A, B, C blocks and no matter of whether passed A, B, C blocks or not.

Based on the analyzed result in chapter 3, we found walking distance factor significantly influence drivers' parking choice behavior. Moreover, we also found the occupancy status of block J, K, L and M by displaying type of both the ECF information and ASL information seems not significantly affect drivers' decision making of parking at block J, K, L and M. Thus, in this chapter, for the establishment of parking choice model of without PGI (null information) and with PGI (ECF information and ASL information), there are only 6 alternatives – block D, E, F, G, H and I. Besides, at a certain extent, ECF information and ASL information also affect drivers parking choice behavior. For estimation of parking choice model under the null information, we only pick up the characteristics of blocks themselves. For the different displayed type of information – parking choice model under ECF information, we will pick up both the characteristics of blocks themselves and the occupancy rate of each block (at some extent, ECF information roughly represent the occupancy rate of each block); for the parking choice model under ASL information, we will also pick up both the characteristics of blocks themselves and the number of available space of each block (at some extent, ASL information provide the information of number of available space of each block).

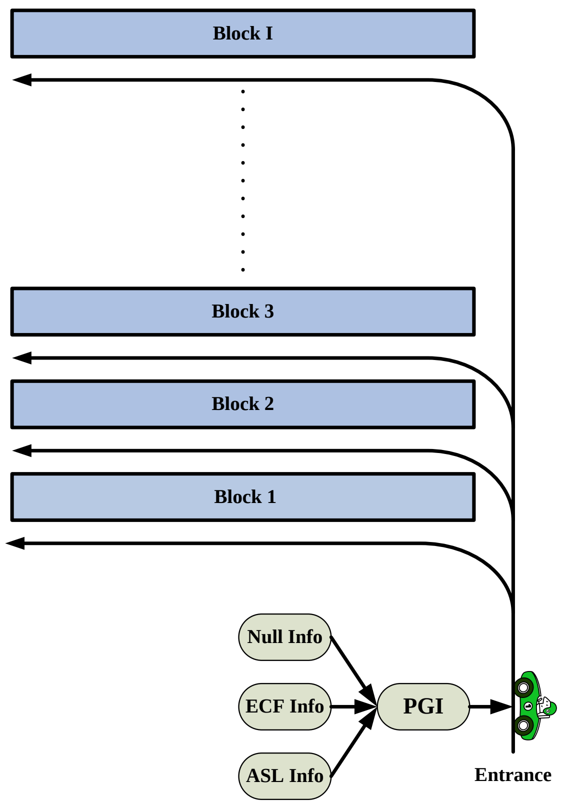

Figure 4.8: Simplified discrete parking choice behavior with and without PGI

4.4.2 Parking choice model under null information

In the discrete choice theory, each possible alternative is assigned a utility for each individual decision maker. In this thesis, there are 6 alternatives from block D to block I, as discussed in the chapter 3 that the occupancy status of block J, K, L and M seems not significantly affect drivers' decision when decided to park at block J, K, L and M no matter under what type of displayed information. Each row of parking spaces, can be seen as one block, which is one alternative for driver. It is assumed that both the conditions with and without PGI are perfect information situations. Multi-nominal Logit model is adopted to estimate the parking choice probability. Then the utility function without route information guidance (null information) for driver k is

$$U_{ki} = \beta_k x_i + \varepsilon_{ki} \tag{4.8}$$

Where i denotes the alternative blocks from 1 to 6 (label as D, E, … , I in the chapter 3); x_i denotes the walking distance from entrance to the block i; β denotes the parameter of the variable x_i; ε_{ki} denotes the uncertainty of the model. For the uncertain variable, we assume ε_{ki} is independently, identically distributed extreme value. It has three components: 1) the difference of recognition of individual drivers to information; 2) the difference of receiving information level of individual drivers; 3) the accuracy and synchronism of occupied status with information board of each block. Then the probability for driver k to choose each alternative block i ($i \in I$) under the situation without PGI and with PGI is shown in the following

$$P_{ki} = \frac{\mathrm{e}^{\beta_k x_i}}{\sum_{j=1}^{I} \mathrm{e}^{\beta_k x_j}} \qquad \sum_{I} P_{ki} = 1 \tag{4.9}$$

Where P_{ki} denotes the probability of driver k choose block i under the condition of without PGI; It is assumed that each driver's choice is independent of that of other drivers, then the probability of each driver chose the preferred alternative without PGI is expressed in Eq. (4.10), then the log-likelihood function of without PGI Eq.(4.11)

$$L(\beta) = \prod_{k=1}^{K} \prod_{i} \left(P_{ki}\right)^{y_{ki}} \tag{4.10}$$

$$\begin{aligned} LL(\beta) &= \sum_{k=1}^{K} \sum_{i} y_{ki} \ln P_{ki} \\ &= \sum_{k=1}^{K} \sum_{i} y_{ki} \ln \frac{e^{\beta_k x_i}}{\sum_{j=1}^{I} e^{\beta_k x_j}} \\ &= \sum_{k=1}^{K} \sum_{i} y_{ki} \beta_k x_i - \sum_{k=1}^{K} \sum_{i} y_{ki} \ln \left(\sum_{I} e^{\beta_k x_i} \right) \end{aligned} \tag{4.11}$$

where $y_{ki} = 1$ if driver k choose block i and zero otherwise. The maximum likelihood estimates without PGI is meet the conditions $\frac{dLL(\beta)}{d\beta} = 0$. Combing the Eq. (4.11), then the first-order condition can be rewritten as $\sum_{k=1}^{K} \sum_{i} y_{ki} x_i - \sum_{k=1}^{K} \sum_{i} y_{ki} \sum_{j} \frac{x_j e^{\beta_k x_j}}{\sum_{I} e^{\beta_k x_j}} = 0$.

4.4.3 Parking choice model under perfect ECF information

Multi-nominal Logit model is applied to estimate the parking choice probability under ECF information. The utility function with PGI (ECF information) for driver k is

$$\tilde{U}_{ki}(t) = \beta_k x_i + \gamma_k \tilde{x}_i(t) + \varepsilon_{ki} \tag{4.12}$$

Where i denotes the alternative blocks from 1 to 6 (label as D, E, … , I in the chapter 3); x_i denotes the walking distance from entrance to the block i; $\tilde{x}_i(t)$ is dummy variable denotes displaying information of occupancy status of block i at time t; β denotes the parameter of the variable x_i; γ_k denotes the parameter of the variable $\tilde{x}_i(t)$; ε_{ki} denotes the uncertainty of the model. For the dummy variable, we define 0 = "Full" and 1 = "Empty" or "Congest" (which is non-full). At here, we category the displayed information of "Empty" and "Congest" as one group of non-full, based on the result we found in section 3.6.3 that the guidance effect of the difference between guidance information of "empty" and "congest" is not very obvious but the difference between guidance information of "empty" and "full" seems much more obvious especially under congested situation. For the uncertain variable, we assume ε_{ki} is independently, identically distributed extreme value. It has three components: 1) the difference of recognition of individual drivers to information; 2) the difference of receiving information level of individual drivers; 3) the accuracy and synchronism of occupied status with information board of each block. Then the probability for driver k to choose each alternative block i ($i \in I$) under the guidance of ECF information, situation with PGI is shown in the following

$$\tilde{P}_{ki}(t) = \frac{\mathrm{e}^{\beta_k x_i + \gamma_k \tilde{x}_i(t)}}{\sum_I \mathrm{e}^{\beta_k x_j + \gamma_k \tilde{x}_j(t)}} \qquad \sum_I \tilde{P}_{ki}(t) = 1 \tag{4.13}$$

$\tilde{P}_{ki}(t)$ denotes the probability of driver k choose block i at time t under the condition of with PGI on which displaying ECF information. We assumed each driver's choice is independent of that of other drivers, then the probability of each driver chose the preferred alternative under ECF information (with PGI) is shown in the Eq.(4.14), then the log-likelihood function of under effect of ECF information (with PGI) is expressed as Eq.(4.15).

$$L(\beta,\gamma) = \prod_{k=1}^{K}\prod_{i}\left(\tilde{P}_{ki}(t)\right)^{y_{ki}} \tag{4.14}$$

$$\begin{aligned} LL(\beta,\gamma) &= \sum_{k=1}^{K}\sum_{i} y_{ki} \ln \tilde{P}_{ki}(t) \\ &= \sum_{k=1}^{K}\sum_{i} y_{ki} \ln \frac{e^{\beta_k x_i + \gamma_k \tilde{x}_i(t)}}{\sum_{j=1}^{I} e^{\beta_k x_j + \gamma_k \tilde{x}_j(t)}} \\ &= \sum_{k=1}^{K}\sum_{i} y_{ki}\left(\beta_k x_i + \gamma_k \tilde{x}_i(t)\right) - \sum_{k=1}^{K}\sum_{i} y_{ki} \ln\left(\sum_I e^{\beta_k x_j + \gamma_k \tilde{x}_j(t)}\right) \end{aligned} \tag{4.15}$$

where $y_{ki} = 1$ if driver k choose block i and zero otherwise. The maximum likelihood estimates under ECF information (with PGI) is meet the conditions $\frac{dLL(\beta)}{d\beta} = 0$ and

$\frac{dLL(\beta,\gamma)}{d\gamma}=0$. Combing the Eq. (4.15), then the first-order condition can be rewritten as

$$\frac{dLL(\beta,\gamma)}{d\beta}=\sum_{k=1}^{K}\sum_{i}y_{ki}x_i-\sum_{k=1}^{K}\sum_{i}y_{ki}\sum_{j}\frac{x_{oj}e^{\beta_k x_j+\gamma_k\tilde{x}_j(t)}}{\sum_{I}e^{\beta_k x_j+\gamma_k\tilde{x}_j(t)}}=0$$

and

$$\frac{dLL(\beta,\gamma)}{d\gamma}=\sum_{k=1}^{K}\sum_{i}y_{ki}x_i(t)-\sum_{k=1}^{K}\sum_{i}y_{ki}\sum_{j}\frac{\tilde{x}_j(t)e^{\beta_k x_j+\gamma_k\tilde{x}_j(t)}}{\sum_{I}e^{\beta_k x_j+\gamma_k\tilde{x}_j(t)}}=0.$$

4.4.4 Parking choice probability under perfect ASL information

In this section, we will estimate the parking choice probability under ASL information. The utility function with PGI (ASL information) for driver k is

$$\bar{U}_{ki}(t)=\beta_k x_i+\gamma_k\bar{x}_i(t)+\varepsilon_{ki} \tag{4.16}$$

Where i denotes the alternative blocks from 1 to 6 (label as D, E, … , I in the chapter 3); x_i denotes the walking distance from entrance to the block i; $\bar{x}_i(t)$ denotes number of available space of block i at time t; β denotes the parameter of the variable x_i; γ_k denotes the parameter of the variable $\bar{x}_i(t)$; ε_{ki} denotes the uncertainty of the model. For the uncertain variable, it is assumed that ε_{ki} is independently, identically distributed extreme value. It has three components: 1) the difference of recognition of individual drivers to information; 2) the difference of receiving information level of individual drivers; 3) the accuracy and synchronism of occupied status with information board of each block. Then the probability for driver k to choose each alternative block i ($i\in I$) under the guidance of ASL information, situation with PGI is shown in the following

$$\bar{P}_{ki}(t)=\frac{\mathrm{e}^{\beta_k x_i+\gamma_k\bar{x}_i(t)}}{\sum_{I}\mathrm{e}^{\beta_k x_j+\gamma_k\bar{x}_j(t)}}\qquad\sum_{I}\bar{P}_{ki}(t)=1 \tag{4.17}$$

$\bar{P}_{ki}(t)$ denotes the probability of driver k choose block i at time t under the condition of with PGI on which displaying ASL information. It is assumed that each driver's choice is independent of that of other drivers, then the probability of each driver chose the preferred alternative under ASL information (with PGI) is shown in the Eq.(4.18), then the log-likelihood function of under effect of ASL information (with PGI) is expressed as Eq.(4.19).

$$L(\beta,\gamma)=\prod_{k=1}^{K}\prod_{i}\left(\bar{P}_{ki}(t)\right)^{y_{ki}} \tag{4.18}$$

$$\begin{aligned}LL(\beta,\gamma)&=\sum_{k=1}^{K}\sum_{i}y_{ki}\ln\bar{P}_{ki}(t)\\&=\sum_{k=1}^{K}\sum_{i}y_{ki}\ln\frac{e^{\beta_k x_i+\gamma_k\bar{x}_i(t)}}{\sum_{j=1}^{I}e^{\beta_k x_j+\gamma_k\bar{x}_j(t)}}\\&=\sum_{k=1}^{K}\sum_{i}y_{ki}\left(\beta_k x_i+\gamma_k\bar{x}_i(t)\right)-\sum_{k=1}^{K}\sum_{i}y_{ki}\ln\left(\sum_{I}e^{\beta_k x_j+\gamma_k\bar{x}_j(t)}\right)\end{aligned} \tag{4.19}$$

where $y_{ki}=1$ if driver k choose block i and zero otherwise. The maximum likelihood estimates under ASL information (with PGI) is meet the conditions $\frac{dLL(\beta)}{d\beta}=0$ and $\frac{dLL(\beta,\gamma)}{d\gamma}=0$. Combing the Eq. (4.19), then the first-order condition can be rewritten as

$$\frac{dLL(\beta,\gamma)}{d\beta}=\sum_{k=1}^{K}\sum_{i}y_{ki}x_i-\sum_{k=1}^{K}\sum_{i}y_{ki}\sum_{j}\frac{x_{oj}e^{\beta_k x_j+\gamma_k\bar{x}_j(t)}}{\sum_{I}e^{\beta_k x_j+\gamma_k\bar{x}_j(t)}}=0 \quad \text{and}$$

$$\frac{dLL(\beta,\gamma)}{d\gamma}=\sum_{k=1}^{K}\sum_{i}y_{ki}\bar{x}_i(t)-\sum_{k=1}^{K}\sum_{i}y_{ki}\sum_{j}\frac{x_j(t)e^{\beta_k x_j+\gamma_k\bar{x}_j(t)}}{\sum_{I}e^{\beta_k x_j+\gamma_k\bar{x}_j(t)}}=0$$

4.5 Estimation result

In this section, estimation result of parking choice model under the effect of null information (without PGI), ECF information (with PGI) and ASL information (with PGI) are compared and discussed. According to the experiment design in section 3.1.2, parking choice model under null information (without PGI) will be estimated by using the data of 9:00 ~ 10:00, 13:00 ~ 14:00 and 15:00 ~ 16:00 on 23rd June 2013; parking choice model under ECF information (with PGI) will be estimated by adopting the data of 9:00 ~ 15:00 on 9th June 2013; parking choice model under ASL information (with PGI) will be estimated by using the data of 10:00 ~ 13:00 on 23rd June 2013. Then the summarized estimation result of parking choice models dividing in three different scenarios is shown in the Table 4.2, Table 4.3 and Table 4.4 respectively.

Table 4.2: Estimation result of parking choice model under null information (without PGI)

Variable	Description	Parameter	T value	ρ	$\bar{\rho}$	N
x_i	walking distance from entrance to the block i	-0.1278	-6.5875	0.17	0.17	302

Table 4.3: Estimation result of parking choice model under ECF information (with PGI)

Variable	Description	Parameter	T value	ρ	$\bar{\rho}$	N
x_i	walking distance from entrance to the block i	-0.0290	-2.7741	0.15	0.14	258
$\tilde{x}_i(t)$	dummy variable reflect occupancy information of block i at time t	0.5375	2.2530			

Table 4.4: Estimation result of parking choice model under ASL information (with PGI)

Variable	Description	Parameter	T value	ρ	$\bar{\rho}$	N
x_i	walking distance from entrance to the block i	-0.1510	-6.9573	0.21	0.20	324
$\bar{x}_i(t)$	number of available space of block i at time t	0.6122	11.4998			

Note: "ρ" – Log-likelihood ratio index. "$\bar{\rho}$" – Adjusted Log-likelihood ratio index.

As can be seen from the above Tables, the result of three models (two models with PGI and one model without PGI) give a first impression of the drivers' response to various attributes that related to the providing information and characteristics of alternatives themselves. The models are estimated based on the attributes of walking distance from entrance to each alternative, number of available space of each alternative at time t, or the occupancy status information of each alternative at time t (represent by dummy variable). It is reassuring to see that all of the coefficients are highly significant, confirming the analyzed result what we found in the chapter 3 that under the effect of PGI drivers' parking choice behavior strongly following the guidance of ECF information or ASL information and also considering the characteristics' of blocks themselves; under the effect of without PGI drivers' parking choice behavior only influenced by the characteristics of blocks.

In all the three models, the coefficients of the variable of walking distance from entrance to each x_i are all negative which indicated that with the increasing of the length of walking distance from entrance to each block, drivers are unwilling to park at no matter with or without PGI. AS dummy variable, we defined 0 = "Full" and 1 = "Empty" or "Congest" (which is non-full). For the parking choice model with PGI (ECF information), the coefficient of dummy variable which represent occupancy status information of each block $\tilde{x}_i(t)$ is positive which indicated the bigger the information dummy variable shows, drivers are prefer to park. That means, drivers prefer to park at uncongested blocks (1 = "Empty" or "Congest"), it is also confirming what we suggested in the chapter. For the variable of number of available space of each block $\bar{x}_i(t)$ is positive which indicated that drivers incline to park at the blocks with more empty spaces, it is also may reflect our earlier hypothesis and the suggestion in data analyzing part. The estimation result further strengthens our finding that information did help drivers to make a decision by assessing the occupancy status of each block regardless of their original assessment. The significances of above variables justify our hypothesis that drivers are sensitive to above variables.

The presentation of MNL results has shown that, in each scenario of with PGI and without PGI, the gains in the model fit are relatively modest. Even though, in the model of without PGI, the estimated result of coefficient of variable of walking distance is sufficient significant, the model of without PGI still need to be further complicated. Due to the limitation of experiment, it couldn't be accomplished in this research. Besides, the parking choice process is made considerably easier by the fact that correlation between random coefficients was not taken into account. Generally, the performance of the models under different scenarios of with PGI and without PGI in terms of correctly predicting the parking choice and the results can be applied in further simulation part.

4.6 Conclusion

In this chapter, the arrival rate and departure rate of drivers have been investigated by assuming the process of arriving at a block and departing from the block is similar with birth-death process of ququing theory, the following distribution and parameters of the distribution are given. Then, drivers' parking choice model under the effect of null information, ECF information and ASL information have been developed by adopting Multinomial Logit model. The result indicates that the utility of choosing a parking block is negatively related to its distance from the entrance of the area to the block (for both of without PGI and with PGI), while positively related to its number of available space (for ASL information only) and positively related to its provided lest congested information (for ECF information only).The result indicates that both the effect of ECF information and ASL information are significantly affect drivers parking choice behavior especially for the drivers who choose to park at block D to block I. The significance of variable of walking distance, dummy variable of occupancy information and variable of number of available space justify our hypothesis that drivers are sensitive to above three variables. Moreover, we also tried to test other variables, such as occupancy rate, walking distance from each block to the destination restaurant or store, etc. or different sample data but the estimation results of those variables under same or different environment are not as significant as the variables what we used in this chapter. In the next chapter, sequential parking choice behavior model will be presented and compared with the MNL model in this chapter.

4.7 References

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5 Modeling sequential parking choice behavior

5.1 Introduction

In this chapter, firstly the background of sequential search process and Multinomial Probit model are presented in section 5.2. Even though, the Multinomial Probit model isn't directly applied to develop the sequential parking choice model in this chapter, the probability derivation schematic process is used in sequential parking choice probability derivation process to solve the uncertainty of random taste variation term. In the section 5.3, utility functions of various scenarios (with PGI and without PGI) are presented and expected utility function is given under the assumption that the error terms following Normal distribution. Besides, the expected utility function derivation process is also presented in this section. In the section 5.4, sequential parking choice model and the probability derivation process are presented by explaining model precondition, sequential parking choice process and the detailed choice probability derivation process. Maximum log-likelihood method is introduced to estimate the parameters of sequential parking choice model. Then, the algorithm for computation of maximum-likelihood estimates in the sequential parking choice model is presented in the section 5.5. A new sequential parking choice model is developed through a new theoretical view, which could be an approach to compare with general parking choice model belong to GEV family. In the next chapter, the agent-based model simulation result for economic evaluation will be presented and discussed by using estimated result of the multinomial discrete choice model which have illustrated in chapter 4.

5.2 Background of sequential search process

5.2.1 Background of sequential search process

Most of the research adopted the utility maximization framework to present the choice behavior with the assessment of already available or specified alternative and not with alternative generation. Often, it is simply assumed that the decision-maker knows all the alternatives. Microeconomic search theory is applied with the principles of utility maximization into the situation that the decision maker will perform a sequential search for alternatives as well as an assessment of the alternatives generated. It can provide one with insights regarding this alternative generation process. Manski (1977) presented a formal analysis of the distributional structure of random utility models and demonstrated the processes induce the distributional properties of a model. Other researchers focused on analyzing search model with varying choice set, such as Weibull (1978) and Richardson (1982), the latter outlined the development of a model of search in which the degree of prior knowledge and the cost of each individual search are allowed to vary.

In such a sequential search process, apart from transaction costs, the cost of rejecting the most recently searched-for alternative can also be included. Such costs may be traded-off against the expected utility to be derived from the next found alternative. The alternative found are mostly assumed to be subsequently assessed following the principles of utility maximization. Several notions of microeconomic search theory can be found in travel demand studies. Williams and Ortuzar (1982) applied Monte Carlo simulation and developed a framework to examine the consequences of the divergence between the behaviors of individuals, the observed, and that description of their behavior. Lerman and Mahmassani (1985) addressed the special econometric aspects associated with analysis of observation on sequential search process of four distinct informational situations. Swait and Ben-Akiva (1987) proposed a behavioral interpretation of the choice set generation process that is useful for structuring and specifying discrete models that incorporate this stage of choice. Polak and Jones (1993) described the impact of in-home pre-trip information, based around the use of a computer-based simulation of a pre-trip information system. Ben-Akiva and Boccara (1995) added an explicit probabilistic representation of the various alternatives into the existed discrete choice model considered by the individual in a choice situation. Arentze and Timmermans (2005 a. b) developed models of mental maps integrated in discrete choice models and activity-based models to simulate dynamic decision-making with and without uncertainty.

There is a significant difference between the applications of utility maximization principles for alternative assessment and for alternative generation: utility maximization for alternative assessment deals with choosing from alternatives, while its application on alternative generation in addition to this also deals with choosing from decision strategies. Choosing a search strategy by applying utility maximization principles, the individual may well end up with an alternative with suboptimal utility because the costs of searching are also taken into account in the decision strategy. Utility maximization principles are thus applied at different levels. Through, the principles of utility maximization have been applied in the research of individual choice (e.g. McFadden, 1974) or travel choice (e.g. Ben-Akiva and Lerman, 1985) and made a great contribution. Generally, many researchers agree that the assumption of trade-off and maximization behavior may follow a less realistic representation of the actual behavioral process which individual performed. The above statement of behavioral process assumption can be found in the research of Edwards (1954), Simon (1955, 1978 a, b), Kahneman and Tversky (1979, 1992), Hargreaves Heap et al., (1992), McFadden (1999), De Palma (1998) and Gärling and Young (2001).

5.2.2 Background of Multinomial Probit model

In this section, the one part of derivation of sequential parking choice model is applied the theory of multinomial Probit model, although not used in this thesis directly, it is worth to briefly look at the model structure. Probit and Probit like models are based on the Normal distribution motive by the Central Limit Theorem. The Logit model is limited in cannot representing random taste variation, restricting on pattern of substitution and cannot apply panel data compare with Probit model. On the converse, the advantage of Probit model is can be applied to capture all correlation among alternatives. However, only a few application of Probit model have been developed because of high complexity of its formulation. The underlying assumption of Probit models is the error terms follow a joint Normal distribution with zero mean and covariance matrix $\sum$, without a prior restrictions on the correlation structure in the distribution. It means that the

Probit model allows for any degree of correlation between the single error term which can represent different substitution patterns.

The Probit model has been firstly applied in the field of psychology (Thurstone, 1927). Marschak (1960) defined the binary choice probability by maximizing utility function which led Probit model to a new consideration level. Hausman and Wise (1978), Daganzo (1979) discussed the condition and application of Probit model to confirm the ability of Probit model for representing diversity substitution patterns, especially random taste variation across the population and between choice situations. Then the Multinomial Probit (MNP) choice probability is given as follow:

$$P_n(i) = P\left(\varepsilon_{j,n} - \varepsilon_{i,n} < V_{i,n} - V_{j,n} \forall j \neq i\right)$$

$$= \int_{\varepsilon_n} I\left(\varepsilon_{j,n} - \varepsilon_{i,n} < V_{i,n} - V_{j,n} \forall j \neq i\right) \phi\left(\varepsilon_n\right) d\varepsilon_n \tag{5.1}$$

Where $I(\cdot)$ is the indicator function and

$$\phi\left(\varepsilon_n\right) = \frac{1}{\left(2\pi\right)^{\frac{I}{2}} \left|\sum_n\right|^{\frac{1}{2}}} e^{-\frac{1}{2}\varepsilon_n' \sum_n^{-1} \varepsilon_n} \tag{5.2}$$

As we can see from Eq. (5.1), the calculation of choice probability require solving an *I*-dimensional integral first, this will need other numerical approaches or simulation methods (Train, 2003). The major disadvantage of the Probit model, is the requirement to use a normal distribution for representing random taste heterogeneity, which leading to significant losses in terms of flexibility, and issues of interpretation in the case of counter-intuitive results suggesting large shares of wrongly-signed coefficient values.

In the probability theory and statistics, the Multivariate Normal distribution or Multivariate Gaussian distribution is a generalization of the one-dimensional normal distribution to higher dimensions. The Multivariate normal distribution is often used to describe, at lease approximately, any set of correlated real-valued random variables each of which clusters around a mean value. Many researchers have made effort in deriving, measuring, testing and estimating of Multivariate normal distribution (Gokhale, 1989; Siotani, 1964; Eaton, 1983; Smith, 1988).

Hamedani (1975) have presented the bivariate case of multivariate normal distribution. In the 2-dimensional nonsingular case, in another word, in the binary choice situation, the joint probability density function of a vector $\left[X, Y\right]'$ is

$$f(x, y) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-\rho^2}} \exp\left[-\frac{1}{2\left(1-\rho^2\right)}\left(\frac{\left(x-\mu_x\right)^2}{\sigma_x^2} + \frac{\left(y-\mu_y\right)^2}{\sigma_y^2} - \frac{2\rho\left(x-\mu_x\right)\left(y-\mu_y\right)}{\sigma_x\sigma_y}\right)\right] \tag{5.3}$$

Where ρ is the correlation between X and Y, μ_x is mean value of X, μ_y is mean value of Y, besides, the covariance of variable X is σ_x,and $\sigma_x > 0$; the covariance of variable Y is σ_y, and $\sigma_y > 0$. In this case, In this chapter, $\mu = \left(\mu_x, \mu_y\right)'$, and the $\sum$ is

$$\sum=\begin{pmatrix}\sigma_x^2 & \rho\sigma_x\sigma_y\\ \rho\sigma_x\sigma_y & \sigma_y^2\end{pmatrix}$$

We will adopt the bivariate case to derive the sequential parking choice probability and expected utility.

5.3 Utility function

5.3.1 Utility of an current alternative

In a parking area, there are I alternatives for driver to make a parking decision, in another words, there are I rows of parking spaces. In this thesis, each row of parking spaces can be seen as a parking block, which denotes as one alternative. The location of each alternative block can be seen as the branch of the main travel link, preferred block destination moving has to pass by the former sequence alternatives. At each junction, drivers make a decision from the current alternative and expectation of further alternatives based on the information they received from the PGI system and information based on their understanding and recognition. So, for each driver, at each junction, there are a utility of current alternative and an expected utility for further alternatives.

Based on discrete choice theory, each possible alternative is assigned a utility for each individual decision maker. In this thesis, random utility model is adopted to describe the utility function for driver k of each alternative after received all types of information. Then, for driver k, the utility block i is:

$$U_{ki}=V_{ki}\left(x_{ki},t_{ki}\right)+\varepsilon_{ki} \tag{5.4}$$

Where, $V_{ki}\left(x_{ki},t_{ki}\right)$ is the representative utility which related with the attributes of alternative i ($i=1,\dots,I$) at time t_i for driver k. With the assumption that each ε_{ki} is independent and follows standard distributed normal, hence $\varepsilon_{ki}\sim N\left(0,1\right)$, the vector composed each ε_{ki} labeled as $\varepsilon_k'\in\left(\varepsilon_{k1},\varepsilon_{k2},\dots,\varepsilon_{kI}\right),\varepsilon_k:I\times 1$ is distributed normal with a mean vector of zero and covariance matrix Ω. So the density for each unobserved component of utility of block i for driver k is:

$$\phi\left(\varepsilon_k\right)=\frac{1}{\left(2\pi\right)^{\frac{I}{2}}\left|\Omega\right|^{\frac{1}{2}}}e^{-\frac{1}{2}\varepsilon_k'\Omega^{-1}\varepsilon_k} \tag{5.5}$$

And covariance Ω can depend on variables faced by driver k, so that Ω_k is the more appropriate notation. Then the utility function and choice probability is derived in the following part. For the standard normal distribution, the density of each uncertainty term just ε_{ki}, just substitute Ω with 1.

5.3.2 Expected utility of further alternatives

In this section, parking choice behavior is a sequence moving activities and decision making process, so it is not like the traditional process that drivers choose the alternative from the set of alternatives which provides the greatest utility at the initial stage, the simplified parking choice process is described in figure 5.1. In the hypothesis of rational expectation, drivers' expectations equal to true statistical expected values. In this thesis, to measure the expected utility, it satisfy the following properties: 1) the probability distribution of each alternative ε_{ki} for each driver's expectation equal to true expected values; 2) at time t, a driver k arrive at the parking area, the information driver k may receive at initial stage is same as the information the driver may receive when t_i driver k arrive at junction i at time ($i \in I$); 3) prior expectation utility correspond with posterior true utility in that uncertainty vector is random. Then, at time t_i, driver k arrive at the junction i, according to the information that driver k received at time t, entering into the parking area, the true utility of block i for driver k is $U_{ki} = V_{ki}\left(x_{ki}, t_{ki}\right) + \varepsilon_{ki}$; the expected utility from block $i+1$ to further blocks is EU_{ki}. If considering the subsequent decision making process, then at junction i, for driver k, the expected utility from block $i+1$ to further blocks can be described as follow:

$$EU_{ki}\left(t\right) = \max\{U_{k(i+1)}\left(t\right), EU_{k(i+1)}\left(t\right)\} \tag{5.6}$$

Where, $i = 0,1 \ldots I-1$, $U_{k(i+1)}\left(t\right)$ is the utility of block $i+1$ for driver k according to acquiring information at time t; $EU_{k(i+1)}\left(t\right)$ is the expected utility from block $i+2$ to further blocks. In this thesis, let's define there are I alternatives in the parking area, and the expected utility from last block I to further blocks is $EU_{k(I-1)}\left(t\right) = \max\{U_{kI}\left(t\right), EU_{kI}\left(t\right)\}$, However, further block after block I is not existed, $I+1$ to further blocks $EU_{kI}\left(t\right)$ equal to constant value of zero, hence $EU_{kI}\left(t\right) = 0$, and then the expected utility from last block I to further blocks is

$$EU_{k(I-1)}(t) = \max\{U_{kI}(t), EU_{kI}(t)\} = U_{kI}(t) \quad (5.7)$$

Applied the Eq. (5.7) into the expected utility from block $I-1$ to further blocks, and get

$$EU_{k(I-2)}(t) = \max\{U_{k(I-1)}(t), EU_{k(I-1)}(t)\} = \max\left\{U_{k(I-1)}(t), U_{kI}(t)\right\}$$

Calculate the above equation by using probability of event occurring

$$EU_{k(I-2)}(t) = U_{k(I-1)}(t) \cdot \Pr ob\left(U_{k(I-1)} > U_{kI}\right) + U_{kI} \cdot \left[1 - \Pr ob\left(U_{k(I-1)} > U_{kI}\right)\right] \quad (5.8)$$

For the sequential parking choice process, at each junction, there are only two current alternatives – turn left and choose block on the left side; go straight and make decision at next junction. Here, at junction $I-1$, there are also two alternatives, according to the maximum utility theory, the probability of driver k at junction $I-1$ choose to park at block $I-1$ is $\tilde{P}_{k(I-1)}$ can be written as

$$\tilde{P}_{k(I-1)} = \Pr ob\left(U_{k(I-1)} > U_{kI}\right) = \Pr ob\left(V_{k(I-1)} + \varepsilon_{k(I-1)} > V_{kI} + \varepsilon_{kI}\right)$$

$$= \int I\left(V_{k(I-1)} + \varepsilon_{k(I-1)} > V_{kI} + \varepsilon_{kI}\right)\phi(\varepsilon_k)\, d\varepsilon_k \quad (5.9)$$

Where, $I(\cdot)$ is an indicator of whether the statement in parentheses holds, and the integral is over all values of ε_k. This integral does not have a closed form and only can be evaluated numerically through simulation. Since, only differences in utility matter, lets difference against alternative of $I-1$ and I. Define $\tilde{U}_{kI(I-1)} = U_{kI} - U_{k(I-1)}$, $\tilde{V}_{kI(I-1)} = V_{kI} - V_{k(I-1)}$, $\tilde{\varepsilon}_{kI(I-1)} = \varepsilon_{kI} - \varepsilon_{k(I-1)}$. Since the difference between two items which are normal distributions is also follows normal distribution, the density of the error difference is

$$\phi\left(\tilde{\varepsilon}_{kI(I-1)}\right) = \frac{1}{(2\pi)^{\frac{1}{2}}\left|\tilde{\Omega}_k\right|^{\frac{1}{2}}} e^{-\frac{1}{2}\tilde{\varepsilon}'_{kI(I-1)}\tilde{\Omega}_k^{-1}\tilde{\varepsilon}_{kI(I-1)}} \quad (5.10)$$

Where $\tilde{\Omega}_k$ is the covariance of $\tilde{\varepsilon}_{kI(I-1)}$, derive from Ω_k, then the Eq. (5.9) can be re-expressed as

$$\tilde{P}_{k(I-1)} = \int I\left(\tilde{V}_{kI(I-1)} + \tilde{\varepsilon}_{kI(I-1)} < 0\right)\phi\left(\tilde{\varepsilon}_{kI(I-1)}\right) d\tilde{\varepsilon}_{kI(I-1)} \quad (5.11)$$

Above equation is a (number of alternative – 1) dimensional integral over all possible values of the error difference, and the equivalent expression is

$$\tilde{P}_{k(I-1)} = \int \phi\left(\tilde{\varepsilon}_{kI(I-1)}\right) d\tilde{\varepsilon}_{kI(I-1)} \quad (5.12)$$

$\tilde{\Omega}_k$ can be calculated by $\tilde{\Omega}_k = M_k \Omega M_k^{'}$, for the two alternatives, the matrix of M_k can be used to transform the covariance matrix of errors into covariance matrix of error differences, then the matrix of M_k is $(1,-1)$, as mentioned in the former section, ε_{kI} and $\varepsilon_{k(I-1)}$ are independent and follows standard normal distribution, and the Ω_k is

$$\Omega_k = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

The covariance matrix can be derived by the transformation $\tilde{\Omega}_k = M_k \Omega M_k^{'}$, and we get

$$\tilde{\Omega}_k = (1,-1)\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 \\ -1 \end{pmatrix} = 2 \tag{5.13}$$

Then, when the $\tilde{V}_{kI(I-1)} + \tilde{\varepsilon}_{kI(I-1)} < 0$, note $\tilde{V}_{kI(I-1)} = V_{kI} - V_{k(I-1)}$, so under the condition of $\tilde{\varepsilon}_{kI(I-1)} < V_{k(I-1)} - V_{kI}$, the probability of driver k at junction $I-1$ choose to park at block $I-1$, see Eq.(5.12) can be rewritten as

$$\begin{aligned}\tilde{P}_{k(I-1)} &= \int \phi\left(\tilde{\varepsilon}_{kI(I-1)}\right) d\tilde{\varepsilon}_{kI(I-1)} \\ &= \int \frac{1}{2\sqrt{\pi}} \exp\left(-\frac{\tilde{\varepsilon}_{kI(I-1)}^2}{2\cdot 2}\right) d\tilde{\varepsilon}_{kI(I-1)} \\ &= \frac{1}{2}\left(1 + erf\,\frac{V_{k(I-1)} - V_{kI}}{2}\right)\end{aligned} \tag{5.14}$$

Adopt the result of Eq. (5.14) into Eq. (5.8), and then we get expected utility from block $I-1$ to further blocks

$$EU_{k(I-2)}(t) = U_{k(I-1)}(t)\cdot\left(\frac{1}{2} + \frac{1}{2} erf\,\frac{V_{k(I-1)} - V_{kI}}{2}\right) + U_{kI}\cdot\left[\frac{1}{2} - \frac{1}{2} erf\,\frac{V_{k(I-1)} - V_{kI}}{2}\right] \tag{5.15}$$

Where, $\left(\frac{1}{2} + \frac{1}{2} erf\,\frac{V_{k(I-1)} - V_{kI}}{2}\right)$ can be calculated by computer simulation and get constant value we define $\left(\frac{1}{2} + \frac{1}{2} erf\,\frac{V_{k(I-1)} - V_{kI}}{2}\right) = \rho_{k(I-1)}$, the expected utility of Eq. (5.15) can be rewritten as

$$EU_{k(I-2)}(t) = \rho_{k(I-1)}\cdot V_{k(I-1)} + \left(1-\rho_{k(I-1)}\right)\cdot V_{kI} + \rho_{k(I-1)}\cdot \varepsilon_{k(I-1)} + \left(1-\rho_{k(I-1)}\right)\cdot \varepsilon_{kI} \tag{5.16}$$

As defined in the section 5.3.2, each ε_{ki} is independently follows standard normal distribution, the we define joint error term of expected utility from block $I-1$ to further blocks is $\hat{\varepsilon}_{k(I-2)} = \rho_{k(I-1)}\cdot\varepsilon_{k(I-1)} + \left(1-\rho_{k(I-1)}\right)\cdot\varepsilon_{kI}$ which follows the normal distribution of $N \sim \left(0, \rho_{k(I-1)}^2 + \left(1-\rho_{k(I-1)}\right)^2\right)$. And define $EV_{k(I-2)} = \rho_{k(I-1)}\cdot V_{k(I-1)} + \left(1-\rho_{k(I-1)}\right)\cdot V_{kI}$ so the Eq. (5.13) can be rewritten as

$$EU_{k(I-2)}(t) = EV_{k(I-2)} + \hat{\varepsilon}_{k(I-2)} \tag{5.17}$$

Applied the Eq. (5.7) into the expected utility from block $I-2$ to further blocks, we get

$$\begin{aligned} EU_{k(I-3)}(t) &= \max\{U_{k(I-2)}(t), EU_{k(I-2)}(t)\} \\ &= U_{k(I-2)}(t)\cdot \Pr ob\left(U_{k(I-2)} > EU_{k(I-2)}\right) + EU_{k(I-2)}(t)\cdot\left[1-\Pr ob\left(U_{k(I-2)} > EU_{k(I-2)}\right)\right] \end{aligned} \tag{5.18}$$

Here, at junction $I-2$, there are also two alternatives, according to the maximum utility theory, the probability of driver k at junction $I-2$ choose to park at block $I-2$ is $\tilde{P}_{k(I-2)}$ can be written as

$$\begin{aligned} \tilde{P}_{k(I-2)} &= \Pr ob\left(U_{k(I-2)} > EU_{k(I-2)}\right) = \Pr ob\left(V_{k(I-2)} + \varepsilon_{k(I-2)} > EV_{k(I-2)} + \hat{\varepsilon}_{k(I-2)}\right) \\ &= \int I\left(V_{k(I-2)} + \varepsilon_{k(I-2)} > EV_{k(I-2)} + \hat{\varepsilon}_{k(I-2)}\right)\phi\left(\varepsilon_k\right) d\varepsilon_k \end{aligned} \tag{5.19}$$

Define, $\tilde{V}_{k(I-2)} = EV_{k(I-2)} - V_{k(I-2)}$, $\tilde{\varepsilon}_{k(I-2)} = \hat{\varepsilon}_{k(I-2)} - \varepsilon_{k(I-2)}$, and Eq. (5.19) becomes

$$\tilde{P}_{k(I-2)} = \int I\left(\tilde{V}_{k(I-2)} + \tilde{\varepsilon}_{k(I-2)} < 0\right)\phi\left(\tilde{\varepsilon}_{k(I-2)}\right) d\tilde{\varepsilon}_{k(I-2)} \tag{5.20}$$

Apply Eq. (5.10), Eq. (5.11) and Eq. (5.12) into the above Eq. (5.20), then we have the probability is

$$\begin{aligned} \tilde{P}_{k(I-2)} &= \int \phi\left(\tilde{\varepsilon}_{k(I-2)}\right) d\tilde{\varepsilon}_{k(I-2)} \\ &= \int \frac{1}{\sqrt{1+\rho_{k(I-1)}^2 + \left(1-\rho_{k(I-1)}\right)^2}\sqrt{2\pi}} \exp\left(-\frac{\tilde{\varepsilon}_{k(I-2)}^2}{2\cdot\left[1+\rho_{k(I-1)}^2 + \left(1-\rho_{k(I-1)}\right)^2\right]}\right) d\tilde{\varepsilon}_{k(I-2)} \\ &= \frac{1}{2}\left(1 + erf\,\frac{V_{k(I-2)} - EV_{k(I-2)}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(I-1)}^2 + \left(1-\rho_{k(I-1)}\right)^2}}\right) \end{aligned} \tag{5.21}$$

Adopt the result of Eq. (5.21) into Eq. (5.18), and combine the Eq. (5.17) then we get expected utility from block $I-2$ to further blocks

$$EU_{k(I-3)}(t) = \max\{U_{k(I-2)}(t), EU_{k(I-2)}(t)\}$$

$$
\begin{aligned}
&= \frac{1}{2}\left(1+erf\,\frac{V_{k(I-2)}-EV_{k(I-2)}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(I-1)}^2+\left(1-\rho_{k(I-1)}\right)^2}}\right)\cdot U_{k(I-2)}\left(t\right)\\
&\quad+\frac{1}{2}\left(erf\,\frac{V_{k(I-2)}-EV_{k(I-2)}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(I-1)}^2+\left(1-\rho_{k(I-1)}\right)^2}}-1\right)\cdot EU_{k(I-2)}\left(t\right)\\
&= \frac{1}{2}\left(1+erf\,\frac{V_{k(I-2)}-EV_{k(I-2)}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(I-1)}^2+\left(1-\rho_{k(I-1)}\right)^2}}\right)\cdot U_{k(I-2)}\left(t\right)\\
&\quad+\frac{1}{2}\left(erf\,\frac{V_{k(I-2)}-EV_{k(I-2)}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(I-1)}^2+\left(1-\rho_{k(I-1)}\right)^2}}-1\right)\cdot\left(EV_{k(I-2)}\left(t\right)+\hat{\varepsilon}_{k(I-2)}\right)
\end{aligned}
\tag{5.22}
$$

Where, $\left(1+erf\,\frac{V_{k(I-2)}-EV_{k(I-2)}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(I-1)}^2+\left(1-\rho_{k(I-1)}\right)^2}}\right)$ is not exist uncertainty term, so it can be calculated by computer simulation and get constant value we define $\frac{1}{2}\left(1+erf\,\frac{V_{k(I-2)}-EV_{k(I-2)}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(I-1)}^2+\left(1-\rho_{k(I-1)}\right)^2}}\right)=\rho_{k(I-2)}$, the expected utility of Eq. (5.21) can be rewritten as

$$
EU_{k(I-3)}\left(t\right)=\rho_{k(I-2)}\cdot U_{k(I-2)}\left(t\right)+\left(1-\rho_{k(I-2)}\right)\cdot\left(EV_{k(I-2)}\left(t\right)+\hat{\varepsilon}_{k(I-2)}\right)
\tag{5.23}
$$

We define joint error term of expected utility from block $I-2$ to further blocks is $\hat{\varepsilon}_{k(I-3)}=\rho_{k(I-2)}\cdot\varepsilon_{k(I-2)}+\left(1-\rho_{k(I-2)}\right)\cdot\hat{\varepsilon}_{k(I-2)}$ which follows the normal distribution of $N\sim\left(0,\rho_{k(I-2)}^2+\left(1-\rho_{k(I-2)}\right)^2\right)$, define $EV_{k(I-3)}=\rho_{k(I-2)}\cdot V_{k(I-2)}+\left(1-\rho_{k(I-2)}\right)\cdot EV_{k(I-2)}$ so the Eq. (5.22) can be rewritten as

$$
EU_{k(I-3)}\left(t\right)=EV_{k(I-3)}+\hat{\varepsilon}_{k(I-3)}
\tag{5.24}
$$

To summarize above equations, the expected utility from block $i+1$ to further blocks

$$
EU_{ki}\left(t\right)=EV_{ki}+\hat{\varepsilon}_{ki}
\tag{5.25}
$$

Apply the definition of $EV_{k(i)}=\rho_{k(i+1)}\cdot V_{k(i+1)}+\left(1-\rho_{k(i+1)}\right)\cdot EV_{k(i+1)}$ from $i+1$ to $I-2$ and summarize the expected utility from block $i+1$ to further blocks of Eq. (5.25) becomes

$$EU_{ki}(t)=\rho_{k(i+1)}V_{k(i+1)}+\rho_{k(i+2)}\left(1-\rho_{k(i+1)}\right)V_{k(i+2)}+\ldots+\prod_{i=i+1}^{I-2}(1-\rho_{ki})\cdot EV_{k(I-2)}+\hat{\varepsilon}_{ki} \quad (5.26)$$

Adopt the definition of $EV_{k(I-2)}=\rho_{k(I-1)}\cdot V_{k(I-1)}+\left(1-\rho_{k(I-1)}\right)\cdot V_{kI}$, we get

$$\begin{aligned}EU_{ki}(t)=&\rho_{k(i+1)}V_{k(i+1)}+\rho_{k(i+2)}\left(1-\rho_{k(i+1)}\right)V_{k(i+2)}+\ldots+\prod_{i=i+1}^{I-2}(1-\rho_{ki})\cdot\rho_{k(I-1)}V_{k(I-1)}\\&+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}+\hat{e}_{ki}\end{aligned} \quad (5.27)$$

Summarize and combine the V_{ki}, $i\in[1,I-1]$,the Eq.(5.27) can be rewritten as

$$EU_{ki}(t)=\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}+\hat{\varepsilon}_{ki} \quad (5.28)$$

Where $\rho_{ki}=\frac{1}{2}\left(1+erf\,\frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)$, $i\in[1,I-2]$

and $\rho_{k(I-1)}=\left(\frac{1}{2}+\frac{1}{2}erf\,\frac{V_{k(I-1)}-V_{kI}}{2}\right)$, $\hat{\varepsilon}_{ki}$ follows $N\sim\left(0,\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}\right)$ distribution.

5.4 Sequential parking choice model

5.4.1 Model precondition

To identify and model the parking choice behavior of a parking area, we assumed the total number of blocks is I of the parking area. Figure 5.1 shows the simplified traffic route of parking area. At the continuous time t_k ($k=1,2,...,K$), driver k enter into the parking area and receiving the comprehensive information related to each block at time t_k. After that, driver k will drive through junction $1,2,...,i$ at time $t_{k1},t_{k2},\ldots t_{ki}$ ($i=1,2,...,I$)and compare the predicted utility of current alternative, block i with the expected utility of further alternatives, block i+1 to block I based on the information that driver k received at time t_k, till he selected and parked at preferred block successfully. In this thesis, it is assumed in the discrete time t_{ki} ($i=1,2,...,I$), driver will receive the same information at each junction and same as the information he received at time t_k when he is entering into the parking area.

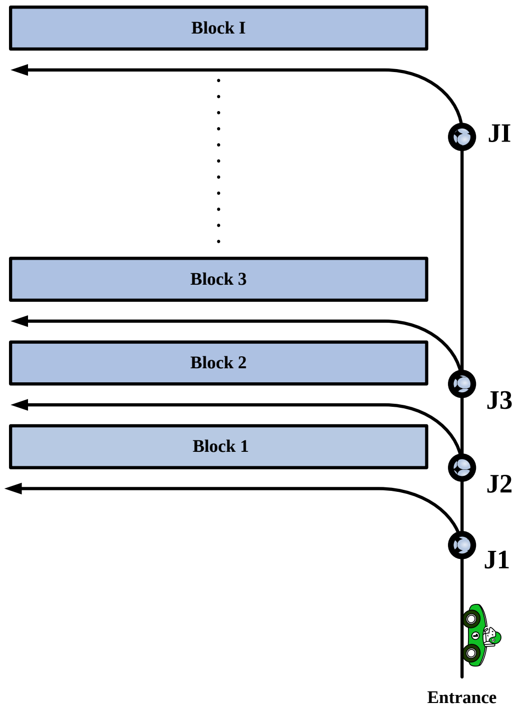

Figure 5.1: Simplified traffic route of parking area
Notes: "J1"- Junction No.1; "J2"- Junction No.2; "J3"- Junction No.3; "JI"- Junction No.I

5.4.2 Sequential parking choice process

For the time t_k, driver k enter into the parking area, there are $m_i(t_k)$ $(0 \le m_i(t_k) \le M_i)$ vehicles in the block i. M_i is denoted as the capacity of block i. For the time t_{ki}, driver k arrives at the junction i, and there are $m_i(t_k)(0 \le m_i(t_k) \le M_i)$ vehicles in the block i, it is assumed that the time interval $\Delta t = t_{ki} - t_{k(i-1)}$ $(i = 1, 2, ..., I)$ reaches sufficient small value, and the probability of two or more than two drivers arrive at and one or more than one drivers depart from the block i is too small, and which can be ignored; and the probability of the information skip to next status for the same driver in the time interval of $\Delta t = t_{ki} - t_{k(i-1)}$ is too small, and which can be ignored. The possible state changes between the time interval t_i and time $t_i + \Delta t$ is either: 1) driver k chooses to park in the block i 2) driver k doesn't choose to park in the block i. Then the probability of the driver k chooses to park in the block i is

$\Pr ob_i\left(t_i, m_i\left(t_k\right)\right)$, and the probability of the driver k doesn't choose to park in the block i is $\left(1-\Pr ob_i\left(t_i, m_i\left(t_k\right)\right)\right)$. As mentioned in the above section, at the junction i, the probability of the driver k chooses to park in the block i related with driver predicted utility of block i and expected utility for further blocks from block $i+1$ to block I, and then the choice probability at junction i for driver k is

$$\tilde{P}_{ki} = \Pr ob_i\left(t_i, m_i\left(t_k\right)\right) = \mathrm{Prob}\left(V_{ki}\left(t_k\right)+\varepsilon_{ki} > EU_{ki}\left(t\right)\right) \tag{5.29}$$

The probability of drive choose to park at block i at junction i can be re-expressed according to the derivation result of $EU_{ki}\left(t\right)$ in Eq. (28)

$$\begin{aligned}\tilde{P}_{ki} &= \Pr ob\left(V_{ki}\left(t\right)+\varepsilon_{ki} > EV_{ki}\left(t\right)+\hat{\varepsilon}_{ki}\right)\\ &= \int I\left(V_{ki}\left(t\right)+\varepsilon_{ki} > EV_{ki}\left(t\right)+\hat{\varepsilon}_{ki}\right)\phi\left(\varepsilon_k\right)d\varepsilon_k\end{aligned} \tag{5.30}$$

Define, $\tilde{V}_{ki} = EV_{ki} - V_{ki}$, $\tilde{\varepsilon}_{ki} = \hat{\varepsilon}_{ki} - \varepsilon_{ki}$, and Eq. (5.30) becomes

$$\tilde{P}_{ki} = \int I\left(\tilde{V}_{ki}+\tilde{\varepsilon}_{ki} < 0\right)\phi\left(\tilde{\varepsilon}_{ki}\right)d\tilde{\varepsilon}_{ki} \tag{5.31}$$

The Probit model can be derived under the assumption of jointly normal density of integrals over the difference between errors. As defined in the section 5.3.2, $\hat{\varepsilon}_{ki}$ follows normal distribution $N \sim \left(0, \rho_{k(i+1)}^2 + \left(1-\rho_{k(i+1)}\right)^2\right)$. And add the density of error difference of $\phi\left(\tilde{\varepsilon}_{ki}\right) = \frac{1}{\left(2\pi\right)^{\frac{1}{2}}\left|\tilde{\Omega}_k\right|^{\frac{1}{2}}} e^{-\frac{1}{2}\tilde{\varepsilon}_{ki}'\tilde{\Omega}_k^{-1}\tilde{\varepsilon}_{ki}}$, and then the probability driver k choose to park at block i at junction i

$$\begin{aligned}\tilde{P}_{ki} &= \int \phi\left(\tilde{\varepsilon}_{ki}\right)d\tilde{\varepsilon}_{ki}\\ &= \int \frac{1}{\sqrt{1+\rho_{k(i+1)}^2+\left(1-\rho_{k(i+1)}\right)^2}\sqrt{2\pi}} \exp\left(-\frac{\tilde{\varepsilon}_{ki}^2}{2\cdot\left[1+\rho_{k(i+1)}^2+\left(1-\rho_{k(i+1)}\right)^2\right]}\right)d\tilde{\varepsilon}_{ki}\\ &= \frac{1}{2}\left(1+erf\,\frac{V_{ki}-EV_{ki}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^2+\left(1-\rho_{k(i+1)}\right)^2}}\right)\end{aligned} \tag{5.32}$$

Where, based on Eq. (5.25) and Eq. (5.28), we can get that

$$EV_{ki}\left(t\right)=\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}\left(1-\rho_{ki}\right)V_{kI}$$

which can be used in Eq. (5.32), and the equivalent expression is

$$\tilde{P}_{ki}=\frac{1}{2}\left(1+erf\;\frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}\left(1-\rho_{ki}\right)V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right) \tag{5.33}$$

Where, $\rho_{ki}=\frac{1}{2}\left(1+erf\;\frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}\left(1-\rho_{ki}\right)V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)$, $i\in\left[1,I-2\right]$ and

$\rho_{k(I-1)}=\left(\frac{1}{2}+\frac{1}{2}erf\;\frac{V_{k(I-1)}-V_{kI}}{2}\right)$. Now the probability driver k choose to park at block i at junction i have been derived, but the parking choice process is a sequential activities as describes in the figure 5.2. Therefore, we also need to derive the transition probability of driving moving from junction i to $i+1$. $i\in\left[1,I-1\right]$.

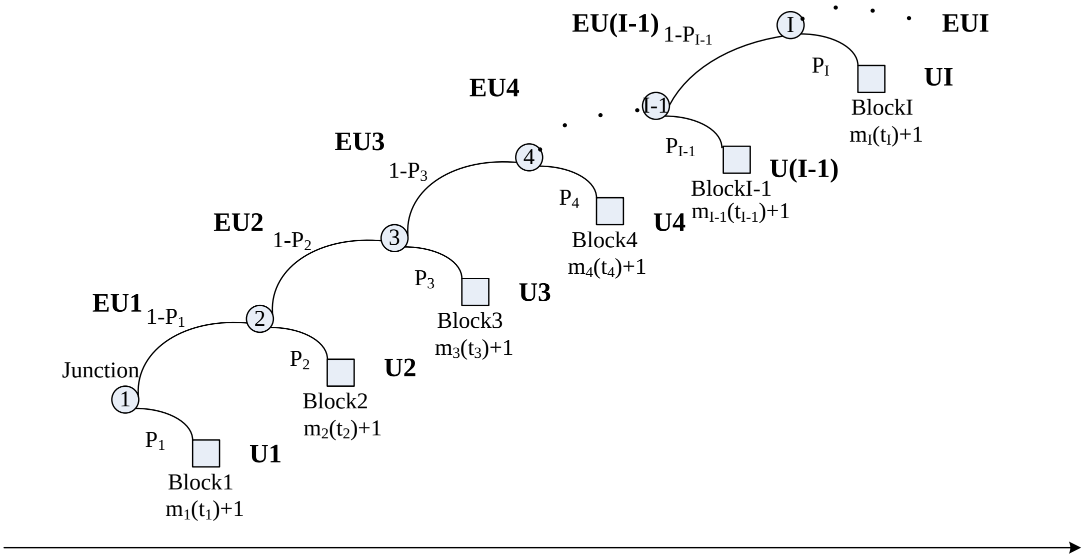

Figure 5.2: Sequential parking choice activity of individual agent

As can be seen from the above figure, the probabilities of choosing at an available space are calculated from past transition probability and using them to project future outcomes, then the probability of driver k choose block i in the whole parking choice process is

$$
\begin{aligned}
P_{ki}(t) &= \Pr ob_i\left(t_i, m_i\left(t_k\right)\right)\times\prod_{j=1}^{i-1}\left(1-\Pr ob_j\left(t_j, m_j\left(t_k\right)\right)\right) \\
&= \tilde{P}_{ki}\left(t\right)\times\prod_{j=1}^{i-1}\left(1-\tilde{P}_{ki}\left(t\right)\right)
\end{aligned}
\tag{5.34}
$$

Here we adopted Eq. (5.33), and then the Eq. (5.34) can be written as

$$
\begin{aligned}
P_{ki}\left(t\right) &= \frac{1}{2}\left(1+erf\ \frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}\left(1-\rho_{ki}\right)V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right) \\
&\times\prod_{j=1}^{i-1}\frac{1}{2}\left(erf\ \frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}\left(1-\rho_{ki}\right)V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}-1\right)
\end{aligned}
\tag{5.35}
$$

5.4.3 Maximum likelihood estimation of the parameters

In the former content, we have considered and analyzed Markov parking choice process for one decision maker — driver k and get the probability for driver k parks at block i after passed by $i-1$ junctions. Consider, a sample of K decision makers is obtained for the purpose of estimation. Then the probability of driver k actually choose to park at block i can be expressed as

$$
\begin{aligned}
\prod_i\left(P_{ki}\left(t_k\right)\right)^{y_{ki}} &= \prod_i\left(\tilde{P}_{ki}\left(t\right)\times\prod_{j=1}^{i-1}\left(1-\tilde{P}_{ki}\left(t\right)\right)\right)^{y_{ki}} \\
&= \prod_i\left(\begin{gathered}\frac{1}{2}\left(1+erf\ \frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}\left(1-\rho_{ki}\right)V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right) \\ \times\prod_{j=1}^{i-1}\frac{1}{2}\left(erf\ \frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}\left(1-\rho_{ki}\right)V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}-1\right)\end{gathered}\right)^{y_{ki}}
\end{aligned}
\tag{5.36}
$$

Where, $y_{ki}=1$ if driver k parked at block i and zero otherwise. Assuming each driver's parking choice is independently from other drivers, and then the probability of each driver in the sample parked at the block that he was observed actually parked is

$$L(\alpha)=\prod_i \left(P_{ki}(t_k)\right)^{y_{ki}} = \prod_{k=1}^{K}\prod_i \left(\tilde{P}_{ki}(t)\times\prod_{j=1}^{i-1}\left(1-\tilde{P}_{ki}(t)\right)\right)^{y_{ki}}$$

$$=\prod_{k=1}^{K}\prod_i \left(\begin{array}{c}\frac{1}{2}\left(1+erf\,\dfrac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^2+\left(1-\rho_{k(i+1)}\right)^2}}\right)\\ \times\prod_{j=1}^{i-1}\frac{1}{2}\left(erf\,\dfrac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^2+\left(1-\rho_{k(i+1)}\right)^2}}-1\right)\end{array}\right)^{y_{ki}} \tag{5.37}$$

Where, α is a parameter vector to describe the attribute of variable x_i in the utility equation of Eq. (5.4),under the effect of PGI, the parameter of α can be describe the significance of the variable reflect the real time occupancy status of each block, then the log-likelihood function is

$$LL(\alpha)=\sum_{k=1}^{K}\sum_i y_{ki}\ln P_{ki}(t_k)=\sum_{k=1}^{K}\sum_i y_{ki}\ln\tilde{P}_{ki}(t)+\sum_{k=1}^{K}\sum_i y_{ki}\sum_{j=1}^{i-1}\left(1-\tilde{P}_{ki}(t)\right)$$

$$=\sum_{k=1}^{K}\sum_i y_{ki}\ln\left(\frac{1}{2}\left(1+erf\,\frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^2+\left(1-\rho_{k(i+1)}\right)^2}}\right)\right)$$

$$+\sum_{k=1}^{K}\sum_i y_{ki}\sum_{j=1}^{i-1}\frac{1}{2}\left(erf\,\frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^2+\left(1-\rho_{k(i+1)}\right)^2}}-1\right) \tag{5.38}$$

A method for computing the likelihood function, the maximum likelihood estimators (MLEs) of the parameters are found by maximizing the log likelihood Eq. (5.38). Manki and McFadden (1981) and Cosslett (1981) describe estimation methods under a variety of sampling procedures. At the maximum of the likelihood function, its derivative with respect to each of the parameters is zero:

$$\frac{\partial LL(\alpha)}{\partial\alpha}=0 \tag{5.39}$$

Using the Eq. (5.4) and Eq. (5.38), the end of the subsection of first-order condition becomes:

$$\frac{\partial\sum_{k=1}^{K}\sum_{i} y_{ki}\ln\left(\frac{1}{2}\left(1+erf\,\frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)\right)}{\partial\alpha}$$

$$+\frac{\partial\sum_{k=1}^{K}\sum_{i} y_{ki}\sum_{j=1}^{i-1}\frac{1}{2}\left(erf\,\frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}-1\right)}{\partial\alpha}=0 \qquad (5.40)$$

Derive the parameter α into each V_{ki}, the Eq. (5.40) can be expressed as

$$\sum_{k=1}^{K}\sum_{i} y_{ki}\frac{\frac{1}{2}\left(erf\,\frac{x_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}x_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})x_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)}{\frac{1}{2}\left(1+erf\,\frac{V_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}V_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})V_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)} \qquad (5.41)$$

$$+\sum_{k=1}^{K}\sum_{i} y_{ki}\sum_{j=1}^{i=1}\frac{1}{2}erf\,\frac{x_{ki}-\sum_{j=i+1}^{I-1}\rho_{kj}x_{kj}\prod_{i=i+1}^{j-1}(1-\rho_{ki})+\prod_{i=i+1}^{I-1}(1-\rho_{ki})x_{kI}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}=0$$

In this thesis, even though maximum-likelihood estimation theory is applied to help in finding the value of parameters, first-order condition cannot be directly derived from the Eq. (5.38). Refers to the complication of probability of selecting an alternative in the sequential decision making activities, the algorithm will be given in the next section by combining the investigation of marginal and conditional probability from the last alternative in the sequential alternatives and the MCMC algorithms for sampling from the distribution of probability.

5.5 Algorithm for estimating parameters of sequential parking choice model

This section discusses the algorithm of sequential parking choice model. In this chapter, parking choice behavior is sequence moving activities with sequence decision making process. The utility of an alternative can be represented by random utility model. Even though, there is no specific utility function of expectation of joint alternatives, in some extent, expected utility can only be calculated by joint utility function of alternatives. As explained in the section 5.3.1, with the assumption, each ε_{ki} is independent and follows standard distributed normal, hence $\varepsilon_{ki} \sim N(0,1)$. Then for the expected utility of further joint alternatives, error term of expected utility can be represented by the joint distribution of the error term of the utility of each expected alternative. So now, the error term of expected utility is a multivariate normal with mean 0 and a matrix of covariance denoted $\tilde{\Omega}$, Note that the matrix size of $\tilde{\Omega}$ is related to the number of further alternatives. As defined in the section 5.3.2, there are I alternatives in the parking area, and further block after block I is not existed, hence $EU_{kI}(t)=0$. So, for the expected utility of $EU_{ki}(t)$, the joint expectation of further alternatives includes block $i+1$ to block I, and then the number of further alternative is $I-i$. Therefore, the covariance matrix of $EU_{ki}(t)$, $\tilde{\Omega}^i$ is $(I-i-1)\times(I-i-1)$.

Considering the complication of error term of expected utility and transition probability of each moving in the sequence parking choice process, the algorithm of sequence choice activities cannot be simply described by one general algorithm. The most popular general algorithms are EM (Expectation, Maximization) algorithm (Dempster, Laird and Rubin, 1977), ECM (Expectation, Conditional Maximization) algorithm (Meng and Rubin, 1993), an extension of EM and called ECME (Expectation, Conditional Maximization of Either) algorithm (Liu and Rubin, 1994) or MCMC (Markov Chain Monte Carlo) algorithms (Gilks et al. 1996; Robert and Casella 1999). In this thesis, a new algorithm will be given and used for obtaining the estimated parameters of sequential parking choice model.

Let's now investigate the marginal and conditional probability from the last alternative in the sequential alternatives. In this section, a Metropolis-Hasting MCMC algorithm is considered to sample from the distribution of acceptance distribution. The kernel density estimator is also described. As described the expected utility after the last alternative, $EU_{kI}(t)=0$. Then the algorithm can be described as following steps.

1. Give an initial value of parameters $\alpha^{(0)}$ and $\beta^{(0)}$ randomly in the utility function, assume the α and β follows standard normal distribution as prior distribution $P(\alpha)$, $P(\beta)$, where $\alpha \sim N(0,1)$; $\beta \sim N(0,1)$ and record iteration times $r=1$.
2. Obtain sampling steps for α from prior distribution of standard normal distribution, a lognormal sampling distribution with the log of the proposal centered on the log of the current

value is used, $q\left(\alpha'|\alpha\right) \propto \frac{1}{\alpha}\exp\left[-\frac{\left(\log\left(\alpha'\right)-\log\left(\alpha\right)\right)^2}{2\sigma_q^2}\right]$, where for this step $\sigma_q = 0.15$. The acceptance for this step is calculated by $P_{accept} = \min\left(1, \frac{P\left(\alpha'\right)q\left(\alpha|\alpha'\right)}{P\left(\alpha\right)q\left(\alpha'|\alpha\right)}\right)$. To complete this sampling step, a uniform random variable is drawn, and α' is accepted if the uniform draw is less than P_{accept}, otherwise α' is rejected.

3. Repeat step 2 until a sample of 2000 was obtained to estimate the mean and covariance for the sampling distribution.
4. Obtain sampling steps for β from prior distribution of standard normal distribution, a lognormal sampling distribution with the log of the proposal centered on the log of the current value is used, $q\left(\beta'|\beta\right) \propto \frac{1}{\beta}\exp\left[-\frac{\left(\log\left(\beta'\right)-\log\left(\beta\right)\right)^2}{2\sigma_q^2}\right]$, where for this step $\sigma_q = 0.15$. The acceptance for this step is calculated by $P_{accept} = \min\left(1, \frac{P\left(\beta'\right)q\left(\beta|\beta'\right)}{P\left(\beta\right)q\left(\beta'|\beta\right)}\right)$. To complete this sampling step, a uniform random variable is drawn, and β' is accepted if the uniform draw is less than P_{accept}, otherwise β' is rejected.
5. Repeat step 4 until a sample of 2000 was obtained to estimate the mean and covariance for the sampling distribution.
6. Use the estimated mean of $\bar{\alpha}$ from step 2, 3, and the estimated mean of $\bar{\beta}$ from step 4, 5 to calculate the likelihood function from step 7 ~ step 15.
7. Calculate probability at penultimate junction $\tilde{P}_{k(I-1)} = \frac{1}{2}\left(1+erf\,\frac{V_{k(I-1)}-V_{kI}}{2}\right)$, Then calculate the expected utility of last two alternatives and get $EU_{k(I-2)}\left(t\right) = U_{k(I-1)}\left(t\right)\cdot\tilde{P}_{k(I-1)} + U_{kI}\cdot\left(1-\tilde{P}_{k(I-1)}\right)$.
8. Compute the probability at the third junction from the end, $\tilde{P}_{k(I-2)} = \frac{1}{2}\left(1+erf\,\frac{V_{k(I-2)}-EV_{k(I-2)}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(I-1)}^2+\left(1-\rho_{k(I-1)}\right)^2}}\right)$ and calculate the expected utility of

last three alternatives and get $EU_{k(I-3)}(t)=U_{k(I-2)}(t)\cdot\tilde{P}_{k(I-2)}+U_{k(I-1)}\cdot\left(1-\tilde{P}_{k(I-2)}\right)$.

9. …compute the probability at the $I-i+1$ junction from the end $\tilde{P}_{ki}=\frac{1}{2}\left(1+erf\,\frac{V_{ki}-EV_{ki}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)$ and calculate the expected utility of last $I-i+1$ alternatives and get $EU_{k(i-1)}(t)=U_{ki}(t)\cdot\tilde{P}_{ki}+U_{k(i+1)}\cdot\left(1-\tilde{P}_{ki}\right)$.
10. Repeat step 9 till compute the probability at the first junction $\tilde{P}_{k1}=\frac{1}{2}\left(1+erf\,\frac{V_{k1}-EV_{k1}}{\sqrt{2}\cdot\sqrt{1+\rho_{k2}^{2}+\left(1-\rho_{k2}\right)^{2}}}\right)$.
11. Calculate the probability of driver chooses alternative 1 is $\tilde{P}_{k1}=\frac{1}{2}\left(1+erf\,\frac{V_{k1}-EV_{k1}}{\sqrt{2}\cdot\sqrt{1+\rho_{k2}^{2}+\left(1-\rho_{k2}\right)^{2}}}\right)$
12. … calculate the probability of driver chooses alternative i since the first move $\frac{1}{2}\left(1+erf\,\frac{V_{ki}-EV_{ki}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)\times\prod_{j=1}^{i-1}\left(\frac{1}{2}-\frac{1}{2}erf\,\frac{V_{ki}-EV_{ki}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)$
13. Repeat step 12 till the probability of driver chooses alternative $I-1$ since the first move $\frac{1}{2}\left(1+erf\,\frac{V_{k(I-1)}-V_{kI}}{2}\right)\times\prod_{j=1}^{I-2}\left(\frac{1}{2}-\frac{1}{2}erf\,\frac{V_{ki}-EV_{ki}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)$
14. Calculate the probability of driver choose alternative I since the first move $\frac{1}{2}\left(1-erf\,\frac{V_{k(I-1)}-V_{kI}}{2}\right)\times\prod_{j=1}^{I-2}\left(\frac{1}{2}-\frac{1}{2}erf\,\frac{V_{ki}-EV_{ki}}{\sqrt{2}\cdot\sqrt{1+\rho_{k(i+1)}^{2}+\left(1-\rho_{k(i+1)}\right)^{2}}}\right)$
15. According to the choice set and compute the likelihood function of $\prod_{i}\left(P_{ki}(t_k)\right)^{y_{ki}}=\prod_{i}\left(\tilde{P}_{ki}(t)\times\prod_{j=1}^{i-1}\left(1-\tilde{P}_{ki}(t)\right)\right)^{y_{ki}}$.
16. Record the likelihood estimate result. And iterate above steps from 2 to 15, 10000 times, draw the distribution of likelihood estimate result
17. Find the value of mean $\bar{\alpha}$ and $\bar{\beta}$ with the maximum likelihood estimate result.

5.6 Conclusion

In this chapter, a new framework of sequential parking choice model has been presented. The basic premise is that individuals choose or whether or not to make a parking based on decision yield to a higher utility of current alternative and the expectation for further alternatives. The sequential choice model assumes a form of behavior in which individuals choose to take an additional trip only after the previous one is complete. Different with traditional discrete parking choice model, at the beginning, driver can only receive the characteristics or information related to the current first alternative but obtain the characteristics or information related to all alternatives. Another differ from the traditional parking choice model is, in the sequence choice model, the number of alternatives can be assumed as undetermined or unlimited. It is also differs from the multinomial choice model (what I used in chapter 4) which treats individual trips as independent and does not typically incorporate the number of trips chosen.

During the sequence choice activities, even though there is no providing information related to further alternatives, drivers can give an expectation for further unknown alternatives. The sequential choice model offers an alternative to the traditional approach to estimate parking choice behavior especially given an assumption of no specific defined variable given in expected utility. While the traditional approach is best suited to some forms of choice behavior, there are many cases where the sequential choice model may offer a more appropriate depiction of actual trip choice behavior. Moreover, it is also could be a comparison with traditional discrete choice model in the same case study. In the further research, the estimated result of sequential parking choice model can be compared with multinomial parking choice model, besides the estimated result of sequential parking choice model can also be used in economic evaluation by agent-based modeling simulation. In the next chapter, the estimated result of multinomial parking choice model in chapter 4 is used for simulating the economic evaluation.

5.7 References

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6 Multi-agent modeling simulation for economic evaluation

6.1 Introduction

In this chapter, firstly the background of agent-based model simulation is introduced through the aspects of development progress, available platforms and programming languages, advantage of application in transportation system. In the section 6.3, the definition and organization of two projects of REPASTPA and REPASTPGI are described. Besides, the integration of choice model with Repast S projects, the individual agent move and algorithm of obtaining two economic indexes are also explained. With the estimation result of parking choice model under the effect of with PGI (ASL information) and without PGI (null information) in the chapter 4, the simulation setting is explained including data, arrival and departure, searching time and initialization in the section 6.4. Then, the simulation result of number of lost agent and average searching time under the effect of with PGI and without PGI is presented with quoting and defining “lost agent”, “searching time” as two economic indexes in section 6.5. To give to deeper understanding, the simulation results with setting different initial occupancy rate are also compared in the section 6.6. In the section 6.7, to give a clearing impression of influence of continuous congested situation, the arrival rate and departure rate are divided into three levels, and the simulation results of these three levels are given and compared in the section 6.7.

6.2 Background of agent-based model simulation

Agent-based modeling and simulation is a microscopic simulation approach to modeling complicated system (e.g. biology, ecology, economics, political science, sociology, transportation etc.) under certain environment which composed of interacting, autonomous ‘agents’ in the last decades (Axelrod 1997, Bonabeau 2002, Mialhe 2012). Thomas Schelling (1971) firstly given and discussed the concept of agent-based models (ABM) in segregation model to explain the interactive dynamics of discriminatory individual choices. During the 1980s, social scientists, mathematicians, operations researchers, and other related fields’ researches developed computational and mathematical organization theory (CMOT). Axelrod and Hamilton (1981) applied a prisoner’s dilemma strategies into an agent-based model to determine a winner. At 1997, Axelrod developed and adopted many other agent-based models into political science to examine the phenomena from ethnocentrism to the dissemination of culture. With the appearance of StarLogo in 1990, Swarm and NetLogo in the mid-1990s and Repast and AnyLogic in 2000, GAMA in 2007 as well as some custom-designed code, modeling software became widely available and range of domains that ABM was applied to grow.

Currently, there are various software platforms and programming languages to support agent-based modeling simulation for performing the intelligent behavior of agent. The most and commonly used ABM platforms are Swarm in Objective-C, Java Swarm, MASON in Java, NetLogo in its own programming language, Repast Java, AnyLogic in Java, Repast HPC in C++ and Repast Simphony. Repast Simphony is the highest-level platform for microscopic traffic simulation which is an open source toolkits for ABM and the second version just released on

March 2012. Repast S can be compatible with multiple programming language and model environment such as Relogo, Groovy, NetLogo, and Java.

Given the increasing complexity of ITS, not only developing and adopting new technology of electronic, information, etc. on the application of traffic and transportation, the individual behavior and interaction need to be understood and added if whole system want to be more efficient. Hence, there is growing need to model and improve traffic and transportation systems at both the individual (micro) and the society (macro) level. It is well established that agent-based approaches suit traffic and transportation management very well given the geographical, functional and temporal distribution of data and control, as well as the frequent and flexible interaction between the participants and their environment. Therefore, traffic and transportation scenarios have become very prominent for coordination and adaptation mechanisms in multi-agent systems. And, agent-based approaches can contribute to the whole effort around the design and control of intelligent transportation system and ultimately to make out cities indeed smart.

Since the advantage of agent-based model simulation in reproducing human decision making and behavior, capturing the level of detail in various traffic scenarios and coordinating decision making for controlling and managing transportation systems, then the application of agent-based model simulation in behavior process can be classified into two categories. They are the researches based on: 1) agent-based simulation focus on the view of travel demand; 2) agent-based simulation focus on the view of traffic related choice process.

For travel demand models, there are a number of agent-based concepts and implementations. Rindsfüser et al. (2004) propose a model of an intelligent agent for adapting daily activity schedule with respect to external events. Zhang and levinson (2004) described a non-activity-based demand modeling. Han et al. (2009) dealt with dynamic location choice sets based on a combination of different forms of learning and psychological theories such as Bayesian learning or social comparison theories. Ronald et al. (2011) analyzed the influence of different interaction protocols on number, frequency and type of activities when multi-agents deciding about an activity. For agent-based models deal with traffic-related choice processes, Wahle et al. (2002) use a microscopic simulation of the traffic flow based on the Nagel-Schreckenberg rules to analyze the effect of specific information types on route choice. Bazzan and Junges (2006) described how congestion tolls can serve as information for guiding the bottom-up coordination of agents in an abstract two route scenario. Amarante and Bazzan (2012) investigated the value of re-planning for drivers with different information.

In this thesis, I use Repast Simphony (Repast S) for Java to create visual Repast projects called REPASTPA and REPASTPAPGI which demonstrate the same parking area and generate a number of agents move to find a parking space. Besides, Repast Simphony (Repast S) is an open source agent-based modeling and simulation toolkit.

6.3 Agent-based model description

6.3.1 REPASTPA and REPASTPAPGI

In particular, agents are organized into collections called Contexts. A context is basically a bucket that can be used to hold agents. Contexts are arranged hierarchically and can contain sub-contexts. The figure 6.1 illustrates the organization of agent-based model. Each context has an associated GIS projection to store the spatial locations of the objects. Projections are used to give the agents a space and define their relationships. For example, 'GIS' projections give each agent an (x, y) spatial location and 'Network' projections allow relationships between agents to be defined. Projections are created for specific contexts and will automatically contain every agent within the context. Shape file layers of GIS can be recognized by Repast S and the spatial location projection can be shown in the background.

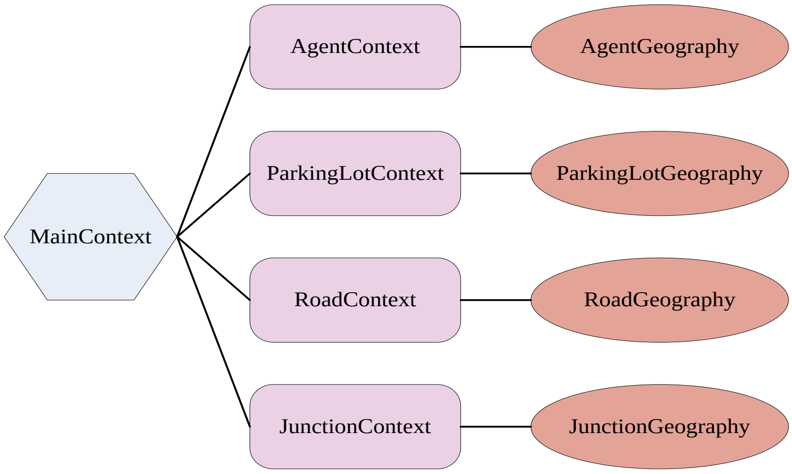

Figure 6.1: Contexts organization of model

The virtual parking area consists of roads, agents, junctions, parking spaces and parking blocks. Agent represents the unit of vehicle and driver who only need to make decision once which happens at the entrance of the rest area, after received information shown in the PGI signs. We use Repast Simphony (Repast S) for Java to create visual Repast projects called REPASTPA and REPASTPAPGI which demonstrate the same rest area and generate a number of agents move to find a parking space. The difference between the agent-based model without PGI system and with PGI system is whether or not to feedback the occupancy of each block after parked at one space successfully or finish park and leave the space for parking choice process.

6.3.2 Integration of parking choice model and Repast S project

Figure 6.2 describes the detail of the parking choice model integrate with Repast projects. In this paper, R program was developed for import the estimated result of multi-nominal discrete choice model of with PGI and without PGI. The difference between the REPASTPA model and REPASTPGI model is whether feedback information of occupancy of block 1 to block I at each tick time. After the same initial setting, and run REPAST model and REPASTPGI model respectively, the simulation results of number of lost agent and average searching time are counted and summarized.

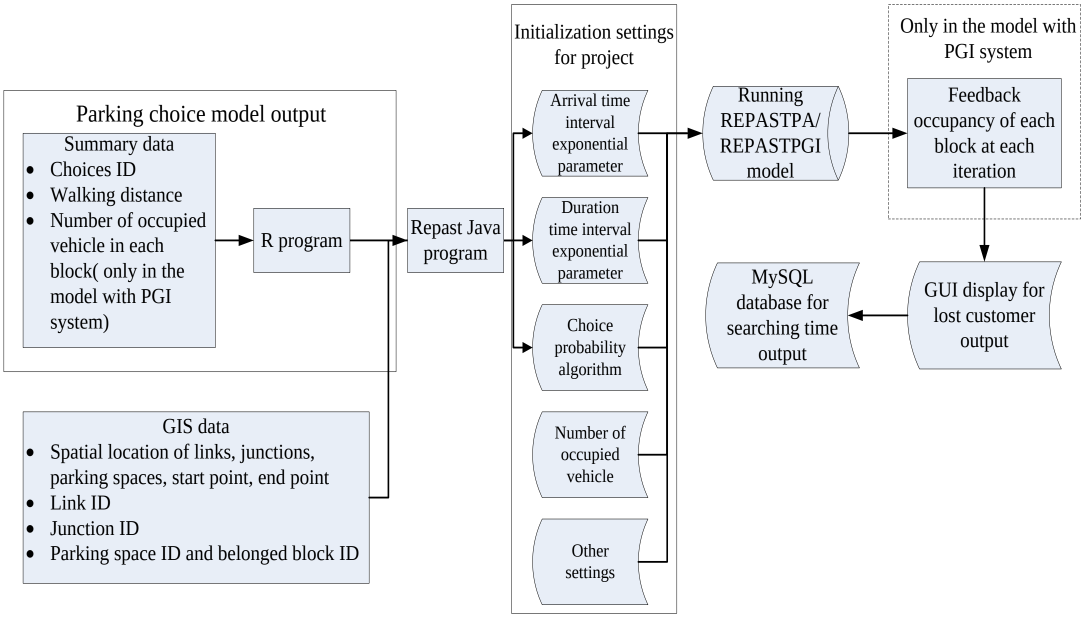

Figure 6.2: Integration of parking choice model and Repast S project

6.3.3 Individual move and algorithm

Figure 6.3 illustrates the algorithm for generating number lost agent and recording individual searching time. Initially there is certain number of agents parked in rest area, and the new generating agents appear from entrance and receive information when arrived at the star point (see Figure 3.8 in section 3.3.2). Based on individual utility, agent chooses a block and drives to the closest junction, if there is empty space in the block, moves to the available space randomly (with PGI) or searches available space according to the ascending order and park (without PGI); otherwise leave the parking area. In this simulation, only one time choice is permitted which occurs at star point (see Figure 3.8 in section 3.3.2). After parking activity, agent leaves the area. The above process will be repeated till all the agents are generated and finished parking activities. The difference between the agent-based model without PGI system and with PGI system is whether update the information related to occupancies status of each block and feed back to PGI system synchronously. It will influence the probability of choosing each block during parking choice process.

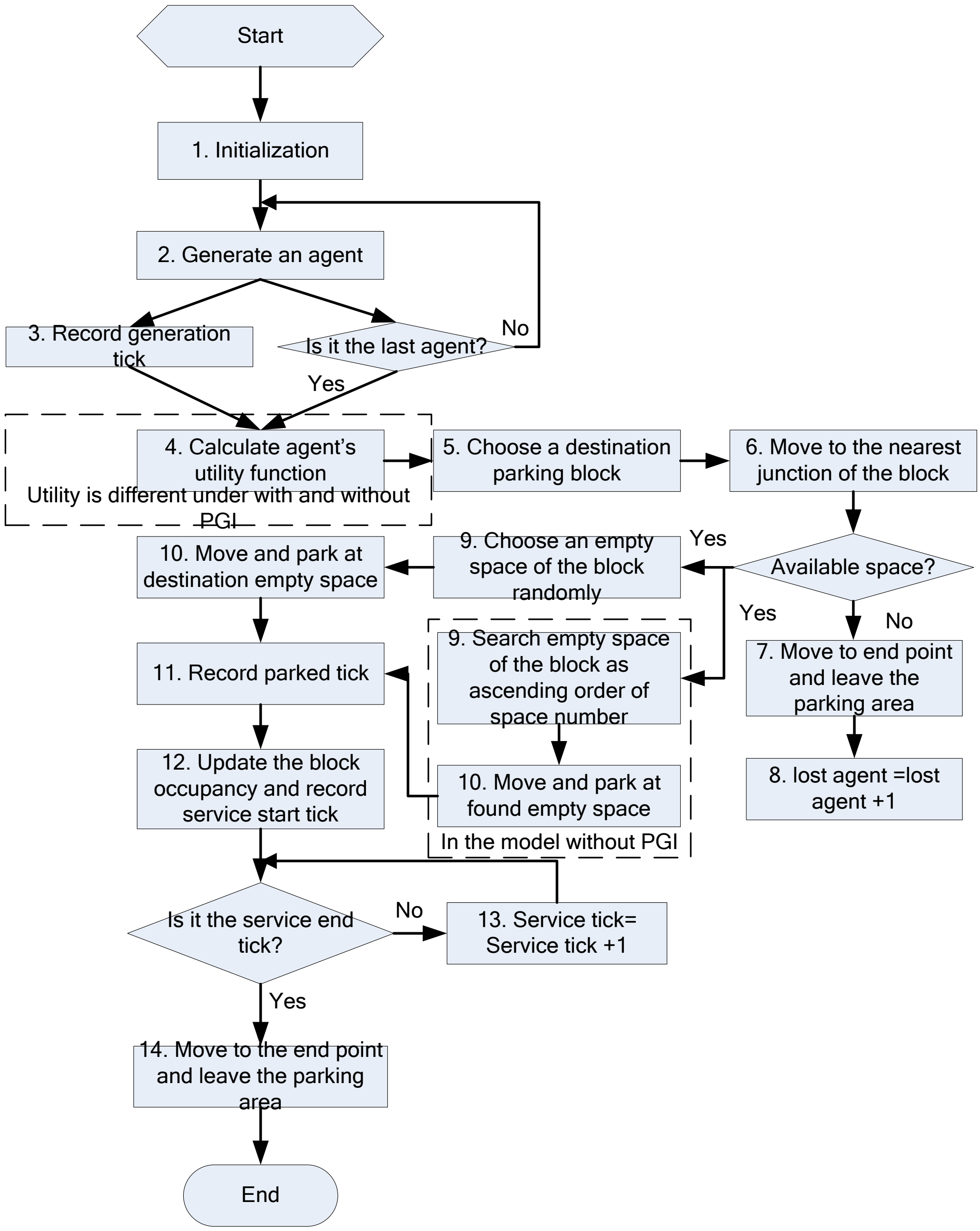

Figure 6.3: Algorithm for generating lost agent and recording search time

6.4 Simulation experiment

6.4.1 Data for simulation

As we known, two periods experiments were conducted during the year 2012 and 2013 (see section 3.1.2), but only on the date of 23rd June 2013, the experiment of ASL information effect was conducted. For estimating the parameter of parking choice model with and without PGI, we selected the data of 23rd June 2013 and total sample number is 884. In this chapter, the estimated results of the parking choice model without PGI (Null information) and with PGI (ASL information) are used in simulating drivers' parking choice behavior. For the simulation, except the initial occupied vehicle in the area, the number of new generating agent is 500, and total running tick is 2500. Considering the GIS projection of background with the scale of actual parking area and agents moving speed, one tick is approximately equal to 10 seconds. Then the total running tick of 2500 is about 7 hours.

6.4.2 Arrival time and duration time

The distribution of arrival and duration time interval frequency by assuming the probability of agent arrival and departure following Poisson distribution is analyzed based on the data collected on 23rd June 2013. Then the estimated result of arrival and duration frequency based on the data of 23rd June 2013 is described in Table 6.1 as follow.

Table 6.1: Model description and exponential model summary

Frequency	Std. Error	Coefficient λ	T value	Sum of Square	Sig.
Arrival	.913	-.579	-7.680	49.143	.000
Duration	.635	-.813	-14.031	79.399	.000

6.4.3 Searching time

Figure 6.4 shows the average searching time of selected blocks under the guidance of ASL information and Null information based on the parking route record data of 23rd June 2013. As we can see from the figure 6.4, the difference between average searching times for drivers who chose block D, E, F under the effect of ASL information and Null information is not very big. For drivers who chose further blocks, the difference between average searching times under situation becomes bigger. Mostly, drivers will cost more time for searching an available space at Null information situation compare with ASL information situation. This finding could help us to define the agent moving speed in later initialization section.

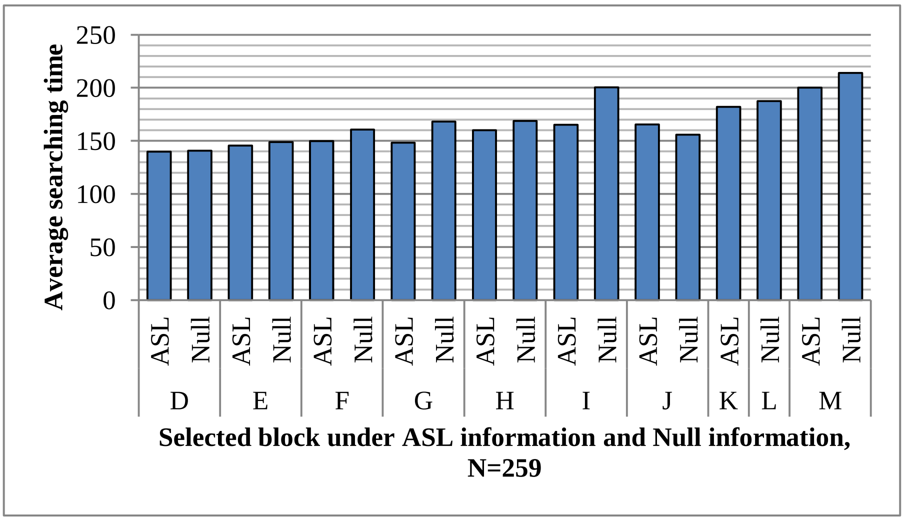

Figure 6.4: Average searching time of selected block under ASL and Null information

6.4.4 Initialization

According to the estimated result in section 4.4.5 and analyzed result in chapter 3, we found that drivers obviously following the guidance of PGI especially when choosing the former 6 blocks. In the real case of upstream of Shimizu parking area, there are ten rows of parking space; each row has 12 available parking spaces. Therefore, in simulation part, all 10 blocks are considered as alternatives. Agent represents the unit of vehicle and driver who only need to make decision once which happens at the entrance of the rest area, after received information shown in the PGI signs. In the initialization, there are a few items need to be set:

- The default number of initial occupied agent in the area is 80 which assigned into each block randomly (initial occupancy rate equal to 66%). And, the number of new generating agent is 500.
- The time unit in Repast S is tick. Here, one tick can be seen as 10 seconds in the virtual parking area. The moving speed of agents follows discrete uniform distribution of [20, 30] (steps per tick which similar to 2~3 meter per second). And the agents' searching speed follows discrete uniform distribution of [20, 25].
- The default value of exponential parameter of arrival tick interval and duration tick interval is -0.579 and -0.813 respectively (see, Table 6.1).
- The headway between two agents is 5 steps, when the value less than 5 steps, the following agent will be stopped till headway over 7 steps.

6.5 Simulation result

The simulation results of "Lost Agent" and "Searching Time" can be obtained. "Lost Agent" means the total number of lost agent, which is generated and counted when driver arrived at the junction of selected block and discovered no empty space to park. "Searching Time" means the average searching time of all agents, which is calculated by recording the time of a new agent generated from entrance and the agent parked at the space of selected block successfully. At every ten ticks (100s), the difference between generating tick and parking tick of each existed agent (including the agent still in the system and the agent who finished parking activity and leave the system) is calculated and summarized as mean value. Despite, "Lost Agent" and "Searching Time" are not traditional economic evaluation indexes, the two indexes can be considered as important factors for economic evaluation of PGI system. In this research, we will use the above two values to measure the economic effects of PGI system. The REPASTPA and REPASTPGI models' running display are similar and shown in the Figure 6.5.

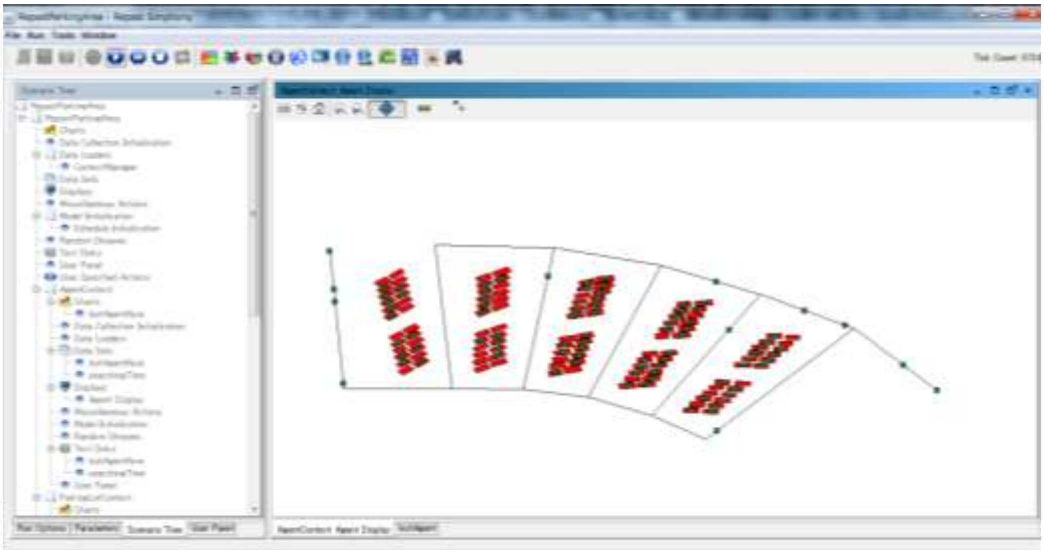

Figure 6.5: Running interface of REPASTPA and REPASTPAPGI

6.5.1 Number of lost agent

After running simulation 10 times of the two projects separately, the simulation results of lost agent of two projects of REPASTPA and REPASTPAPGI are shown in the Figure 6.6.

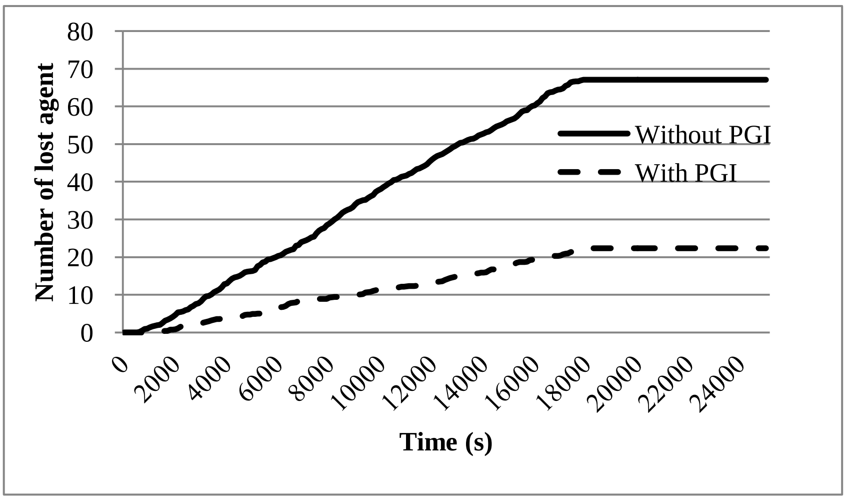

Figure 6.6: Cumulative number of lost agent of REPASTPA and REPASTPAPGI

The above figure compares the value of “Lost Agent”, the maximum number of lost agent under the environment without PGI is 68, and the maximum number of lost agent is 21, besides, in the course of tick time, the difference of number of lost agent between the two models is also increasing from 0 to 47. The result indicates that information did guide drivers to less congested blocks and PGI system indeed places a significant effect on reducing the number of lost customers especially when providing ASL information.

6.5.2 Searching time

After running simulation 10 times of the two projects separately, simulation result of average searching time of REPASTPA and REPASTPAPGI is shown in the figure 6.7. To give a deep impression, the simulation result of average searching time of REPASTPA and REPASTPAPGI divided by selected block is shown in the figure 6.8 as follow.

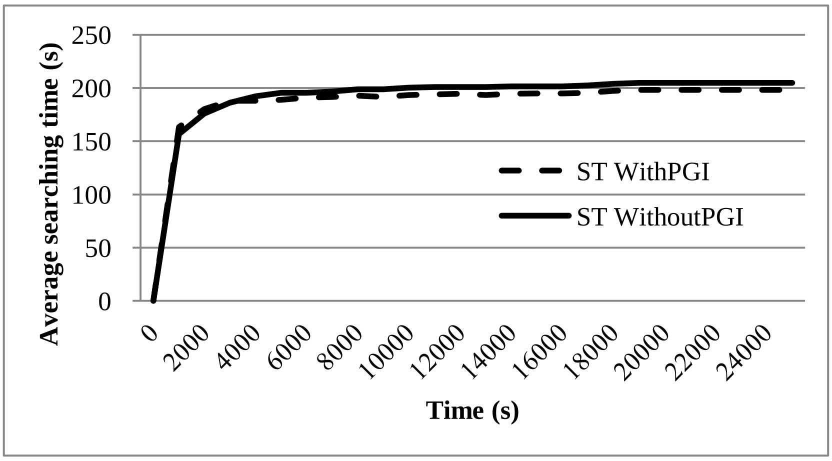

Figure 6.7: Average searching time (s) of REPASTPA and REPASTPAPGI

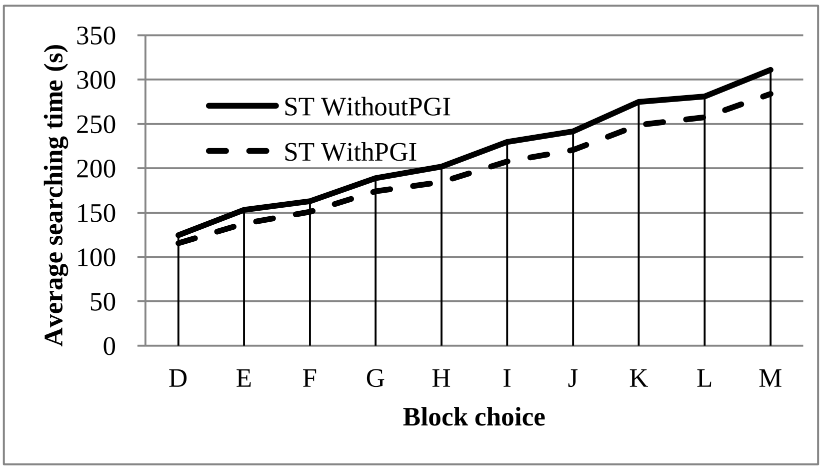

Figure 6.8: Average searching time (s) of REPASTPA and REPASTPAPGI divided by selected blocks

The simulation result of “Searching Time” shown in Figure 6.7 compares the average searching time of all agents of with PGI and without PGI. The average searching time difference is only about 10 seconds. It suggests that PGI system plays a positive effect in saving searching time but it is not as significant as what we expected. This may because the average searching time is related with choice frequency and selected block. Another interesting founding is when time varies from 0 to 3000 s, the average searching time of with PGI even higher than the average searching time of without PGI. This may be attributed to the fact that, at the beginning, without the guidance of PGI, drivers prefer to park at closed blocks and find empty space more easily when the rest area is less congested; on the converse, with PGI, drivers follow the guidance of PGI and more likely park at distant blocks even through there are empty space in closed blocks. Figure 6.8 shows that the difference of average searching time between with PGI and without PGI varies from 10 s to 40 s with the increasing of selected block's label. The result indicates that PGI system indeed places a significant effect on reducing the searching time especially when choosing distant blocks.

6.6 Simulation result of different initial occupancy rate

According to the analyzed result from figure 3.18 to figure 3.23 in the section 3.4.2, we knew that the occupancy rate of the area vary from 40% to about 83%. Then in this section, the number of initial occupied vehicles is defined with the difference of occupancy rate. The scenario of number of initial occupied vehicle is shown in the Table 6.2.

Table 6.2: Number of initial occupied vehicle correspond with occupancy rate

ID	Occupancy rate (%)	No. of Initial occupied vehicle
1	40	48
2	50	60
3	60	72
4	70	84
5	80	96

Notes: The capacity of study area is 120

6.6.1 Number of lost agent

According to the scenario of different number of initial occupied vehicle, after running simulation 10 times, the simulation result of number of lost agent with initial occupancy rate vary from 40% to 80% is shown in the figure 6.9, 6.10, 6.11, 6.12, 6.13 respectively.

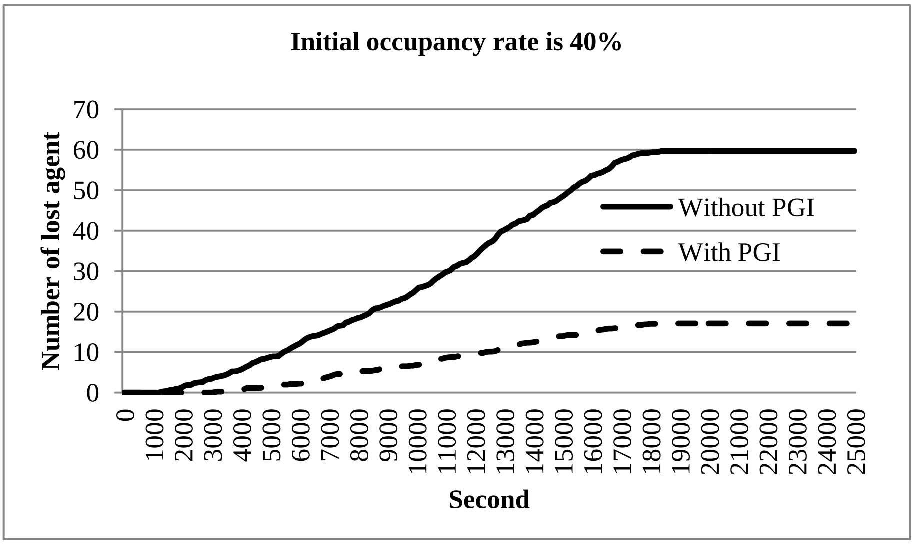

Figure 6.9: Cumulative number of lost agent with initial occupancy rate is 40%

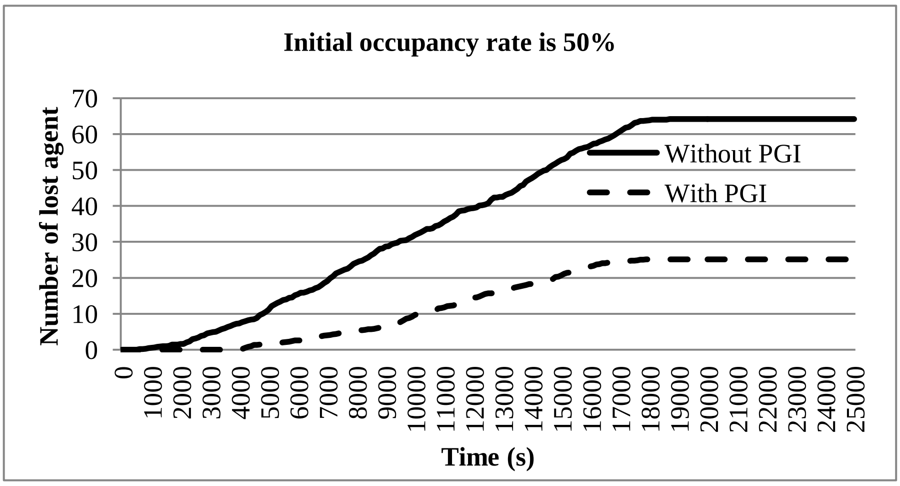

Figure 6.10: Cumulative number of lost agent with initial occupancy rate is 50%

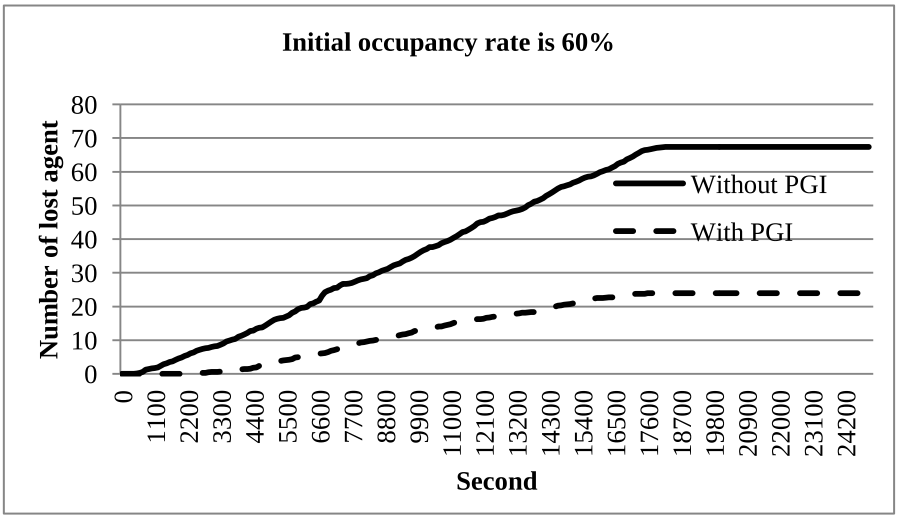

Figure 6.11: Cumulative number of lost agent with initial occupancy rate is 60%

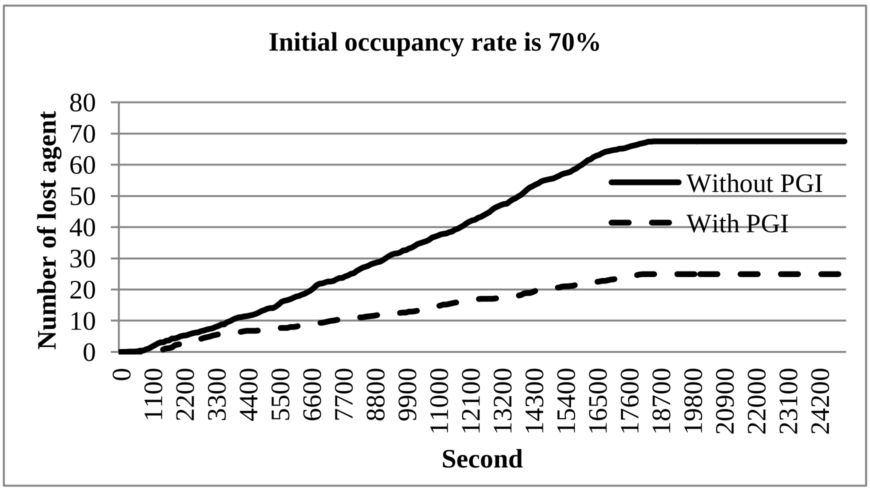

Figure 6.12: Cumulative number of lost agent with initial occupancy rate is 70%

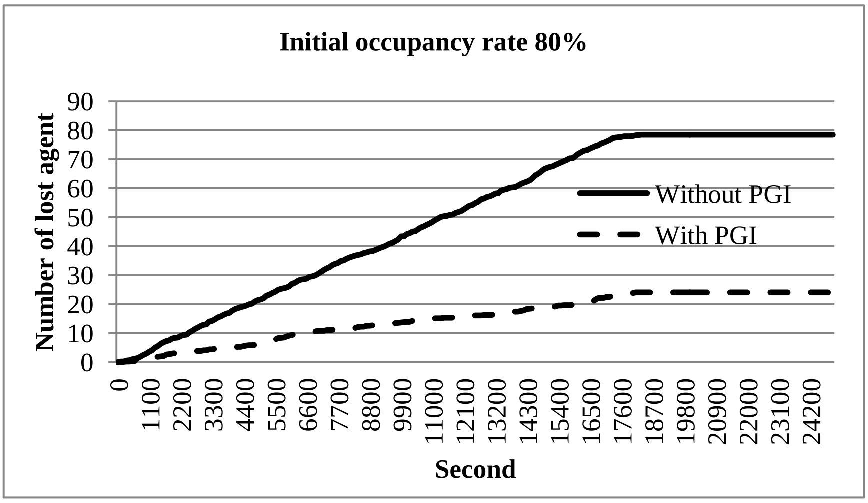

Figure 6.13: Cumulative number of lost agent with initial occupancy rate is 80%

The above figures compares the value of “Lost Agent”, in the figure 6.9 (initial occupancy rate is 40%) the maximum number of lost agent under the environment without PGI is 60, and the maximum number of lost agent under the environment with PGI is 19. In the figure 6.10 (initial occupancy rate is 50%) the maximum number of lost agent under the environment without PGI is 64, and the maximum number of lost agent under the environment with PGI is 25. In the figure 6.11 (initial occupancy rate is 60%) the maximum number of lost agent under the environment without PGI is 68, and the maximum number of lost agent under the environment with PGI is 25. In the figure 6.12 (initial occupancy rate is 70%) the maximum number of lost agent under the environment without PGI is 69, and the maximum number of lost agent under the environment with PGI is 25. In the figure 6.13 (initial occupancy rate is 80%) the maximum number of lost agent under the environment without PGI is 79, and the maximum number of lost agent under the environment with PGI is 25. The result indicates that, without the guidance of information, the number of lost agent has enhanced at more congested situation. For the situation of with the guidance of information, the growing number of lost agent is limited, and total number of lost agent is same and approximately equal to 25when the initial occupancy rate reaches 50%, 60%, 70% and 80%. Hence, the effect of reducing the number of lost agent is more significantly at even congested situation.

Besides, the difference of number of lost agent between the two situations is also increasing with the varying of tick from 0 to 2500. The result indicates that information did guide drivers to less congested blocks and PGI system indeed places a significant effect on reducing the number of lost customers especially when providing ASL information.

6.6.2 Searching time

According to the simulation result of searching time in section 6.6.2, we knew that the average searching time difference of all agents is not as significant as what we expected. To give a clear impression, in this section, only the average searching time of two projects divided by different selected block is analyzed in this section. After running the two projects 50 times separately, the simulation result of average searching time of REPASTPA and REPASTPAPGI divided by selected block is shown in the figure 6.14, 6.15, 6.16, 6.17 and 6.18 respectively.

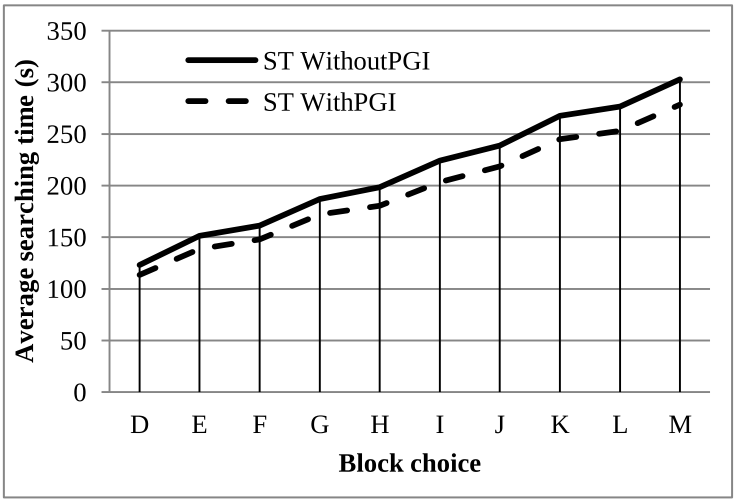

Figure 6.14: Average searching time (s) of REPASTPA and REPASTPAPGI divided by selected blocks with initial occupancy rate is 40%

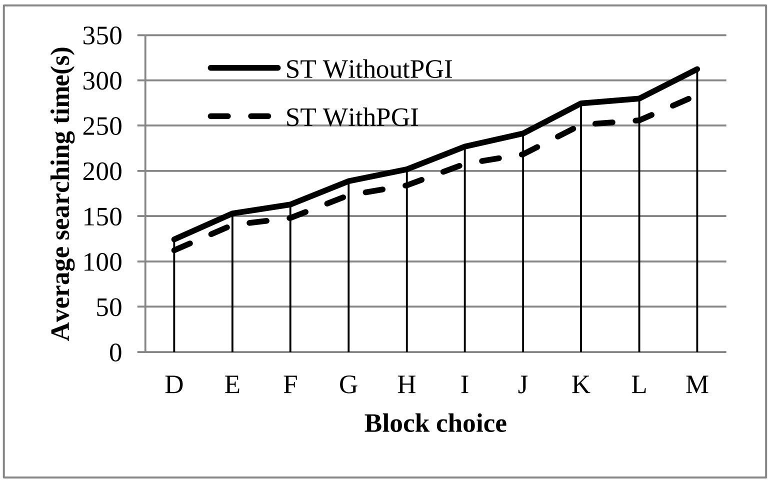

Figure 6.15: Average searching time (s) of REPASTPA and REPASTPAPGI divided by selected blocks with initial occupancy rate is 50%

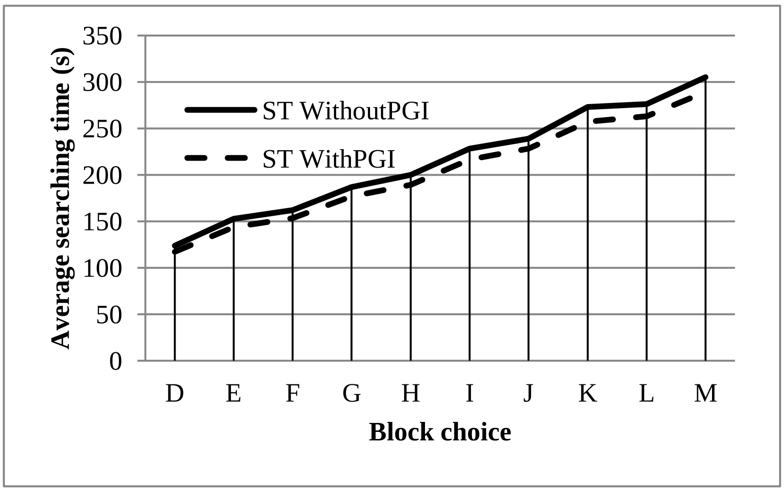

Figure 6.16: Average searching time (s) of REPASTPA and REPASTPAPGI divided by selected blocks with initial occupancy rate is 60%

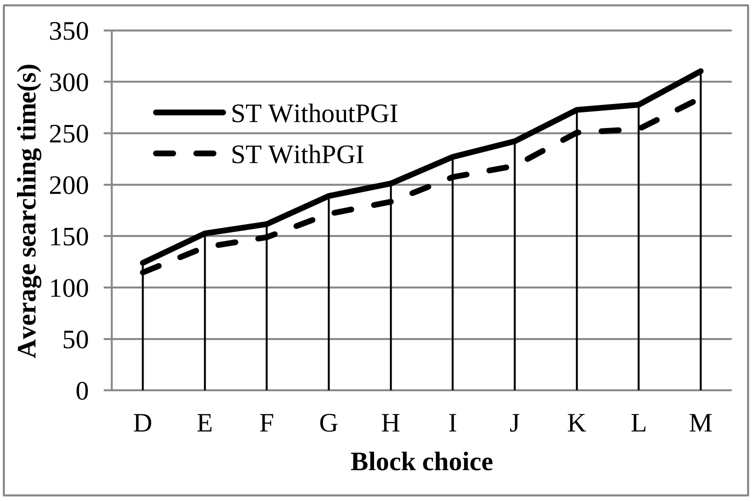

Figure 6.17: Average searching time (s) of REPASTPA and REPASTPAPGI divided by selected blocks with initial occupancy rate is 70%

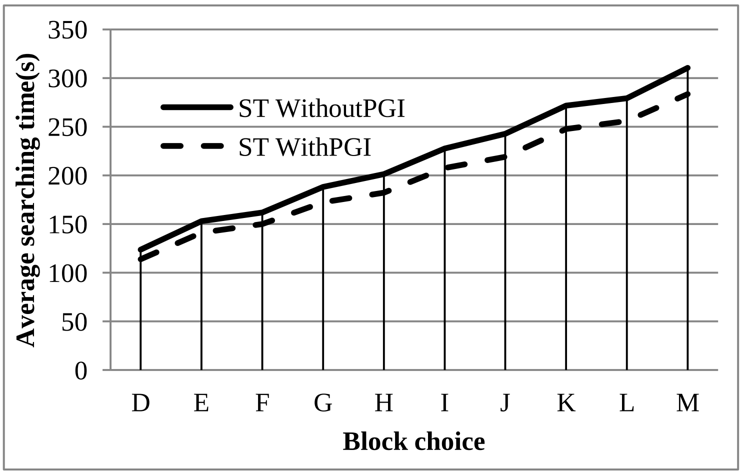

Figure 6.18: Average searching time (s) of REPASTPA and REPASTPAPGI divided by selected

blocks with initial occupancy rate is 80%

The above figures show that, with the varied initial occupancy rate, the difference of average searching time between with PGI and without PGI varies from 10 s to 40 s with the increasing of selected block's label expect the situation of initial occupancy rate is 60%. When initial occupancy rate is 60%, the difference of average searching time between with PGI and without PGI varies from 10s to 20s. The result indicates that PGI system indeed places a significant effect on reducing the searching time especially when choosing distant blocks. But the effect of reducing difference of average searching time between with PGI and without PGI under varied initial occupancy rate is broadly similar. This may be attributed to the fact that, in the system, the searching time is more influence by the correlation among agents. Even though, the initial occupancy rate is varying, the arrival interval follows exponential distribution with same parameters and duration interval also follows exponential distribution with same parameters. Therefore, the length of searching time is more related to the correlation among agents, in another word, the continuous congested situation and not just the initial congested situation.

6.7 Simulation result of different arrival and departure rate

6.7.1 Arrival time and duration time of peak, medium and non-peak date

In this section, the simulation result of REPASTPA and REPASTPAPGI projects under the scenarios of arrival time interval and duration time interval following the exponential distribution with different coefficient are presented. To give a clear comparison to the simulation result in the section 6.5, the initial setting is same (in section 6.5, number of initial occupied vehicle is 80). As mentioned in the section 4.3, from the sample date of 15th April 2012 to the date of 18th September 2012, total 71 days, the highest number of total arrival vehicle in a day has been happened on 6th May 2012 (4439 vehicle/day), and the lowest number of total arrival vehicle in a day has been happened on 12th September 2012 (2452 vehicle/day). Then to make a clear comparison, the sample of 27th May 2012 is adopted as a medium number of total arrival vehicles in a day and the value is 473vehicle/day. The estimation results of relationship between choice percentage and arrival/duration time interval of sample date 6th May 2012, 27th May 2012 and 12th September 2012 are estimated and summarized in the Table 4.1 in section 4.3. The coefficients of arrival time models of 6th May 2012, 27th May 2012 and 12th September 2012 are -0.9, -0.705, -0.595 respectively. Moreover, the coefficients of duration time models of 6th May 2012, 27th May 2012 and 12th September 2012 are -0.941, -0.831, -0.861 respectively. Then the coefficients of arrival time and duration time are used in simulating the economic effect of PGI system and the results will be explained in the next section.

6.7.2 Number of lost agent

Setting each project the coefficients of arrival and duration time interval model estimation result three times, then REPASTPA and REPASTPAPGI project have been run 10 times separately, the simulation results of lost agent of two projects of REPASTPA and REPASTPAPGI with coefficients of arrival time and duration time as -0.9 and -0.941 (based on sample date of 6th May 2012) is shown in the figure 6.19; coefficients of arrival time and duration time as -0.705 and -0.831 (based on sample date of 27th May 2012) is shown in the figure 6.20; coefficients of arrival time and duration time as -0.595 and -0.861 (based on sample date of 12th September 2012) is shown in the figure 6.21 as follows.

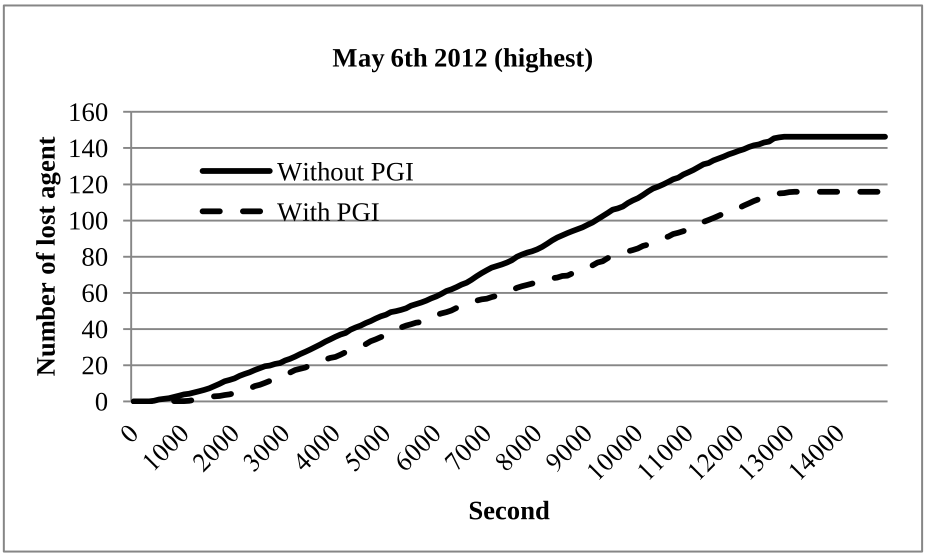

Figure 6.19: Cumulative number of lost agent based on data of May 6th 2012

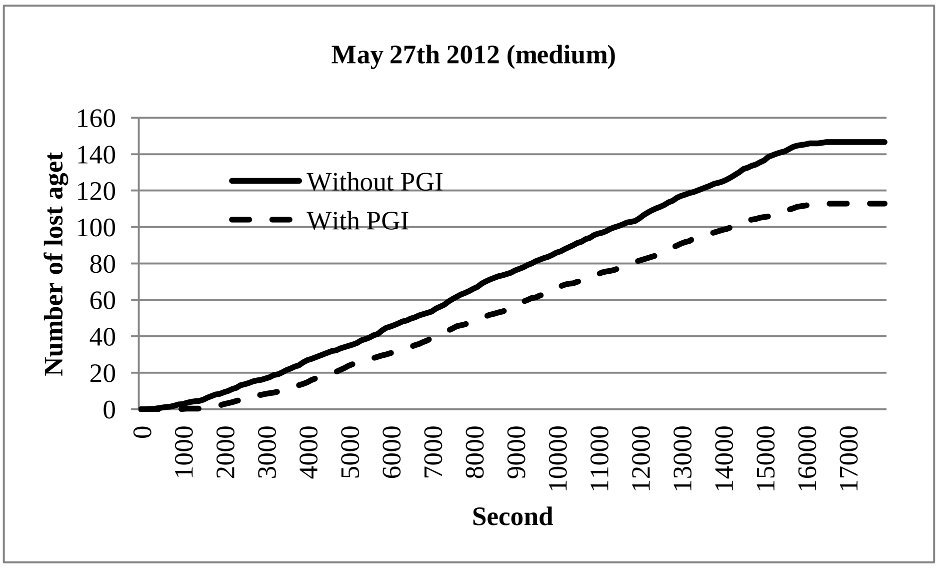

Figure 6.20: Cumulative number of lost agent based on data of May 27th 2012

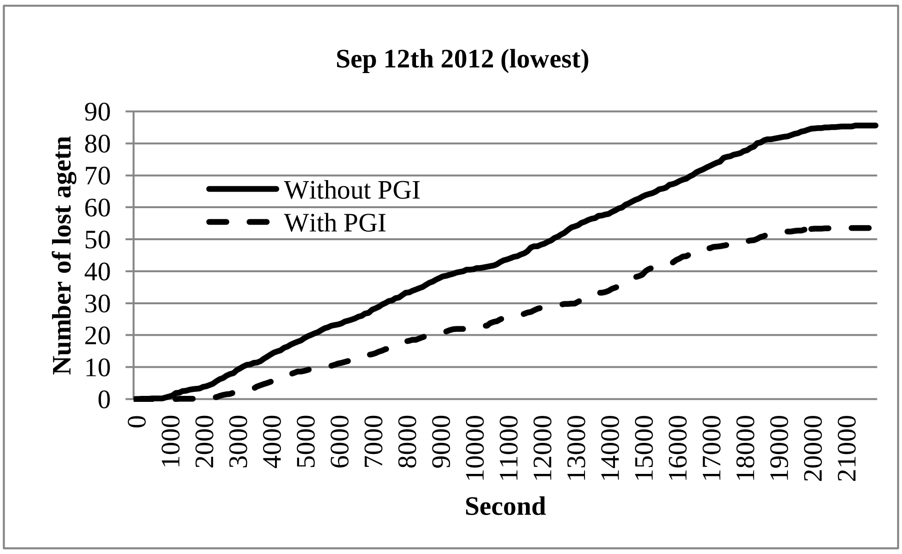

Figure 6.21: Cumulative number of lost agent based on data of Sep 12th 2012

To give a clearly comparison among figure 6.19, 6.20 and 6.21, three sample days' cumulative number of lost agent are summarized by whether with the effect of PGI or not, see figure 6.22 and 6.23 as follow.

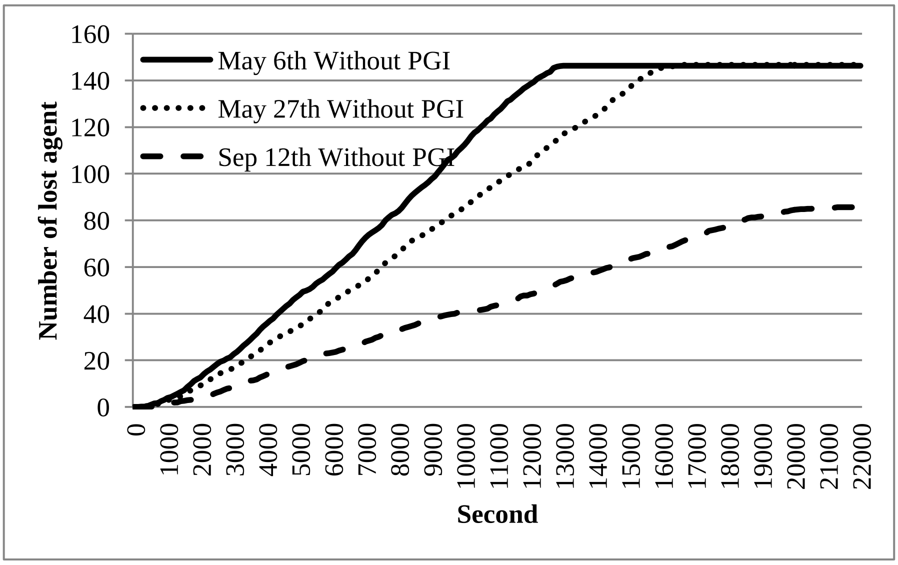

Figure 6.22: Cumulative number of lost agent without PGI

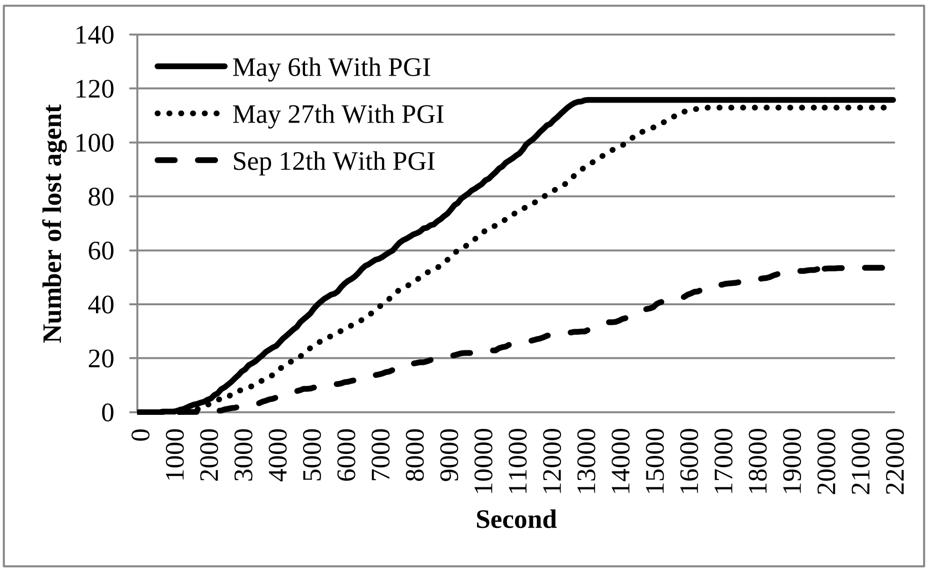

Figure 6.23: Cumulative number of lost agent with PGI

Figure 6.19, 6.20 and 6.21 compares the varying of accumulative number of lost agent and illustrates the maximum number of lost agent of different scenarios', the length of simulation time is increasing from rush date to inrush date. In the all three scenarios, the accumulative number of lost agent with PGI is less than the situation without PGI. It indicated again that, PGI system make a positive effect in reducing the number of lost customer. In the figure 6.19 and figure 6.20, arrival time interval more likely to turn longer in the figure 6.20, but the maximum accumulative number of lost agent in the two figure almost same. The reason may be the duration time interval coefficient in the figure 6.19 is -0.941 and in figure 6.20 is -0.831, then the duration time in figure 6.19 more likely to turn shorter than the situation in figure 6.20. Hence, in general, the maximum accumulative number of lost agent of with PGI and without PGI in the figure 6.19 and figure 6.20 almost same. The result of above three figures also indicates that, the system will be lost more customers in the more congested situation.

6.7.3 Searching time

Setting each project the coefficients of arrival and duration time interval model estimation result three times, then REPASTPA and REPASTPAPGI project have been run 10 times separately, the simulation results of average searching time of two projects of REPASTPA and REPASTPAPGI divided by selected blocks with coefficients of arrival time and duration time as -0.9 and -0.941 (based on sample date of 6th May 2012) is shown in the figure 6.24; coefficients of arrival time and duration time as -0.705 and -0.831 (based on sample date of 27th May 2012) is shown in the figure 6.25; coefficients of arrival time and duration time as -0.595 and -0.861 (based on sample date of 12th September 2012) is shown in the figure 6.26 as follows. To be remembered, in this section, all the simulations with a same number of initial occupied vehicle of 80.

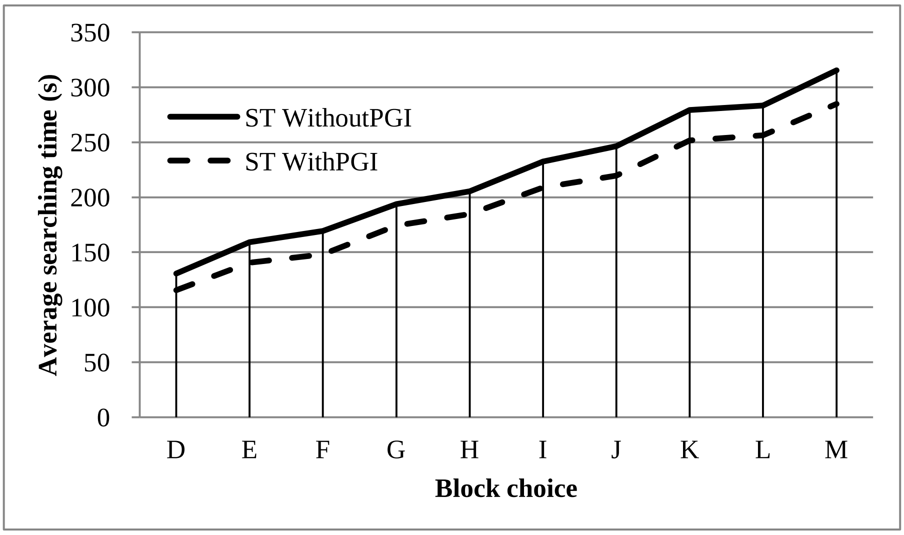

Figure 6.24: Average searching time (s) of REPASTPA and REPASTPAPGI divided by selected blocks of May 6th 2012

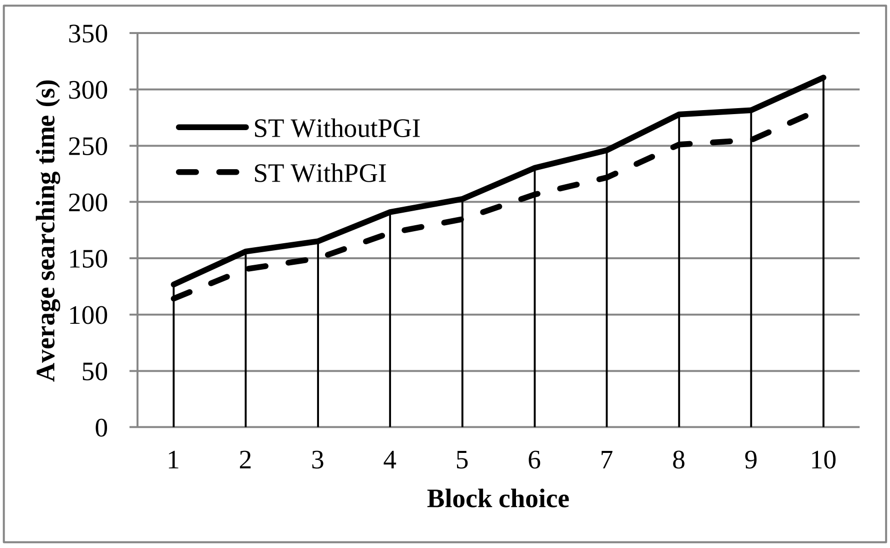

Figure 6.25: Average searching time (s) of REPASTPA and REPASTPAPGI divided by selected blocks of May 27th 2012

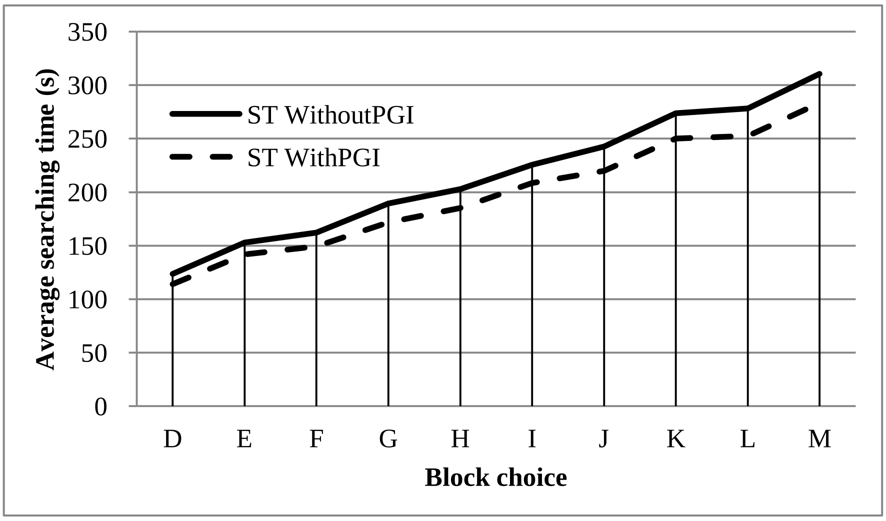

Figure 6.26: Average searching time (s) of REPASTPA and REPASTPAPGI divided by selected blocks of Sep 12th 2012

Figure 6.24, 6.25, 6.26 have presented and compared the average searching time divided by selected blocks of different scenarios. With the same initial occupancy rate and various arrival and departure rate, the difference of average searching time between without PGI and with PGI on May 6th 2012 (highest), May 27th 2012 (medium) and Sep 12th 2012 (lowest) varies from 10 s to 30 s when selected block changing from block D to block M. In the all scenarios, average searching time of each block of the scenario of without PGI is higher than the scenarios of with PGI. The result indicates again that PGI system does make a significant effect on reducing searching time.

In the figure 6.24 (data of May 6th 2012), the average searching time of selecting block D without PGI is 131s and with PGI is 115, the difference between with PGI and without PGI is 16s which is the biggest compare with the average searching time of selecting block D in figure 6.25 and figure 6.26. Here in figure 6.25 (data of 27th May 2012), the average searching time of selecting block D without PGI is 127s and with PGI is 114, the difference between with PGI and without PGI is 13s. And as shown in the figure 6.24, the average searching time of selecting block D without PGI is 124s, with PGI is 114; the difference between with PGI and without PGI is 10s.

For selecting block M, in the figure 6.24 (data of May 6th 2012), the average searching time of selecting block M without PGI is 315s and with PGI is 285, the difference between with PGI and without PGI is 30s which is the biggest compare with the average searching time of selecting block M in figure 6.25 and figure 6.26. Here in figure 6.25 (data of 27th May 2012), the average searching time of selecting block M without PGI is 311s and with PGI is 284, the difference between with PGI and without PGI is 27s. And as shown in the figure 6.26, the average searching time of selecting block M without PGI is 311s, with PGI is 283; the difference between with PGI and without PGI is 28s.

The result indicates that, the length of searching time related to the correlations of among agents such as arrival interval and departure interval, and the continuous congested situation is more significantly than initial congested situation in influencing average searching time. Drivers will cost more time on finding an available space in a more congested situation especially in the scenario of without PGI system.

6.8 Conclusion

This study has developed an agent-based model of a parking area to measure the economic benefits of PGI system by modeling driver behavior under the effect of PGI system. For performing drivers' parking choice behavior, multi-nominal Logit model is adopted into projects of REPASTPA and REPASTPAPGI. As a case study, the integrated agent-based model can be used to quantify the economic effect of parking search process under the influence with and without PGI system. From the above results, it indicates, after setting the PGI system in the rest area, PGI makes a significantly positive effect on reducing the number of lost agent and decreasing average searching time. The results also indicate that, with the varied initial occupancy rate, information places a significant effect on guiding drivers to less congested blocks which can be seen from the reduced number of lost customers easily. But the result of saving average searching time is not as obvious as the reducing number of lost agent. The simulation results with three different groups of arrival time and duration time coefficients indicate that the continuous congested situation is more significantly than initial congested situation in influencing average searching time.

Despite "Lost Agent" and "Searching Time" are not traditional economic evaluation indexes, the result shows that the two values can be applied to measure the economic effects of PGI system. There are several future research directions which the authors of this article plan to pursue. Key among the directions is sophisticated the agent-based model through the aspects to make agent more intelligent or accurate and sophisticated modeling the parking choice process.

6.9 References

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7 Summary, conclusion and directions for future research

This chapter provides a summary of the work described in this thesis, suggests for future research and the conclusion of this thesis.

7.1 Summary

7.1.1 Theoretical part

The theoretical part of the thesis can be divided into two sub-parts, discussing the issue of drivers' parking behavior in the sequence choice and the issue of adopting "Lost Agent" and "Searching Time", two untraditional economic evaluation indexes to measure the economic effect.

The work described in Chapter 5 looks at the way of modeling sequential parking choice behavior. The basic premise of discussion in this thesis is that individuals choose or whether or not to make a parking based on decision yield to a higher utility of current alternative and the expectation for further alternatives. The review of the background sequential search process highlights the major differences between traditional discrete choice models, where the error terms may follow the same distribution, but the expected value and variance may different for each current utility and expected further alternatives. Another differ is, at the beginning, driver can only receive the characteristics or information related to the current alternative but obtain the characteristics or information related to all alternatives. Besides, in the sequence choice model, the number of alternatives can be assumed as undetermined or unlimited. It is also differs from the multinomial choice model (presented in chapter 4) which treats individual trips as independent and does not typically incorporate the number of trips chosen.

As discussed in detail in chapter 5, the sequential choice model offers an alternative to the traditional approach to estimate parking choice behavior especially given an assumption of no specific defined variable given in expected utility. While the traditional approach is best suited to some forms of choice behavior, there are many cases where the sequential choice model may offer a more appropriate depiction of actual trip choice behavior. Moreover, it is also could be a comparison with traditional discrete choice model in the same case study.

The work presented in Chapter 6 is measuring the PGI system by obtain the simulation result of the number of lost agent and average searching time. The results indicate that, after setting the PGi system in the rest area, it makes a significantly positive effect on reducing the number of lost agent and decreasing average searching time. Moreover, we summarized the above two simulated result as indexes of "Lost Agent" and "Searching Time". Despite "Lost Agent" and "Searching Time" are not traditional economic evaluation indexes, the result shows that the two values can be applied to measure the economic effects of PGI system.

7.1.2 Applied Part

The applied part of the thesis discuss the finding of case study of parking choice behavior and the effectiveness of PGI system by using RP data collected in the Shimizu parking area located in the Shin-tomei expressway (Japan). The finding can be divided into three sub-parts.

In the Chapter 3, the effect of PGI on drivers' parking behavior and the effect of different information displayed type are analyzed by using RP data. There are three information displayed types, Null information (PGI shows no information), ASL information (PGI shows the number of available space and location) and ECF information (PGI shows occupancy status information as empty, congested and full). It is found that only the drivers who didn't pass A, B and C blocks are seems more sensitive to the ECF information and all the drivers are sensitive to the ASL information. Besides, the percentage of parking at block J, K, L and M is few and nearly remain unchangeable which would suggest that the effect of difference types of displayed information on the drivers' choice behavior of selecting block J, K, L and M is not obvious. Additionally, the result what have been discussed in Chapter 3 also suggests that the main attributes affecting choice behavior are walking distance and number of available space.

In the Chapter 4, based on what we found in Chapter 3, MNL model is applied to estimated the effect of null information, ECF information and ASL information on drivers' parking choice behavior. The result shows that the utility of choosing a parking block is negatively related to its distance from the entrance of the area to the block (for both of without PGI and with PGI), while positively related to its number of available space (for ASL information only) and positively related to its provided lest congested information (for ECF information only).The result indicated that both the effect of ECF information and ASL information are significantly affect drivers parking choice behavior especially for the drivers who choose to park at block D to block I. The significance of variable of walking distance, dummy variable of occupancy information and variable of number of available space justify our hypothesis that drivers are sensitive to above three variables.

In the Chapter 6, an agent-based model is developed to compare and measure the economic benefits of PGI system by adopting the RP data collected from Shimizu parking area. Multi-nominal Logit model is adopted to measure the effect of ASL information and make a comparison with Null information. Two projects of REPASTPA (Null information, without PGI) and REPASTPAPGI (ASL information, with PGI) are established and compared for evaluating the economic effect of PGI system. The result indicated that PGI makes a significantly positive effect on reducing the number of lost agent and decreasing average searching time.

7.2 Directions for future research

There are several future research directions which the authors of this article plan to pursue. Key among the directions is sophisticated the agent-based model through the aspects to make agent more intelligent or accurate and sophisticated modeling the parking choice process.

First, it is still possible to improve the decision making mechanism of agents. Based on what we observed for the RP data of individual parking route data, some drivers may make a parking decision based on their observation rather than provided information on PGI. This is related to the information recognition and acceptance issue.

In this thesis, a new framework of sequential parking choice model has been presented and compared with traditional discrete choice model. In the further research, the sequential parking choice model what has been presented can be estimated and compared with multinomial parking choice model. Besides the estimated result of sequential parking choice model can also be used in agent-based model simulation as describing a different type of parking behavior.

For the economic evaluation of PGI system by using agent-based modeling simulation, in this thesis, the “Lost Agent” and “Searching Time” are used as two economic indexes. It is important to further explore the other values based on different point of views such as the environmental cost of CO2 emission.

7.3 Conclusion

The research presented in the theoretical parts of this thesis highlights the problems of specification and interpretation that arise with use of advanced, traditional model, for example in terms of assumptions of error term follows the same distribution, different expected value and same variance what the traditional discrete choice model defined.

Indeed, discrete choice model have been successfully applied in many fields and used to describe the most behavior analysis very well. There are still some scenarios or alternative sets which the traditional discrete model cannot be perfectly performed. Clearly, advanced models have the potential to offer improvement in performance and accuracy in cases where the assumption of error term follows the same distribution, different expected value and different variance or the alternative set is unlimited. However, with the gain in popularity of models offering a flexible treatment of the error term, models are showing the tendency of explaining processes that could otherwise be accommodated in the observed part of utility, which, for interpretation purposes, is clearly preferable.

The applied part of this thesis shows that agent-based model simulation approach have performed drivers’ behavior very well, which have been applied in the traffic field for solving many problems. Of course, agent-based modeling simulation has the potential to lead to a better performance and combination with complicated behavior models than the more basic approaches. Overall, the advantage of such approach can evaluate the effectiveness through the multiple views, e.g. economic cost or environmental cost. Additionally, the use of advanced ITS can lead to the increases in advanced data collection and application. The combination of advanced ITS system and advanced evaluation approach can illustrate more complicated, difficult issues in the real-world. It is also make the theoretical models moving to a new level.

Appendix A

Main Java source codes created in this thesis

Negative exponential distribution

```
import cern.jet.random.Exponential;
import repast.simphony.random.RandomHelper;
import repast.simphony.parameter.Parameters;
import RepastParkingArea.main.GlobalVars;

@SuppressWarnings("unused")
public class NegtiveExponential {
public void Exponential(int length,double lamda){
Exponential Random_Exponential = RandomHelper.createExponential(lamda);
int num = length;
double x;
x = 1/lamda;
double z;
for(int i = 0; i < num; i ++){
do{z = Random_Exponential.nextDouble();
}while((z == 0) || (z == 1));
GlobalVars.AGENTS_PARAMS.EXPN[i] = (int)(x * z + 0.5);
System.out.println("NO-PGI: exponential is ,"+ GlobalVars.AGENTS_PARAMS.EXPN[i]);
        }
    }
}
```

Utility function

```
import java.lang.Math;
import repast.simphony.random.RandomHelper;
import repast.simphony.util.SimUtilities;
import RepastParkingAreaPGI.main.GlobalVars;
public class expectedfun{
public static void utility()
{
int BlockNum = GlobalVars.BlockNum;
double TotalBlock = 0;
double BlockIndex[] = new double[BlockNum];
for(int i = 0; i < BlockNum; i++)
```

```
{
BlockIndex[i] = Math.exp(GlobalVars.IndexOfVehicles * (12 - GlobalVars.AgentsNumberOfBlo
ck[i]) +
GlobalVars.IndexOfDistanceMall * GlobalVars.DistanceMall[i]);
TotalBlock += BlockIndex[i];
}
for(int i = 0; i < BlockNum; i++)
{
GlobalVars.BlockPro[i] = BlockIndex[i] / TotalBlock;
}
utilityfunctionPGI(GlobalVars.ArrayNum,GlobalVars.BlockPro);
}
public static void utilityfunctionPGI(int n, double[] p)
{
int Pd =(int) (p[0] * n);
int Pe = (int) (p[1] *n);
int Pf = (int) (p[2] *n);
int Pg = (int) (p[3] *n);
int Ph = (int) (p[4] *n);
int Pi = (int) (p[5] *n);
int Pj = (int) (p[6] *n);
int Pk = (int) (p[7] *n);
int Pl = (int) (p[8] *n);
int Pm = (int) (p[9] *n);
int a = 0;
for(int i = 0; i < n; i ++)
{
if(i < Pd)
{
GlobalVars.TmpUtilityArrayPGI[i] = 1;
}else if((i >= Pd) && (i < Pe +Pd))
{
GlobalVars.TmpUtilityArrayPGI[i] = 2;
}else if((i >= Pe +Pd) && (i < Pf +Pe +Pd))
{
GlobalVars.TmpUtilityArrayPGI[i] = 3;
}else if((i >= Pf +Pe +Pd) && (i < Pg +Pf +Pe +Pd))
{
GlobalVars.TmpUtilityArrayPGI[i] = 4;
}else if( (i >= Pg +Pf +Pe +Pd) && (i < Ph+ Pg +Pf +Pe +Pd))
{
GlobalVars.TmpUtilityArrayPGI[i] = 5;
}else if((i >=Ph+ Pg +Pf +Pe +Pd) && (i < Pi + Ph+ Pg +Pf +Pe +Pd))
{
```

```
GlobalVars.TmpUtilityArrayPGI[i] = 6;
}else if((i >=  Pi + Ph+ Pg +Pf +Pe +Pd) && (i < Pj +  Pi + Ph+ Pg +Pf +Pe +Pd))
{
GlobalVars.TmpUtilityArrayPGI[i] = 7;
}else if((i >=Pj +  Pi + Ph+ Pg +Pf +Pe +Pd) && (i < Pk+Pj +  Pi + Ph+ Pg +Pf +Pe +Pd))
{
GlobalVars.TmpUtilityArrayPGI[i] = 8;
}else if((i >= Pk+Pj +  Pi + Ph+ Pg +Pf +Pe +Pd) && (i < Pl + Pk+Pj +  Pi + Ph+ Pg +Pf +Pe +Pd
))
{
GlobalVars.TmpUtilityArrayPGI[i] = 9;
}else
{
GlobalVars.TmpUtilityArrayPGI[i] = 10;
    }
}
SimUtilities.shuffle(GlobalVars.TmpUtilityArrayPGI, RandomHelper.createUniform());
for(int i = 0; i < n; i++)
{
if(GlobalVars.TmpUtilityArrayPGI[i] == 1)
{
GlobalVars.UtilityArrayPGI[i] = 'D';
}else if(GlobalVars.TmpUtilityArrayPGI[i] == 2)
{
GlobalVars.UtilityArrayPGI[i] = 'E';
}else if(GlobalVars.TmpUtilityArrayPGI[i] == 3)
{
GlobalVars.UtilityArrayPGI[i] = 'F';
}else if(GlobalVars.TmpUtilityArrayPGI[i] == 4)
{
GlobalVars.UtilityArrayPGI[i] = 'G';
}else if(GlobalVars.TmpUtilityArrayPGI[i] == 5)
{
GlobalVars.UtilityArrayPGI[i] = 'H';
}else if(GlobalVars.TmpUtilityArrayPGI[i] == 6)
{
GlobalVars.UtilityArrayPGI[i] = 'I';
}else if(GlobalVars.TmpUtilityArrayPGI[i] == 7)
{
GlobalVars.UtilityArrayPGI[i] = 'J';
}else if(GlobalVars.TmpUtilityArrayPGI[i] == 8)
{
GlobalVars.UtilityArrayPGI[i] = 'K';
}else if(GlobalVars.TmpUtilityArrayPGI[i] == 9)
```

```
{
GlobalVars.UtilityArrayPGI[i] = 'L';
}else
{
GlobalVars.UtilityArrayPGI[i] = 'M';
            }
        }
    }
}
```

Agent move for new generating agents

```
public class DefaultAgent implements IAgent {

private static Logger LOGGER = Logger.getLogger(DefaultAgent.class.getName());

private ParkingLot end;
private ParkingLot home; // Where the agent lives
private ParkingLot Parking;
private Route route; // An object to move the agent around the world
private ParkingLot TmpParking;
private boolean goingHome = false; // Whether the agent is going to or from their home
private boolean goingEnd = false;
private static int uniqueID = 0;
private int id;
private String State = null;
private int TimeForLeaving = 0;
private int TmpUniform = 0;
private int SearchedParkingNum = 0;
private char ParkingLotID;
private char TmpParkingLotName;
private int NumberParkingLotName;
private double StartingTime = 0.0;
private double EndingTime = 0.0;
private boolean ReachedFlag = false;//first time reached to parkinglot ,mark it true, record the tick
time count
private boolean RemoveFlag = false;
private boolean LostStatus = false;
private int Speed = 0;
private String Block = "LostOrInit";
Uniform Random_Uniform = RandomHelper.createUniform(1, 10);
public DefaultAgent() {
```

```
this.id = uniqueID++;
}
if(this.getState() == GlobalVars.AGENTS_PARAMS.STATE_OUTFROM)
{
if(this.route == null)
{
//calculate the property of each block
expectedfun.utility();
this.goingHome = false; // arrival agent leave home to go parkinglot
        while(this.route == null)
        {
         SearchedParkingNum = 0;
          Iterator<ParkingLot> i = ContextManager.ParkingLotContext
              .getRandomObjects(ParkingLot.class,GlobalVars.AllParkinglotNum).iterator();
          while(i.hasNext())
          {
              ParkingLot b = i.next();
              if(((b.toString().subSequence(0, 1).charAt(0) != (GlobalVars.UtilityArrayPGI[1])))
 )
              {
                // did not find target, continue find
                continue;
              }
              else
              {
            if (b.getOccupid() == true)
            {
            SearchedParkingNum++;
            if (SearchedParkingNum != 12)
            {
            continue;
            }
            else
            {
            // no more empty park, become lost agent
            GlobalVars.UtilityArrayPGI[1] = 'e';
            this.LostStatus = true;
            SearchedParkingNum = 0;
            continue;
                }
            }
            else
            {
            this.route = new Route(this, b.getCoords(), b, this.Speed);
```

```
                    if (!(b.getIdentifier().equals("end")))
                    {
                    b.setOccupied();
                    GlobalVars.AgentsNumberOfBlock[getBlockIndex( b.toString().subSequence(0, 1).
charAt(0))]++;
                    this.setBlock(b.getIdentifier());
                    System.out.println("PGI: Block is" + this.Block.charAt(0));
                    }
                    this.setParking(b);
                    break;
                    }
                      }
                  } // for- while(i.hasnext())
              } // for- while(this.route == NULL)
}
if (!this.route.atDestination()) {
this.route.travel();
LOGGER.log(Level.FINE, this.toString() + " travelling to " + this.route.getDestinationBuilding().
toString());
}else
{
if(this.ReachedFlag == false)
{
this.setEndingTime(RunEnvironment.getInstance().getCurrentSchedule().getTickCount());
this.ReachedFlag = true;
System.out.println("PGI: My searching time is :" + (this.EndingTime - this.StartingTime));
}
TimeForLeaving --;
if( (TimeForLeaving == 0))
{
Iterator<ParkingLot> p1 = ContextManager.ParkingLotContext.getRandomObjects(ParkingLot.cl
ass,GlobalVars.AllParkinglotNum)
.iterator();
while (p1.hasNext())
{
ParkingLot p2 = p1.next();
try
{
if(p2.getIdentifier().equals("end"))
{
GlobalVars.AGENTS_PARAMS.AgentsInParkingLot--;
this.route = new Route(this, p2.getCoords(), p2, this.Speed);
this.getParking().setNotOccupied();
```

```
// when a agent leave parkinglot, agent number of this Block should -1.
if (this.getParking().toString().subSequence(0, 1).charAt(0) != 'e')
{
GlobalVars.AgentsNumberOfBlock[getBlockIndex( this.getParking().toString().subSequence(0, 1
).charAt(0))]--;
}
GlobalVars.gRemoveAgentList.add(this);
}
} catch (NoIdentifierException e) {
e.printStackTrace();
                    }
                }
            }
        }
    }
}
```