The Pennsylvania State University

The Graduate School

Civil and Environmental Engineering

IMPROVING THE LOCATION OF TEMPORARY PARKING SPOTS FOR TOURIST BUSES IN DOWNTOWN BEIJING

A Thesis in

Civil Engineering

by

Xu Lin

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

May 2018

The thesis of Xu Lin was reviewed and approved* by the following:

S. Ilgin Guler

Assistant Professor of Civil and Environmental Engineering

Thesis Advisor

Eric T. Donnell

Professor of Civil and Environmental Engineering

Vikash V. Gayah

Assistant Professor of Civil and Environmental Engineering

Patrick J. Fox

Department Head of Civil and Environmental Engineering

*Signatures are on file in the Graduate School

ABSTRACT

The mode choice of tourists around the world can differ greatly. For example, travelers within the United States tend to drive to their destination or rent a car locally to do sightseeing. However, tourists in China typically choose to use tourist buses, operated by travel agencies. Due to the excessive number of visitors in many scenic spots in China, the scenic spots encourage visitors to take group tours instead of individual tours since the group tours are easier to manage and arrange. Additionally, China's car-rental industry is less popular and less convenient than America's. As a result, tourist buses are commonly used by visitors. However, the large number of tourist buses within the central cities leads to many traffic problems. Tourist buses require parking spots on roadways to unload and load guests, which causes disruption to the traffic flow especially in the downtown of Beijing. Currently, the regulations for the parking spots for tourist buses is not well informed, and leads to large traffic jams and delays within the central city. To this end, the goal of this work is to provide general guidelines for regulating the parking spots of tourist buses within central cities, and as a case study use microscopic simulation to improve the traffic conditions in central Beijing by relocating tourist bus stops. The results of this work show that traffic delays in central Beijing can be reduced by up to 16.9% as a result of improving the parking locations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Firstly, I would like to express my appreciation to my advisor, Dr. Guler, for her support, guidance, comments and ideas. She has mentored and helped me patiently for a long time. Whenever I encounter a research problem or make a mistake, she can always help me to solve the problem and revise my mistake.

I would like to specially thank my colleagues, Mr. Bai and Mr. Sun in Beijing Transport Institute for providing me much data in my simulation. I would also like to express my sincere gratitude to my committee member, Dr. Gayah. Thanks for giving me much suggestions about my research.

Finally, I would like to specially thank my mother and father for their support, help and encouragement. When I face difficulties, they always give me energy and motivation.

Chapter 1 Introduction

1.1 Background

In Beijing, due to the large population and the development of the tourism industry, tourist buses are a travelers' main mode of transport. The advantage of using tourist buses is its large capacity, which can release the traffic pressure on the road network. In downtown Beijing, there are many closely spaced attractions. Each attraction has its own tourist demand, and hence, the parking supply for tourist buses needs to match this demand. When the supply does not match the demand, this will lead to increased delay on the road network.

Currently, the locations of the temporary parking spots in downtown Beijing do not match the parking demand. Additionally, simple regulations on the parking duration are lacking leading to some tourist buses dwelling at these locations for longer than necessary to load and unload passengers. Hence, tourist buses cause long traffic jams and traffic delays in downtown Beijing.

The goal of this work is: 1) to describe systematic guidelines for city transportation planners for implementation and regulation of parking spots for tourist buses, and 2) to improve the placement of temporary parking spots for tourist buses in downtown Beijing to decrease traffic delays. To achieve this goal, a qualitative discussion on the impacts of the location of parking spots, the type of parking spots and the parking duration on the delays for tourist buses and general traffic is provided. Next, to improve the placement of temporary parking spots for tourist buses and reduce the total traffic delay in downtown of Beijing, a VISSIM simulation is used to evaluate the traffic flow and delay in target area. In VISSIM, the entire road network of downtown Beijing is constructed using basic traffic data. This simulation is used first to simulate and evaluate current traffic flow operation. Next, using the quantitative discussion, multiple different parking locations, types and durations are tested to determine a setting that will significantly improve upon the existing conditions.

The benefits of this improvement are considerable both for the visitors and general users of the traffic network. For visitors, they can save more time in traffic and spend more time doing sightseeing. For the road network, it can improve transport efficiency, reduce operating costs and save energy.

1.2 Project Scope

Beijing is one of the largest tourist cities in China. Its road network is a grid network with several freeways around the city. Beijing road network is shown in Figure 1-1. The research area is in the center of Beijing, and is bounded by West Fourth Avenue on the west, East Fourth Avenue on the east, Peace Street on the north, and Zhushikou Avenue on the south. The research area is a total of 62 square kilometers, only 6% of the total area of Beijing, but it contains more than 50% of the tourist buses and more than 70% of Beijing's popular attractions. According to field surveys and data collection, traffic congestion in the area is very serious and there are many conflicts between tourist buses and regular traffic, partially caused by improper setting of parking spaces. This thesis simulates the traffic operation of the research area, and evaluates the total delay. Additionally, by providing quantitative guidelines and utilizing these for the research area, an improved plan for the placement and regulation of tourist buses is proposed.

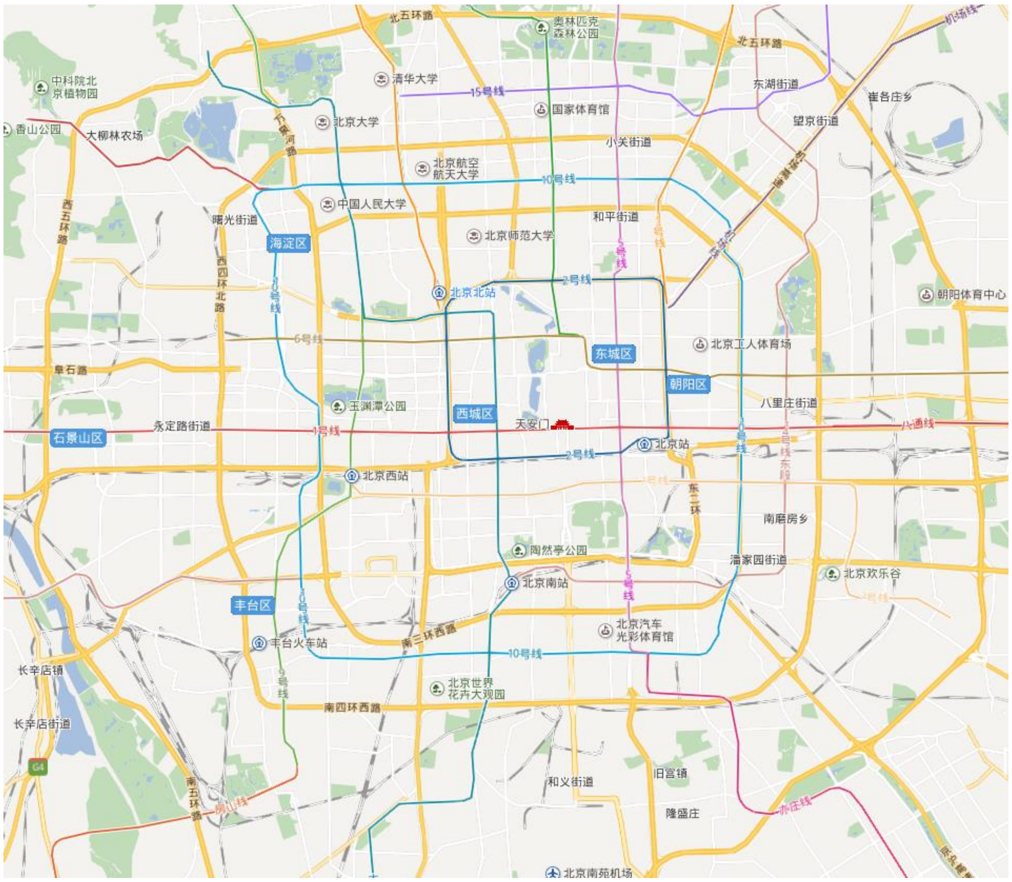


Figure 1-1 Beijing road network

Since transportation networks are inherently complex, any improvements or modifications applied to one road will inevitably influence other parts of the network. Therefore, this simulation will include all the main roads and important secondary roads in the study area, to make the results as accurate as possible. All the roads included in the simulation are shown in red in Figure 1-2. The blue links are the remainder of the road network.

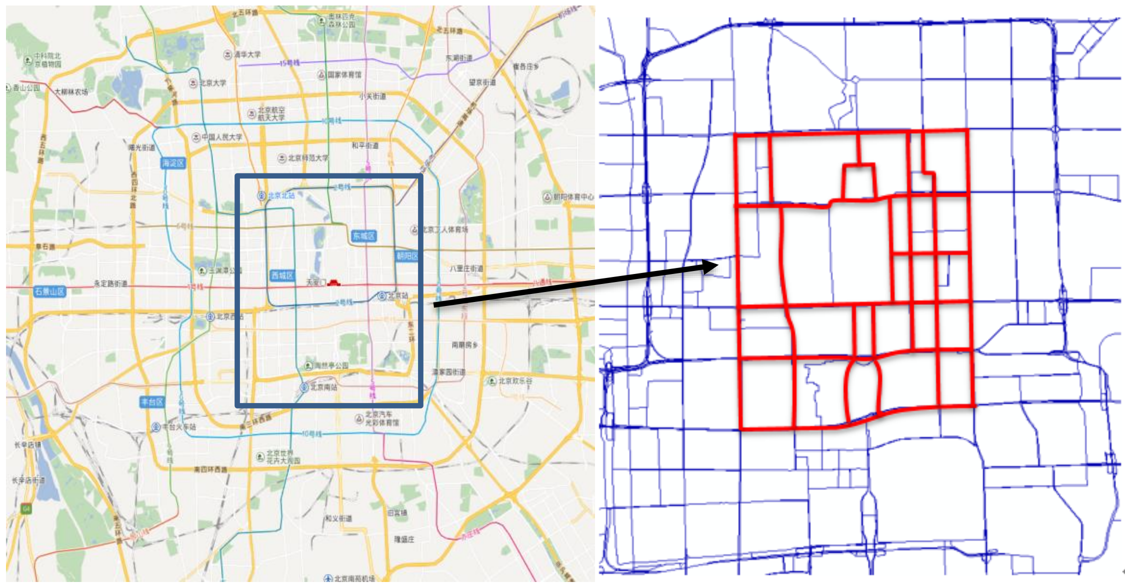


Figure 1-2 Research area

1.3 Motivation

With the continuous improvement of people's living standards, more and more people choose to travel during holidays. According to statistics, in 2015, Beijing received 273 million tourists and grew by 10% annually. Beijing city center contains more than 70% of Beijing's famous scenic spots, including the National Palace, the National Museum, Tiananmen Square, Beihai Park and so on, which prompts lots of tourist buses to enter the downtown of Beijing. These attractions are depicted with green dots in Figure 1-3. Therefore, Beijing's traffic pressure is increasing a lot, especially in Beijing downtown. In addition to this, the office area for Chinese national leaders is also located in the heart of Beijing so traffic jams can also increase their travel time, which is shown as the yellow dot in Figure 1-3.

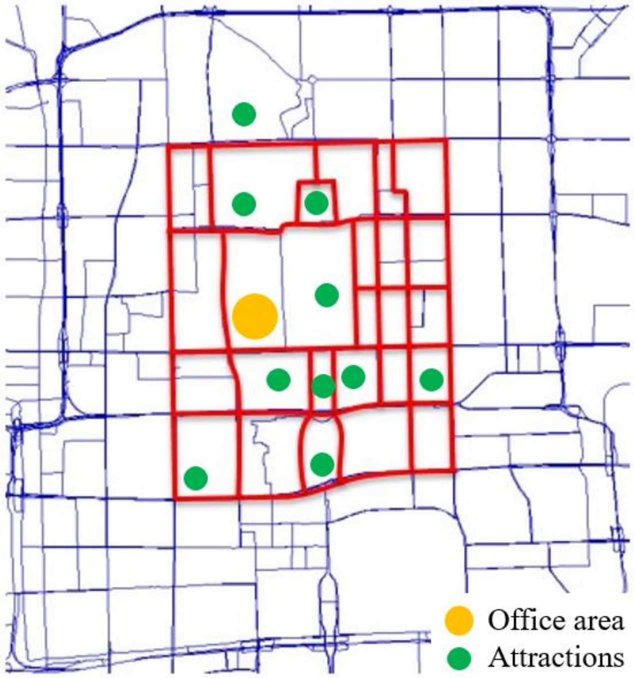


Figure 1-3 The distribution of attractions in research area

Hence, it is necessary to reduce traffic congestion in the center of Beijing. An important step toward alleviating the traffic congestion is to improve the placement of tourist bus drop-off and pick-up locations in the road network.

1.4 Literature Review

There is a limited amount of previous work that consider tourist buses, their impacts on traffic and how to reduce their negative impacts. Some insights into this problem can be gained by considering public transportation buses, and how bus stops impact traffic flow. Most experts and scholars focus their attention on the impacts of the location of bus stops, the types of bus stops (bus bays or on-street parking spots), and the size of stops (such as the size of the platform) on regular traffic [1]. In many cities, road congestion is becoming more and more serious due to the development of public transport. A significant portion of road congestion in urban areas can be caused by public transportation vehicles.

The parking duration depends on how long it takes passengers to get on and off the bus. It has been shown that there is no difference in the average service time for each successive passenger to board, except that the first passenger may require less time due to the ready storage area on the steps between the bus door and the driver, and the minimum service time is approximately half of the average service time [2]. Moreover, the distribution of passengers along a bus route follows a negative binomial distribution such that the parking duration at each individual bus stop along a route is also influenced [3]. Additionally, there are many general determinants of bus dwell time, including the size of buses, bus routes and station utilization rate. The maximum dwell time should be determined by passengers' activities and door opening time [4].

Two different types of bus stops, curb-side and bus bay, are typically used in practice. TCRP Report 19 provides some information on the advantages and disadvantages of each type of bus stop [5]. The curb-side stop can provide minimal delay to buses and can be relocated easily. On the other hand, the advantages of bus bays include that it is safer for passengers and buses, and it can minimize delays to through traffic. Additionally, this literature described the disadvantages of these types of bus stops. The curb-side stops can cause traffic congestion since a part of traffic must queue behind parked buses and some bus drivers can make dangerous maneuvers when changing lanes. Bus bays may cause delays to buses when trying to re-enter traffic. Also, the relocation process for a bus bay is difficult and expensive [5]. Additionally, this work provides some guidelines on when to use bus bays such as, traffic flows exceeding 250 vehicles/hour/lane, traffic speeds greater than 40 mph, more than 10 buses per hour, and dwell times that exceed 30 seconds per bus. Some of these results are confirmed by microscopic simulation of the different parameters [6]. Analytical work on comparing bus bays and curbside bus stops has also shown that for high bus passenger occupancies, low car demands, and short bus dwell times curbside bus stops would reduce the overall passenger delay [7].

Several studies have considered the number of berths required at each parking spot. The number of vehicle berths at each bus station can impact car capacity since more vehicles berths will take up more road space. The number of berths needed for each bus station can be determined by the arrival frequency of buses in an hour and the maximum number of cars passing the bus-stop area [1]. An additional issue is that due to underutilization of some bus berths, the effective number of parking berths may not be the same as the total number provided [8]. Simulation work has found that the efficient number of parking berths was less than expected, and that the dwelling behavior was the main factor for the reduced number of effective spots [4]. Additional work has tried to address this problem by providing heuristic berth assignment plans to improve the utilization of parking berths [9].

Some studies have explored the impact of bus stops near signalized intersections on car traffic. Analytical models to describe the changes in car delay due to bus stops near signalized intersections were formulated and used to determine where to locate bus stops to improve car operations. Additionally, a bus-holding strategy is proposed to reduce the impact of buses on cars [10]. A similar study considered using Variational theory of kinematic waves in a moving-time coordinate system to calculate the loss of capacity caused by an obstruction, which could include a stopped bus, near a signalized intersection

[11]. A deterministic model was formulated to explain the deceleration, acceleration and queue interference of buses, concluding that far-side bus stop placement increases car delays by less than near-side bus stops in most situations [12].

Based on the analysis of the existing literature, the article will analyze the location and design of parking spots for tourist buses from the qualitative and quantitative perspectives.

1.5 Research Goal and Methodology

With the continuous development of tourism, tourist buses have been adopted by more and more cities as a choice of transportation for visitors, however, only a limited amount of guidance on how to provide parking spots for these tourist buses exist. The purpose of this research is to provide qualitative guidelines on the impacts of different types of bus stops and different location of bus stops, and conduct a case study to implement the findings in Beijing, China. The research approach is shown in Figure 1-4.

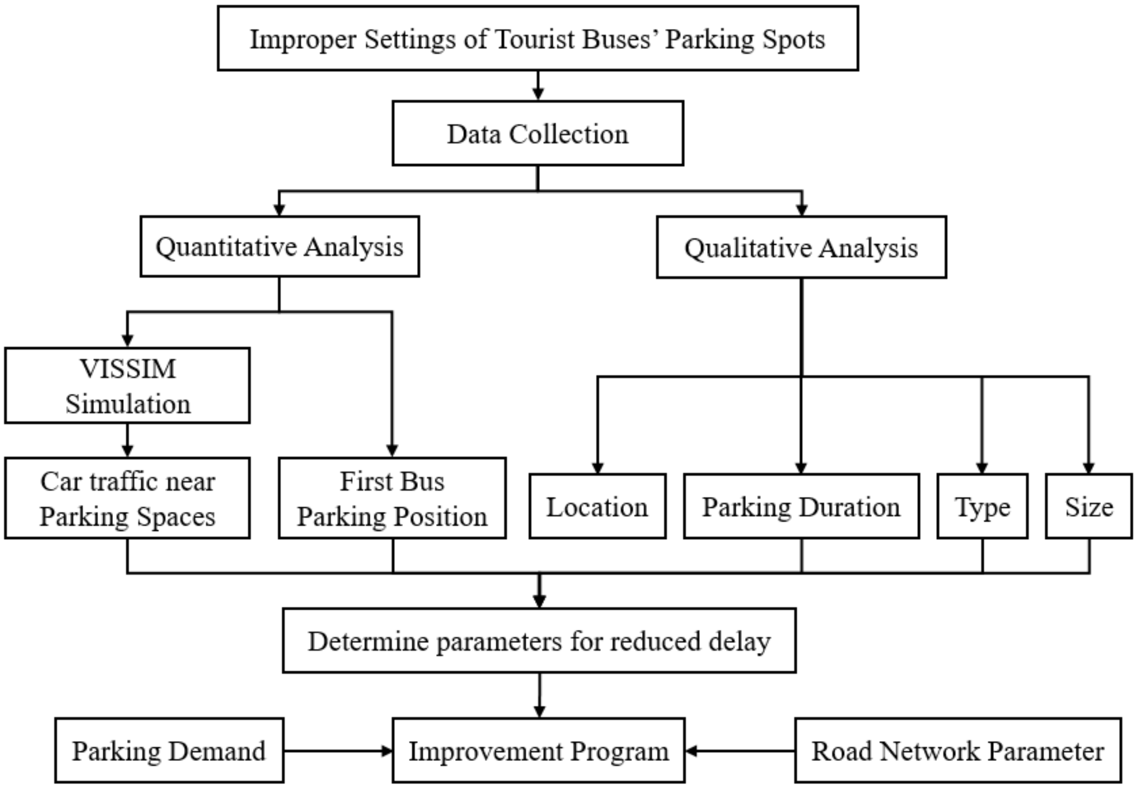


Figure 1-4 Approach of research

The methodology of the article includes the qualitative analysis and quantitative analysis. The qualitative analysis is based on literature and experiences learned from implemented projects. The location, parking duration, type and size are discussed qualitatively as four factors to consider when determining an improvement program. The quantitative analysis is based on the literature and simulation experiments to study the impact of car traffic and first bus parking position. A microscopic simulation in the VISSIM simulation environment is used to conduct the simulation experiments [13]. VISSIM is an effective tool for evaluating traffic engineering design and urban planning. The simulation is based on driving behaviors, which are used to model and analyze the operation of urban traffic and public transport vehicles under various traffic conditions.

The basic data of the VISSIM simulation contains the traffic environment (road network, signal control, speed limit, etc.), the driver behavior (following car, lane overtaking, etc.), vehicle parameters, traffic demand characteristics and other traffic elements. The VISSIM concept diagram is shown in Figure 1-5. This is used to conduct the case study implementation program considered for downtown Beijing.

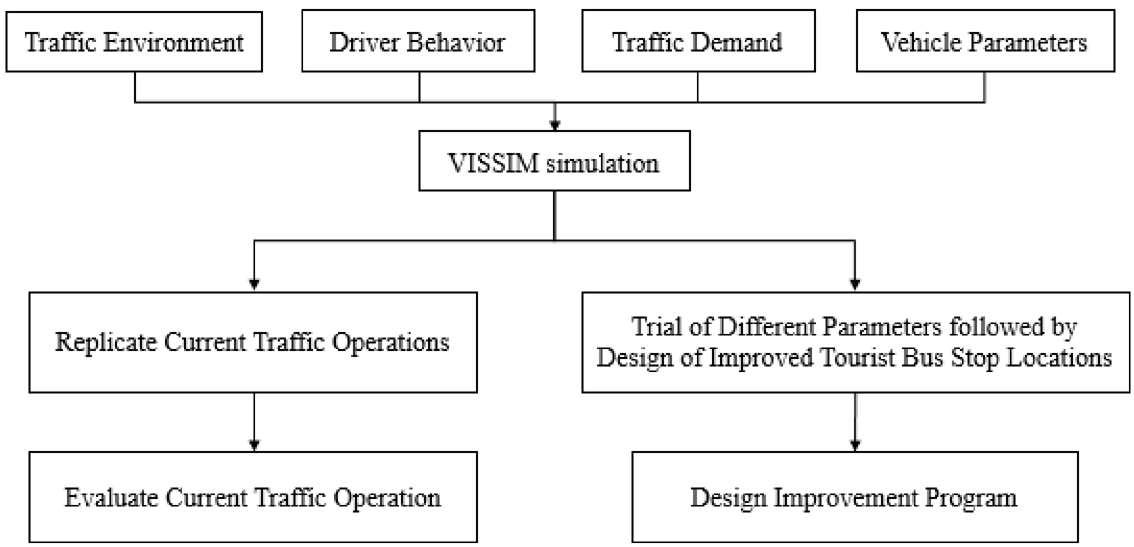


Figure 1-5 VISSIM concept diagram

1.6 Organizations

This thesis consists of five chapters. Following the introduction, Chapter 2 presents a qualitative discussion of factors which may influence the setting of parking spots. The location, parking duration, type and size of parking spots are important factors to consider, because these factors can affect the rationality of temporary parking spots for tourist buses. All the factors are included in the elements that will be improved when doing the simulation of road network in Beijing downtown.

Chapter 3 presents a quantitative and simulation analysis of two factors that may impact the setting of parking spaces. These factors consist of the traffic flow near parking spots and the first bus's location. The traffic flow will largely impact the network delay caused by temporary parking spaces and the parking location of first coach will influence follow-up tourist buses parking behaviors, especially for the road parking spots.

Chapter 4 presents the case study including all the data, the improvement process and the simulation results. Based on the simulation results, an improved parking policy for the city of Beijing is provided. Finally, Chapter 5 will discuss some issues that are not addressed in the thesis and potential future work.

Chapter 2 Qualitative discussion of factors impacting traffic conditions

While it is hard to quantify the impact of certain factors related to the parking spots of tourist buses on traffic, all of their impacts still need to be discussed and considered for the tourist bus parking problem. Hence, this section provides a qualitative discussion on: 1) parking location, 2) type of parking spot, 3) parking duration and 4) size of parking spot and their impacts on traffic conditions.

2.1 Temporary Parking Location for Tourist Bus

The site selection is an important step towards reducing the impacts of tourist bus stops. The basic principle to adjust and determine the location is based on the road parameters and traffic conditions. Choosing a proper parking location will not only make it easier for passengers to travel to attractions but also reduce the impact on traffic flow due to the setting of stops.

2.1.1 Analysis on the Factors Influencing the Selection of Parking Spaces

There are many factors that affect the site selection of tourist bus stops. This section considers the convenience, safety and the impact on traffic flow of different bus stop locations [14].

2.1.1.1 Convenience of Travelers to Attractions

The first consideration for the tourist buses' parking spot should be the distance to the attractions, since the main purpose is to serve this demand. In general, if conditions permit, the distance should be minimized for the convenience of travelers. If, however, limited by the objective conditions, it is unreasonable to set up a temporary parking lot close to the attraction, the location of parking spots should be determined by the distance to the nearest public transport station, such as public bus stops, subway stations and bicycle-share stations.

2.1.1.2 Safety of Travelers' Activities

When passengers arrive and leave the platform, they often need to cross the road in many cases. This involves the safety of passengers when crossing the road. In the case of crossing, it is safer to cross at marked crosswalks often present at intersections. Additionally, considering Chinese driving conditions, crossing behind the coach is safer than crossing in front of the coach. Typically, car drivers do not expect pedestrians to pass in front of a bus since these pedestrians are blocked by the bus. However, when crossing behind the bus the pedestrians are more visible. Therefore, the location of parking spaces should consider the relative position of the crosswalk, that is, the safety of passengers arriving and leaving the station. As a general conclusion, it is safer to set parking spaces at the downstream of the intersection and it is the most dangerous to set the parking spaces on general roads.

2.1.1.3 Impact on Traffic Flow

Due to the layout of the temporary parking spots, traffic flow will be influenced to some extent, mainly reflected in blocking a lane of traffic, interfering with the movement of turning vehicles, and traffic impacts due to maneuvering in and out of parking spots. The impact on the entire traffic flow is measured by the total delay on the road network, which can be calculated within a microsimulation framework.

2.1.2 Road Parking and Intersection Parking Site Analysis

In many tourist cities, the distance between different scenic spots is often not very far so tourists can visit many different attractions in a very short period of time. For example, in the center of Beijing, the Forbidden City is only a mile from the Capital Museum and Tiananmen Square is only 0.6 miles from the Forbidden City. Therefore, when setting a parking space, it is important to consider the distance from each attraction.

Since intersections allocate lanes with different phases, the capacity of each lane is lower than that of road sections, the specific impact degree is determined by signal timing, road width and other factors [15]. To enhance the efficiency, designers often increase the number of lanes as much as possible to improve the intersection capacity [13]. However, the increase in the number of lanes makes less land available at the intersection, which is one of the disadvantages for parking spots near intersections. Combined with the above analysis and related literature, the comparison of advantages and disadvantages of temporary parking spaces at intersections and roads is shown in Table 2-1.

Table 2-1 Advantages and disadvantages of parking spots at intersections and roads

	Advantages	Disadvantages

Parking Spots at Intersections	1. Take full advantage of the crosswalk at the intersection. 2. Safer for passenger crossing. 3. Shorten the deceleration distance of coaches when parking. 4. Tourist buses can effectively use the red signal time to pick up and unload visitors. 5. Tourist buses can easily use the gap produced by signal timing to leave parking spaces.	1. Traffic capacity is lower. 2. Easily lead to traffic jams. 3. Land resources are limited in intersections.
Parking Spots at General Roads	1. Setting condition is easier.	1. Not convenient to transfer to public transport. 2. Could be problematic for pedestrian crossing

2.1.3 The Principle of Parking Site Selection

On urban roadways, intersections are the major bottlenecks. Combined with a bus stop near the intersection, the capacity of this bottleneck will even further be reduced. Hence, locating parking spots on roadways could help relieve some of the capacity pressure from intersections. However, if a bus stop needs to be located to the intersection (for example for ease of passengers), then the literature has shown that a far-side bus stop might have less impact on cars [12, 14]. Locating tourist bus stops at the upstream of an intersection can lead to conflicts with right-turning vehicles, which need to change lanes and interfere with both cars and buses. However, if the intersection is over-saturated, a near-side bus stop with a set back from the intersection could reduce the probability of queue spillbacks and increase intersection capacity [12]. Based on the above analysis and related literature, the general principle of parking location near the intersection is described below:

(1) For under saturated intersections, bus parking spots should be set at the downstream of intersections.

(2) If there is a high volume of right-turning traffic flow at the intersection the parking spot should be set at the downstream of the intersection.

(3) For oversaturated intersections, the bus parking spots should be located on the near-side but with a set back to allow cars to use all lanes at the intersection.

Even after a qualitative analysis of the choice of location of the temporary parking spot, the actual setting of the location of the temporary parking spot still has a great variability. In practice, different planners have used different types of parking spots in similar situations where similar qualitative criteria apply [16]. Therefore, based on it is also necessary to conduct a quantitative study of the location selection of bus stops [17]. The quantitative analysis is evaluated by VISSIM experiment.

2.2 Selection on the Type of Parking Spaces

Two different types of parking spots, namely on-street parking or bay parking, can be provided for tourist buses. Choosing the appropriate type of parking spaces can improve the passenger safety, reduce the impact of the parking spots on traffic flow or reduce the tourist bus delays.

On-street parking spots are the most common form of parking spots in China. It is a simple, easy-to-use form of construction that places parking spots directly on the roadway. Bay parking spots refers to when the parking spot is located in a widened area of the road. It can set the parking position outside the general lane to reduce the impact caused by the parking of tourist buses on traffic flow [13]. The two type of parking spots are depicted in Figure 2-1.

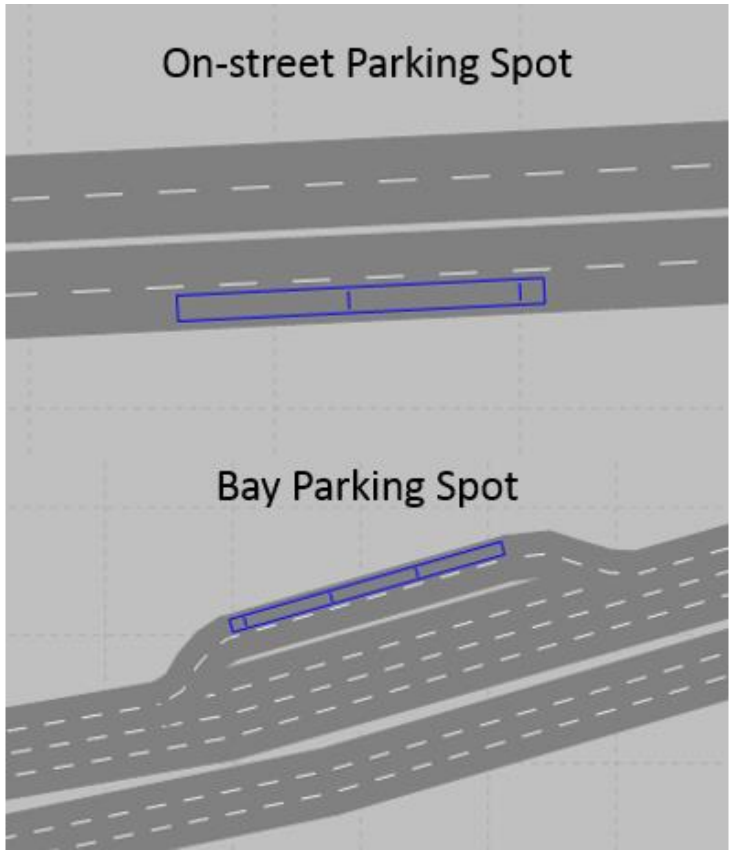


Figure 2-1 On-street and bay parking spots

Based on some projects related to the setting of parking spots for tourist buses in different cities, there are two options for these two types of temporary parking spots in many countries. Some small and medium-sized cities do not have the space or budget to insert bay parking spots hence all temporary parking spots for tourist buses are uniformly set as the on-street parking spots. However, some large and medium-sized cities, with more serious traffic problems, both have the space to and see the necessary investment in bay parking spots as justifiable to release traffic pressure and require all parking spots to be bay parking spots.

In fact, these two practices reflect the lack of understanding of these two types of parking spots. Only when the relevant transportation departments fully recognize the characteristics of the two types of parking spots, combined with the actual conditions of the local city, can they reasonably determine the most suitable type of parking spots for the city.

(1) Comparison and Analysis of Parking Delay of Tourist Bus

When considering the delays of a tourist bus, on-street and bus bay stops can have different impacts. On one hand, on-street parking stops allow for buses to decelerate, stop and accelerate without turning [18]. Hence, they do not have to interact with general cars or compete for space with them in their acceleration process. This is expected to minimize their additional delays due to stopping. On the other hand, when parking at a bus bay, tourist buses are required to leave their lane of travel and then join it back. Hence, they need to compete with regular traffic for space on the roadway when they are trying to leave the parking spot. This can lead to additional delays for the tourist buses.

(2) Comparison and Analysis of Impact on Traffic Flow

The type of parking spot can also influence general traffic delays. When a tourist bus stops at an on-street parking stop it occupies one lane of travel. Hence, during the entire parking process, including deceleration, stopped time and acceleration, all general traffic on the same lane as the bus (and other adjacent lanes too) will be impacted [19]. Cars will either continue to slow down, stop and accelerate (i.e., follow the behavior of the bus) or try to find available gaps in adjacent lanes, which can produce disorder in traffic flow, increasing the delay of cars [20].

As for the bay parking spot, while the bus is stopped it does not occupy road space. However, general traffic can still be impacts when a tourist bus needs to decelerate and accelerate into its parking spot. In general, this is expected to have less influence on traffic flow.

Thus, both road parking spot and bay parking spot will have an impact on the traffic flow, the difference of the two impacts on the traffic flow needs to be quantitatively analyzed, see experimental simulation in VISSIM in section 3.2.

(3) Comparison and Analysis of the Construction and Maintenance

Because of the simple design, the on-street parking spots have relatively less investment in construction and low maintenance cost. Due to the complicated design of the bay parking spots, it occupies more land resources, high construction costs and high maintenance costs [21].

In summary, the advantages of on-street parking spots include the simple design, low construction and maintenance costs, and the ease of driving in and out of to reduce additional delays of tourist buses [22]. The disadvantage is the greater impact on traffic flow, and the large delay on cars. To the contrary, the impact of bay parking spots on traffic flow is relatively smaller and parking does not occupy the road space [23]. Bay parking spots also have high level of service level. However, the disadvantages include high cost of construction, greater delay on tourist bus itself and more land resources consumption. In Table 2-2, the advantages and disadvantages for the two types of parking spots are summarized.

Table 2-2 Advantages and disadvantages of road parking spots and harbor parking spots

	Advantage	Disadvantage

On-street Parking Space	1. Parking is easy. 2. Lower bus parking delay. 3. Simple design. 4. Low construction costs.	1. High impact on traffic flow.
Bay Parking Space	1. Lower impact on traffic flow. 2. High service level.	1. Large delay for tourist bus. 2. High construction costs.

2.3 Parking Duration

The parking duration of tourist buses is one of the important considerations when setting up parking spots. The parking duration determines whether visitors have enough time to get in and out of the coach, determining the degree of impact on the traffic flow [24].

Figure 2-2 45-seat tourist bus

For on-street parking spots, the parking duration directly affects the impact time on traffic flow. In theory, the longer the parking duration, the larger delay and security risks on the road network [25]. Therefore, in the premise of travelers having enough time to get on and off the tourist buses, the parking duration of road parking spots should be minimized as much as possible. The shorter the duration, the less impact on traffic flow. The maximum parking duration can be approximated as the number of passengers that a tourist bus can carry multiplied by a constant value for the time it takes each individual to get on or off the bus, plus additional time for doors opening and closing, and acceleration and deceleration. Regulations should be implemented to ensure that buses do not dwell more than this maximum time at on-street bus stops.

The impact of bay parking spots on traffic flow mainly arises from traffic conflicts with cars when tourist buses leave the parking lot, but bay parking spots will not block the lanes on general roads. As a result, bay parking spots can allow for longer parking durations than road parking spot, providing coaches more time to wait for passengers and giving passengers enough time to load and unload their luggage [26].

Data collected in Beijing shows that the suitable time for loading and unloading a standard 45-seat tourist bus (shown in Figure 2-2) is 120 seconds. Based on data collected by the researcher himself looking at 493 buses, 120 seconds was found to be long enough for 85% of buses to finish boarding and alighting, except for that buses which carry many old people. Based on this data and the *Beijing Parking Management Policy (2015)*, the parking duration is set as 120 seconds for on-street parking spots. For bay parking spots, a duration of 360 seconds is implemented since often buses prefer to dwell at the parking spots after they are done loading/unloading passengers to either unload luggage or reduce the time they need to park at off-street parking locations. By allowing for this at bay parking spots the violations of parking duration at on-street parking spots could be reduced. Hence, 360 seconds of dwell time will be used for bay parking spots for the remainder of this thesis.

2.4 Size of Parking Spaces

Before setting up a parking spot for a coach, it is necessary to consider the number of parking spaces and the length of the parking spaces. The number of parking spaces is set mainly based on the parking demand and the road conditions [27]. The number of parking spaces to be set should satisfy the parking demand of the tourist buses, otherwise the queuing phenomenon may occur at the end of parking spots.

The length of each parking spot mainly depends on the size of tourist buses. At present, tourist buses leased by travel agencies are usually divided into 6 meters to 11 meters according to their carrying capacity [28]. The proportion of each type of tourist bus in Beijing downtown is shown in Figure 2-3. Parking spaces should meet parking needs of various types of tourist buses. If the length of the parking space is too short, it will greatly increase the difficulty of parking process and cause inconvenience when entering and leaving the parking spaces, resulting in delays. Therefore, different length of parking spaces should also be simulated separately to reduce the delay of tourist buses inside the parking lot.

Figure 2-3 Proportion and size of three types of tourist buses

Chapter 3 Quantitative discussion of factors impacting traffic conditions

3.1 Factors considered

In this chapter, a quantitative analysis on how the traffic flow and the first buses parking location might impact congestion and tourist bus delays is presented.

The first factor is the car traffic flow near the parking spot [29]. The level of traffic demand can influence both the impacts of buses on cars and cars on buses. Hence, both bus and car delay need to be considered. The impacts of buses on cars will be more prominent for the on-street parking spots while differences for bay parking spots can also be observed [30]. The impacts of cars on buses will be more prominent for bay parking spots since buses trying to exit the parking spot will have a more difficult time finding a gap to merge into [31]. Section 3.2 will analyze impact of car traffic flow on these two types of parking spaces through microsimulation experiments.

The second factor is the position of the first coach in a parking spot with multiple berths [32]. Ideally, all tourist buses will follow the parking rules and park in a complete parking space. However, in practice, many drivers often park their coaches across two parking spaces though it is an illegal behavior, especially in some developing countries, like China and India. If the first coach parks across two parking spaces, it will reduce the effective parking spaces in a parking spot. And this dynamic factor varies from city to city and needs to be obtained during the data collection. Section 3.3 will introduce this factor in detail.

3.2 Impact of Car Traffic Flow on Parking Spots

To study the impact of car traffic on the two types of parking spots, we design two experiments for on-street parking spots and bay parking spots to simulate the average delays per vehicle of both buses and cars by changing the car traffic flow near the parking spaces and arrival frequency of tourist buses. Two experiments adopt the same simulation parameters. The purpose of this study is to understand the advantages and disadvantages of two types of parking spots under different car traffic flow and provide ideas and basis for setting up parking spots in the road network.

3.2.1 On-street Parking Spot

The experiment is based on VISSIM software. First, a four-lane link is built with an on-street road parking spot which includes two parking spaces, and parking duration is 300 seconds, as is shown in Figure 3-1. Second, different values of arrival frequency of tourist buses and car traffic flows are assigned to this link. The simulation is run for an hour to get the average delays per car and bus. The total number of replications for the simulation is 20, as this number has been shown to provide results that are reliable for VISSIM simulations in previous studies [33]. All the input data and delay results are seen in Table 3-1. The average delays of tourist buses are the additional time buses spend at the stops after they have completed their dwell, i.e., this additional time is due to the interactions with cars that slow down buses' departure.

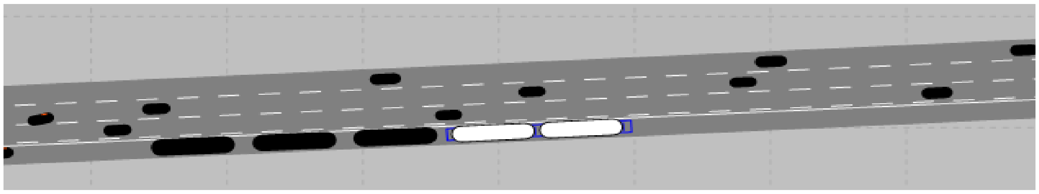


Figure 3-1 Simulation link in experiment for on-street parking spot

Table 3-1 Input data and simulation results of on-street parking spot

Arrival Frequency of Buses (bus/h/lane)	Car Traffic Flow (vehicle/h/lane)	Car Delays		Bus Delays	
		Average (s)	St.Dev	Average (s)	St.Dev
100	1000	7.76	0.81	9.62	0.96
100	1200	10.00	0.86	13.24	0.98
100	1400	11.97	0.84	15.81	1.07
125	1000	8.28	0.92	10.37	1.49
125	1200	10.83	0.91	14.76	1.68
125	1400	12.40	0.92	17.52	1.67
150	1000	9.29	1.15	13.23	1.96
150	1200	11.36	1.27	16.17	2.18
150	1400	13.35	1.23	19.46	2.25
175	1000	10.81	1.65	15.85	2.37
175	1200	11.95	1.73	18.57	2.56
175	1400	14.08	1.88	21.54	2.97

As shown in the results, as the car traffic increases and the arrival frequency of tourist buses increase, the average car delays also increase. Notice that the standard deviation of the samples is small, indicating high confidence around the mean and justifying the use of 20 seeds per run. The delay of cars seems to increase exponentially with the arrival frequency of tourist buses. On the other hand, the impact of the car traffic flow is approximately linear on the average delay per vehicle, as shown in Figure 3-2. This is expected since the scenarios considered remain under saturated. Similar to car delays, the average delays of tourist buses seem to increase with the arrival frequency of tourist buses and car traffic flow. The increase in car frequency creates more conflicts for the bus to move out of the bus stop, hence increasing its delays. On the other hand, the increase in frequency of tourist buses implies that the buses might have to wait to get into the bus stop, i.e., the buses start interacting with each other, and hence the average bus delay increases.

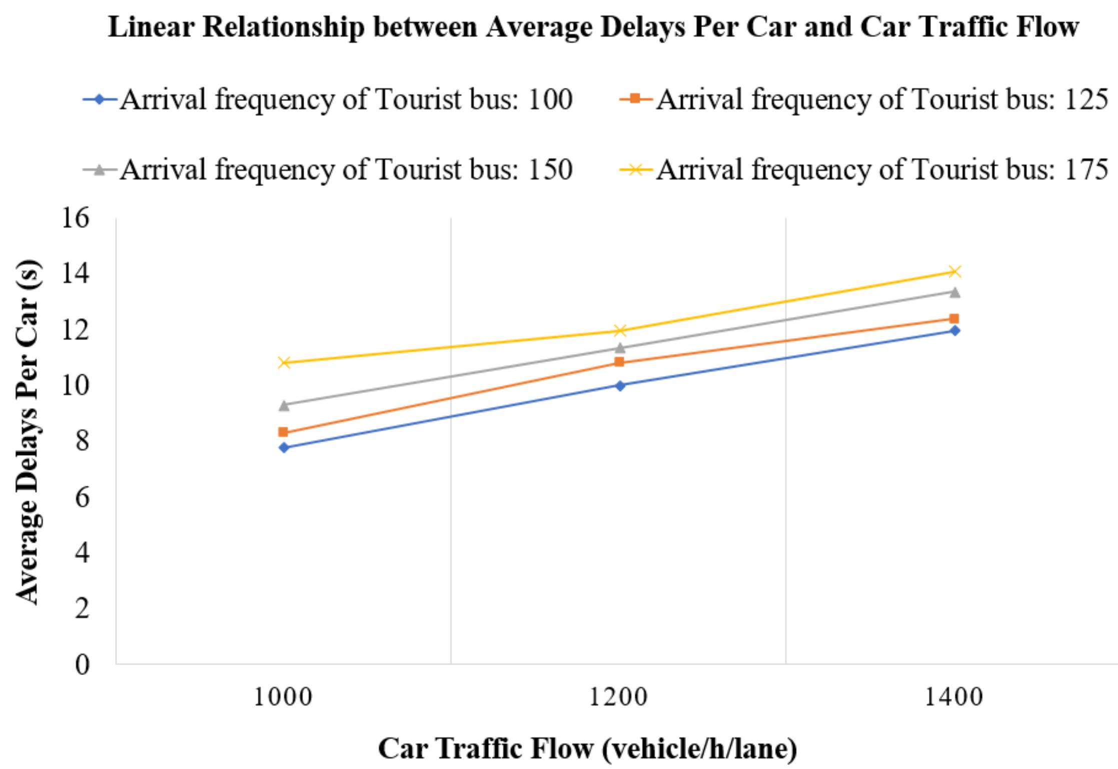


Figure 3-2 Linear relationship between average delays per car and car traffic flow

3.2.2 Bay Parking Spot

In the experiment on bay parking spot, all the road parameters are the same as the experiment on road parking spot, including the total number of lanes. The only difference is that the on-street parking spot is changed to a bay parking spot, as is shown in Figure 3-2. All the input data and delay result are shown in Table 3-2.

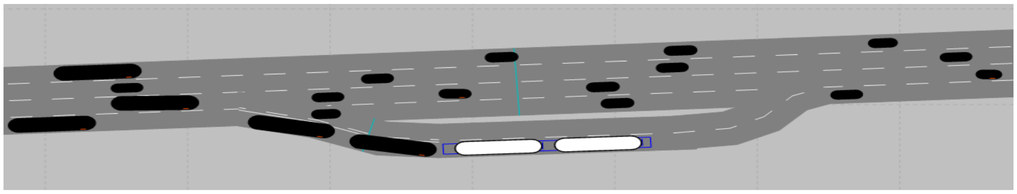


Figure 3-3 Simulation link in experiment for bay parking spot

Table 3-2 Input data and simulation results of bay parking spot

Arrival Frequency of Buses (bus/h/lane)	Car Traffic Flow (vehicle/h/lane)	Car Delays		Bus Delays	
		Average (s)	St.Dev	Average (s)	St.Dev
100	1000	4.52	0.613	14.45	0.851
100	1200	4.60	0.654	17.23	0.862
100	1400	4.91	0.686	19.97	0.948
125	1000	5.98	0.749	15.55	1.230
125	1200	6.26	0.785	18.12	1.417
125	1400	6.87	0.792	20.92	1.543
150	1000	6.44	0.936	16.74	1.745
150	1200	6.92	0.980	19.28	1.898
150	1400	7.35	0.996	21.75	2.029
175	1000	7.23	1.193	17.89	2.354
175	1200	7.76	1.272	19.58	2.488
175	1400	8.10	1.364	22.68	2.597

As shown in the results, the bay bus stop adds much fewer delays to general cars and tourist buses as expected. Again, the standard deviations are small indicating a high confidence around the mean. Additionally, the change in additional delay as the car traffic flow increases appears to be minimal. For this case, the increase in the frequency of tourist buses has a larger impact on the car delay than the car traffic flow. On the other hand, as expected the bus delays are larger than for the case of an on-street bus stop since buses have to find a gap in the car stream to be able to pull out of the bus stop.

3.2.3 Experiment Result Analysis

All the experimental results in Table 3-1 and Table 3-2 are made into bar charts in Figure 3-3, Figure 3-4.

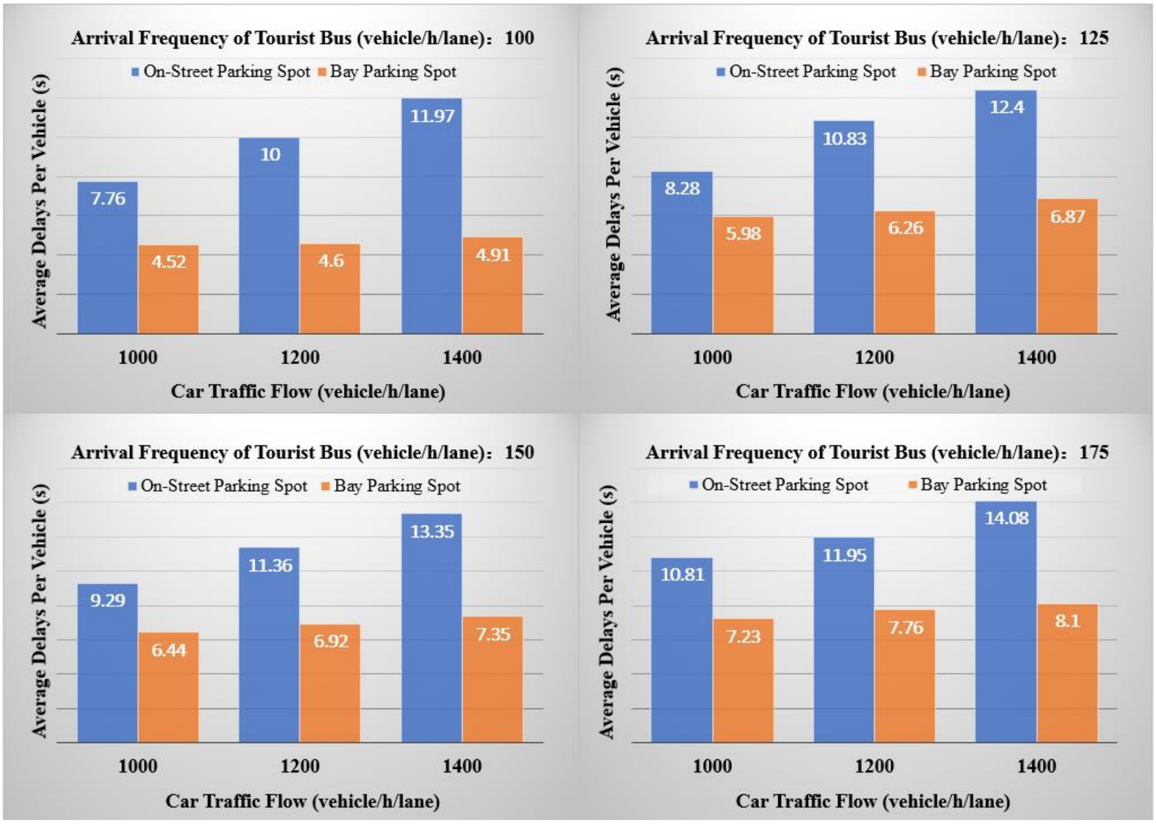


Figure 3-4 Comparison of average delays per car on two types of parking spots

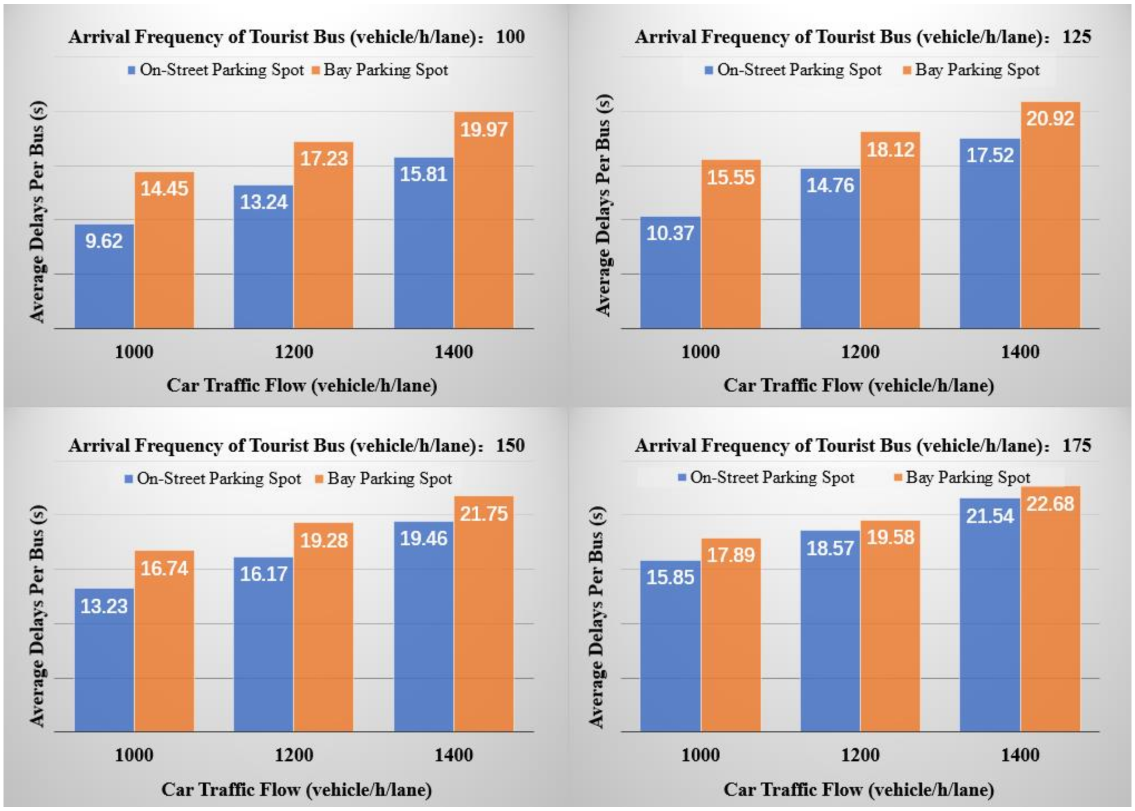


Figure 3-5 Comparison of average delays per bus on two types of parking spots

As shown in the figure, when the arrival frequency of the tourist bus is constant, the average delay of cars impacted by a bay parking spot is significantly less than that for an on-street parking spot. On the other hand, the average delay of tourist buses impacted by a bay parking spot is slightly larger than that for an on-street parking spot. Therefore, due to the large difference between the number of tourist buses and number of cars, we can conclude that a bay parking spot performs well in most situations, regardless of the car traffic flow and arrival frequency of tourist buses when considering vehicular delay. Considering that buses have larger passenger occupancies, the total passenger delay for on-street parking spots and bay parking spots could be expected to be more similar. In practice, the geometric constraints should also be considered to ensure that there is enough space to construct a bay parking spot. If not, on-street parking spot will be selected.

In summary, in the design of parking spots, we must make reasonable arrangements for the parking location, parking duration, type and size of parking spot, to achieve the efficient use of urban roads, increase road transport capacity.

3.3 Impact of the First Coach's Parking Position

Based on field observations, the first coach has the highest proportion of improper parking behaviors. Most of the improper behavior consists of parking across the line, resulting in the waste of parking spaces inside the parking lot. Due to the difference in the parking positions of the first tourist bus entering the parking spots, the subsequent stops of tourist buses will be impacted and the number of usable parking spaces at the parking spot will be reduced. In this case, we need to introduce a new concept, called the usable parking correction parameter, denoted η. Therefore, the number of usable parking spaces is calculated by the following formula:

$$n_{usable} = \lfloor \eta \times n_{total} \rfloor \tag{3-1}$$

In the equation,

n_{usable}: The usable number of parking spaces.

η: Usable parking correction parameter.

n_{total}: The total number of parking spaces that have been set.

Notice that equation 3-1 rounds down non-integer values to account for the fact that buses cannot park in less than one unit of space. When we study the impact of first bus's parking location, the assumption is that all subsequent coaches will entirely park in the available parking spaces without any improper parking behaviors.

An example which has three parking spaces is used for illustration. Notice that on-street and bay bus stops behave in the same way. In our example, there are five possible situations for the first coach's parking position, and these cases are shown in Figures 3-5, 3-6 and 3-7.

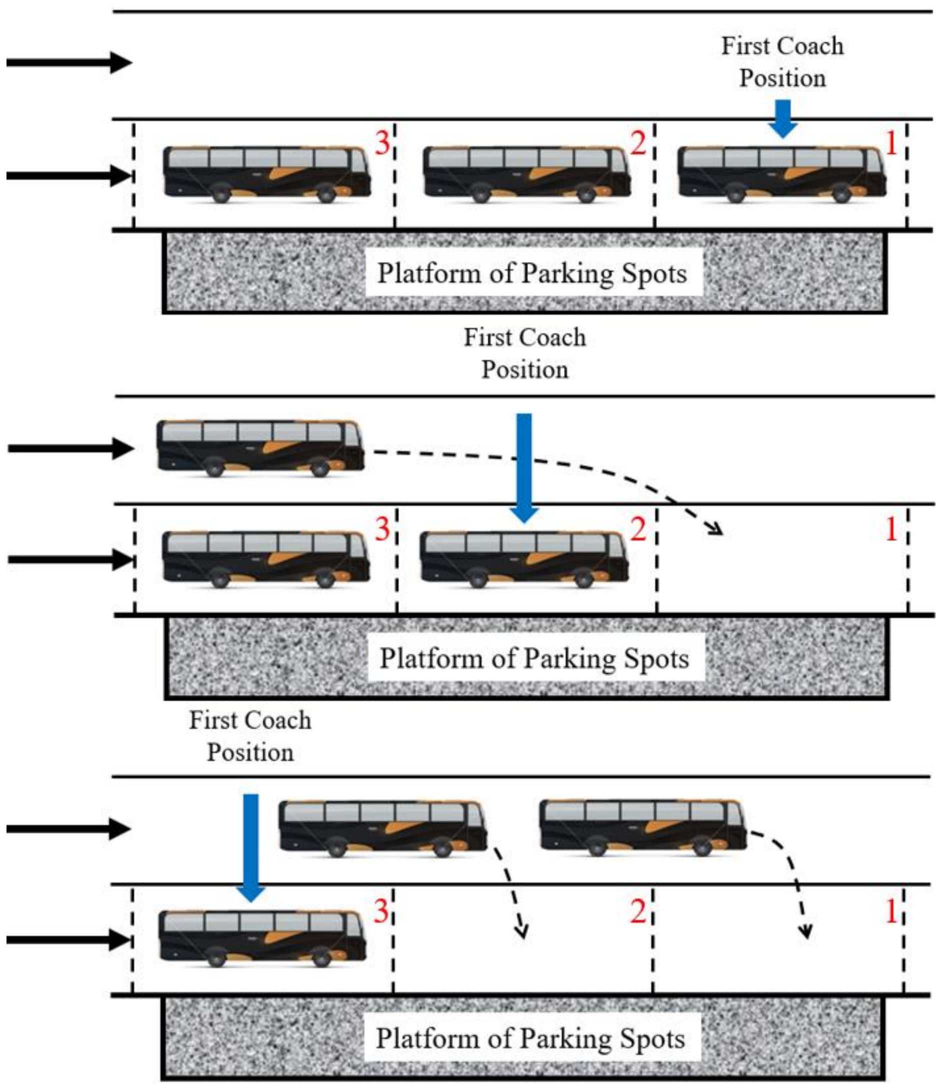


Figure 3-6 Ideal situations of first coach's parking position

Figure 3-5 shows the three ideal situations. The first tourist bus parks entirely in the parking space, so there is no occupation of adjacent parking spaces. Following coaches can park at other spaces. In the above three situations, the number of available parking spaces is equal to the number of parking spaces already set. Hence, for the ideal situations, we believe that the valid parking correction parameter, η is 1.

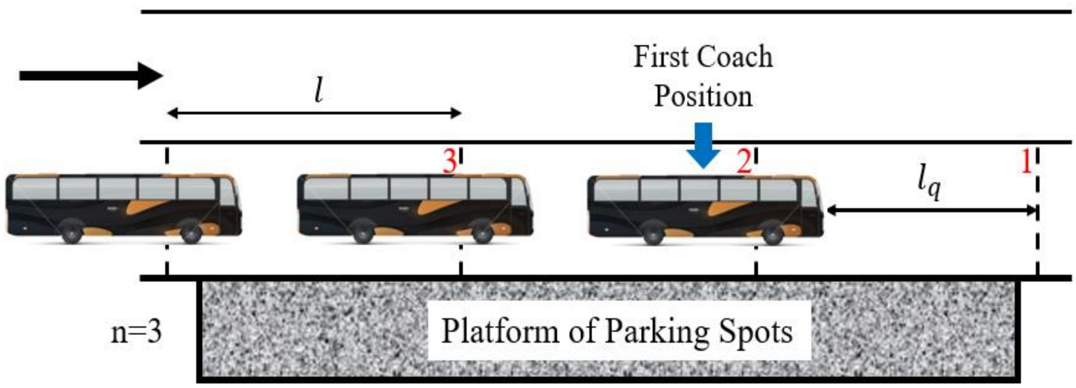


Figure 3-7 The first improper parking position

Figure 3-6 shows a case when the first tourist bus parks in the middle of the first and second parking space, so there is not enough room in front of the first tourist bus to allow other coaches to park. This phenomenon occurs commonly in practice, for example, when passengers wait for the tourist bus in the middle of the first and second parking space. To save passengers' waiting time, bus drivers often park their vehicles as close as possible to these passengers, forgetting whether the tourist bus has taken up the room in two parking spaces.

Since the room before the first tourist bus is not effectively used, it could increase the waiting time of the queuing coaches outside the parking spot and reduce the effective utilization of parking spaces. The usable length of parking spaces can be determined by following correction parameter.

$$\eta = \frac{nl - l_q}{nl} \tag{3-2}$$

In this equation,

n: The number of parking spaces.

l: The length of each parking space.

l_q: The distance between the front of the first coach and the first parking space.

η: Valid parking correction parameter.

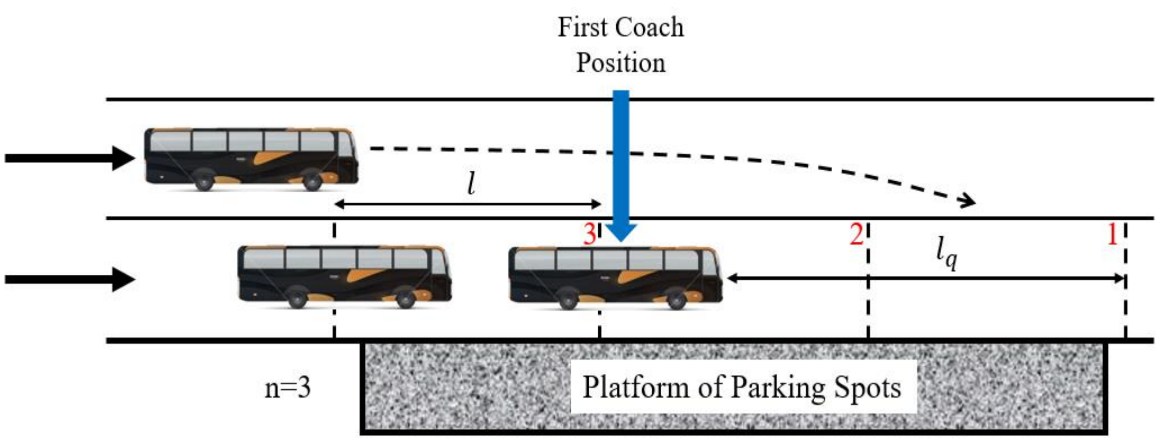


Figure 3-8 The second improper parking position

Figure 3-7 shows a case that is similar to that of Figure 3-5, except that the first coach stops between the second and the third parking spaces. The correction parameter can then be determined by the following equation:

$$\eta = \frac{(n+1)l - l_q}{nl} \tag{3-3}$$

Notice that we assume that the first parking spot can still be used by a bus in this case, and hence, only the last parking spot is lost.

This equation can be generalized to parking spots with more than three berths as follows:

$$\eta = \frac{(n+m)l - l_q}{nl} \tag{3-4}$$

In the equation,

n: The number of parking spaces.

l: The length of each parking space.

l_q: The distance from the front of the first coach and the first parking space.

η: Valid parking correction parameter.

m: The number of complete parking spaces in front of the first coach.

Chapter 4 Case Study

4.1 Simulation Data

Before the simulation, data collection is necessary, including the input of traffic flow, the overview of road network, distribution of attractions, parking demand for each attraction, current temporary parking spots and assumptions for the simulation. These data were collected from July 4th, 2017 to July 21st, 2017 during a peak hour in the center of Beijing. Figure 4-1 shows road network in the simulation, and Table 4-1 shows the summary of vehicle input.

4.1.1 Input of Traffic Flow and Overview of Road Network

In the project, the number of entrance roads is 21, as is shown in Figure 4-1. The traffic flow of each entrance road is counted at the peak hour for two weeks, and the input traffic flow is obtained by the average value. When counting the traffic flow, the vehicle composition is also counted for the simulation. The input data is shown in Table 4-1.

Table 4-1 Input of traffic flow and vehicle composition

#	Entrance Name	Vehicle Input (Vehicles/h)	Vehicle Composition (Car/Public Bus/Tourist Bus)
1	Peace Street S	3000	7:2:1
2	Peace Street N	4000	7:2:1
3	Xisi street N to S	1000	7:2:1
4	Xisi street S to N	1550	7:2:1
5	Xishiku street N to S	1000	7:2:1
6	Xishiku street S to N	1600	7:2:1
7	Dianmen street N to S	600	8:1.5:0.5

8	Wangfujing street N to S	800	8:1.5:0.5
9	Wangfujing street S to N	1400	8:1.5:0.5
10	Dongsi street N to S	800	7:2:1
11	Dongsi street S to N	1700	7:2:1
12	Jingshanhou street E to W	3000	7:2:1
13	Guangchangdong street S to N	900	1:0:0
14	Changan street W to E	4520	9:1:0
15	Changan street E to W	2560	9:1:0
16	Qianmen street W to E	1729	8:1.5:0.5
17	Qianmen street E to W	1650	8:1.5:0.5
18	Zhushikou street W to E	1300	8:1.5:0.5
19	Zhushikou street E to W	1800	8:1.5:0.5
20	Deshengmen street N to S	400	1:0:0
21	Jinbao street	2065	7:2:1

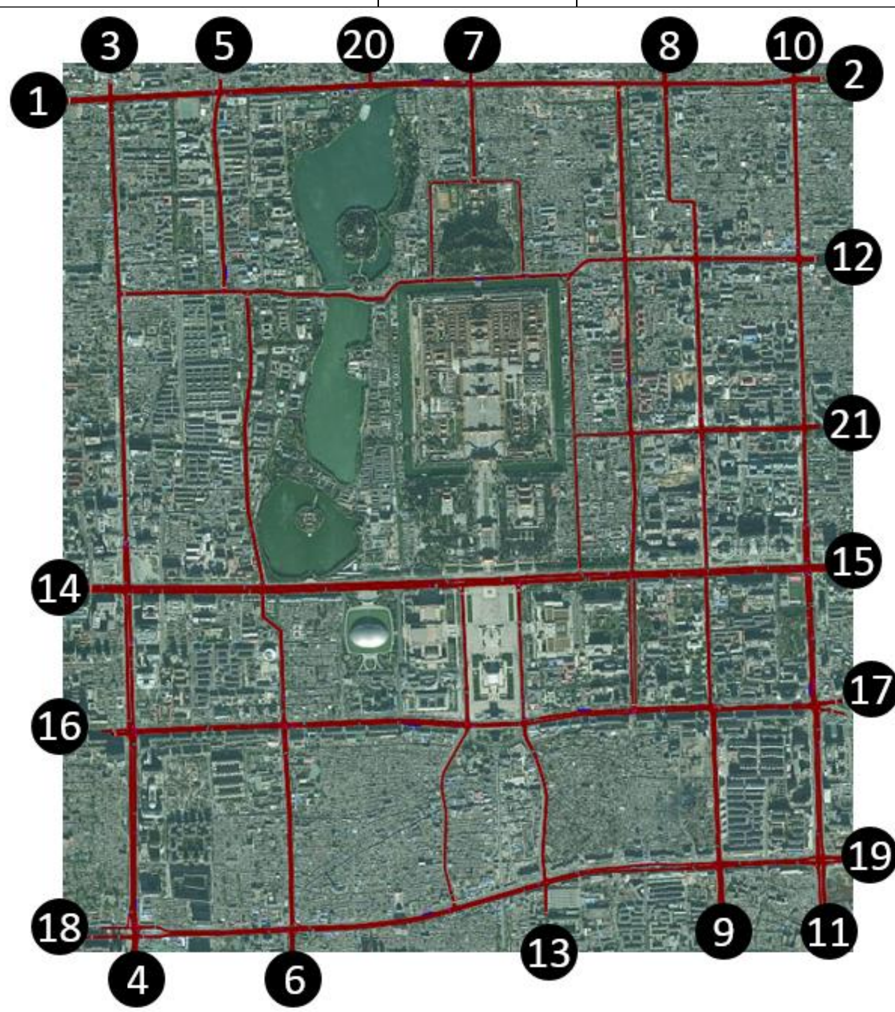


Figure 4-1 All entrance roads and overview of road network in Beijing downtown

The OD information is obtained from Beijing Transport Institute, which recorded the route of each vehicle by using vehicle license label recognition cameras set at every intersection. The overview of all intersections is shown in Figure 4-2. The signal timing at each intersection, which is shown in Table 4-2, was measured by the author himself in summer of 2017 during a field study. Notice that "/" in the table indicates that this phase was not available, and intersection 17 was uncontrolled (hence, no signal timing information is available)

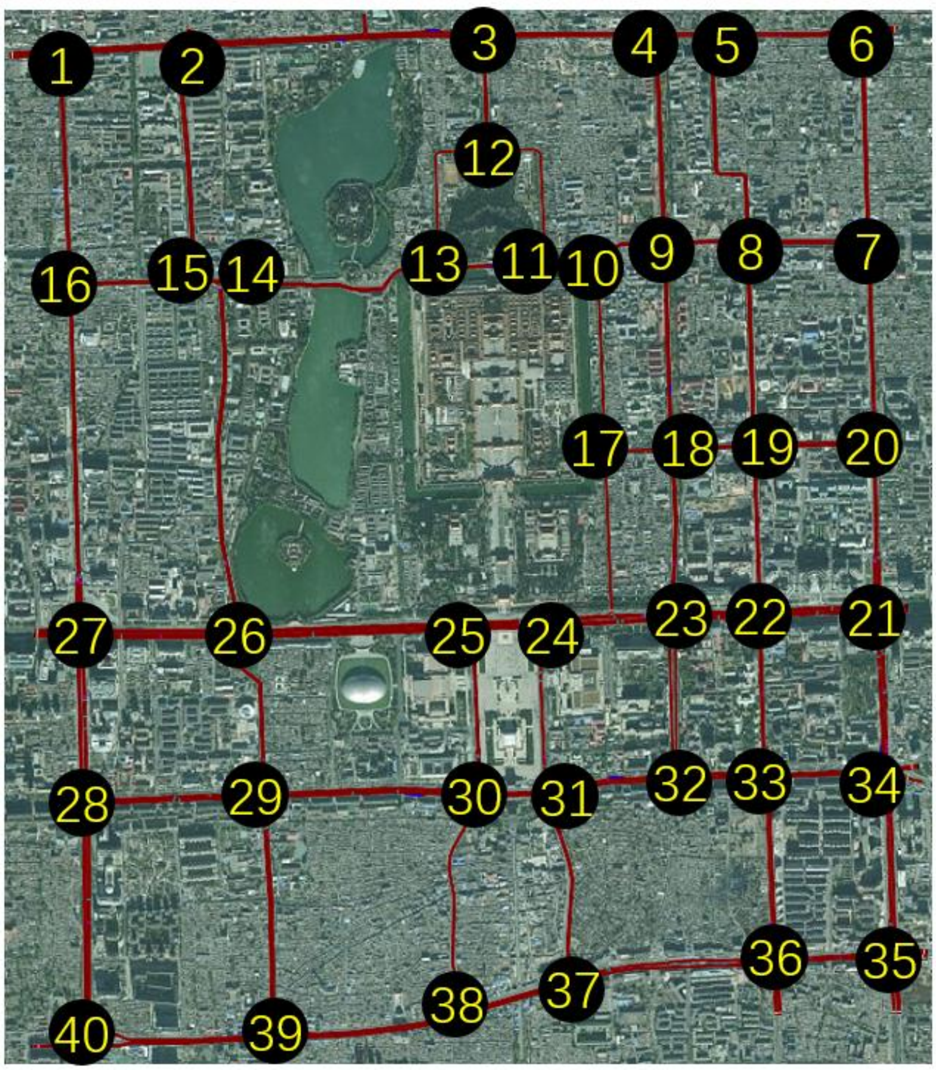


Figure 4-2 Overview of all intersections

Table 4-2 Detailed input for the signal settings

I/S #	Phase 1 N/S (s)			Phase 2 N/S left (s)			Phase3 E/W (s)			Phase 4 E/W left (s)		
	R	Y	G	R	Y	G	R	Y	G	R	Y	G
1	55	3	30	73	3	12	37	3	23	73	3	12
2	55	3	30	73	3	12	37	3	23	73	3	12
3	55	3	30	/	/	/	37	3	23	/	/	/
4	55	3	30	73	3	12	37	3	23	73	3	12
5	55	3	30	73	3	12	37	3	23	73	3	12
6	55	3	30	73	3	12	37	3	23	73	3	12
7	55	3	30	66	3	12	40	3	23	73	3	12
8	55	3	30	66	3	12	40	3	23	73	3	12
9	55	3	30	66	3	12	40	3	23	73	3	12
10	55	3	30	66	3	12	/	/	/	/	/	/
11	55	3	30	66	3	12	/	/	/	/	/	/
12	55	3	30	66	3	12	42	3	30	/	/	/
13	55	3	30	66	3	12	40	3	23	73	3	12
14	/	/	/	/	/	/	/	/	/	/	/	/
15	55	3	30	66	3	12	/	/	/	73	3	12
16	/	/	/	66	3	12	40	3	23	73	3	12
17	/	/	/	/	/	/	/	/	/	/	/	/
18	55	3	30	/	/	/	40	3	23	/	/	/
19	55	3	30	73	3	12	40	3	23	73	3	12
20	55	3	30	73	3	12	40	3	23	73	3	12
21	60	3	41	73	3	14	40	3	23	70	3	12
22	60	3	41	/	/	/	40	3	23	/	/	/
23	60	3	41	/	/	/	40	3	23	/	/	/
24	60	3	41	/	/	/	/	/	/	70	3	12
25	60	3	41	73	3	14	/	/	/	/	/	/
26	60	3	41	/	/	/	40	3	23	/	/	/
27	60	3	41	73	3	14	40	3	23	70	3	12
28	55	3	30	73	3	12	40	3	23	73	3	12
29	55	3	30	73	3	12	40	3	23	73	3	12
30	55	3	30	73	3	12	40	3	23	73	3	12
31	55	3	30	73	3	12	40	3	23	73	3	12
32	55	3	30	73	3	12	/	/	/	73	3	12
33	55	3	30	73	3	12	40	3	23	73	3	12
34	55	3	30	73	3	12	40	3	23	73	3	12
35	53	3	26	73	3	12	40	3	23	68	3	12
36	53	3	26	73	3	12	40	3	23	68	3	12
37	53	3	26	73	3	12	40	3	23	68	3	12
38	53	3	26	/	/	/	/	/	/	68	3	12

39	53	3	26	73	3	12	40	3	23	68	3	12
40	53	3	26	73	3	12	40	3	23	68	3	12

4.1.2 Distribution of Attractions and Parking Demand for Each Attraction

In this project, we will improve the setting of temporary parking spots for 10 attractions. The distribution of attractions in the road network is shown in the Figure 4-3. And the parking demand and parking supply are described in Table 4-3.

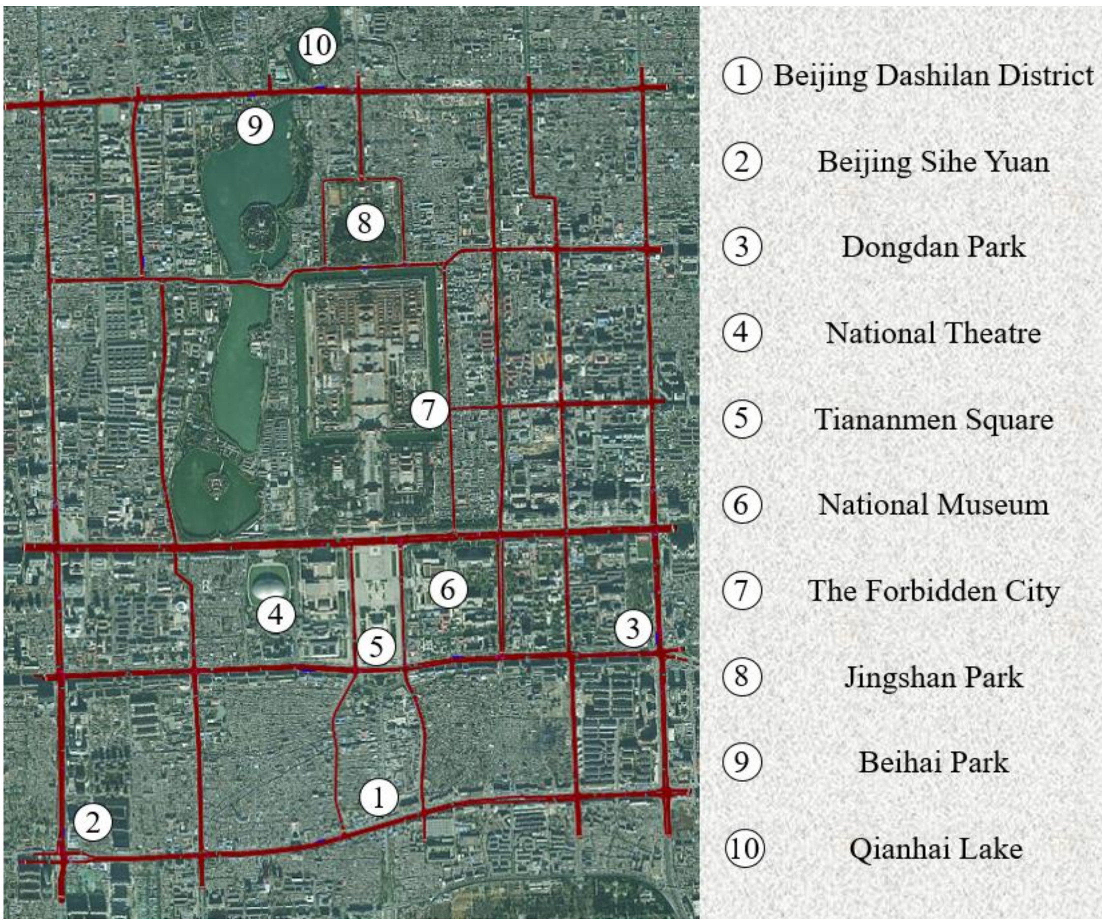


Figure 4-3 Distribution of attractions in Beijing downtown

The parking demand is also collected at each attraction. To do this, the number of travelers that arrive to each attraction during the peak hour is counted, and converted to an equivalent number of buses given the bus distribution shown in Figure 2-3. During data collection, the usable parking correction parameter is also collected from the parking spots already set. We calculate the value of η by recording the parking position of the first coach in each parking spot. Then, we use the equation (4-1) to get the value of parking supply.

$$\lceil P_S \rceil = \frac{P_D}{\eta} \tag{4-1}$$

In the equation,

P_S: Number of parking spaces required per hour (parking supply).

P_D: Bus demand per attraction per hour.

η: Usable parking correction parameter.

Table 4-3 Parking demand and required number of parking spots for attractions

Attraction Number	Attraction Name	Bus Parking Demand (buses/h)	η	Number of parking spots required (Parking Spaces/h)
1	Beijing Dashilan District	27	0.9	30
2	Beijing Sihe Yuan	52	0.9	60
3	Dongdan Park	35	0.9	40
4	National Theatre	9	0.9	10
5	Tiananmen Square	35	0.9	40
6	National Museum	36	0.9	40
7	The Forbidden City	53	0.9	60
8	Jingshan Park	50	0.9	60
9	Beihai Park	34	0.9	40
10	Qianhai Lake	35	0.9	40

The parking supply eventually needs to be reflected in the setting of parking spaces. The relationship between parking supply, parking spaces and duration is shown in the equation (4-2).

$$n = P_S / \frac{60}{t} \tag{4-2}$$

In the equation,

n: The number of parking spaces in a parking spot.

P_S: Number of parking spaces required per hour (parking supply)

t: Average parking duration (min).

4.1.3 Current Temporary Parking Spots

The field study identified that at present there are 6 parking spots set in the center of Beijing and all the parking spots are on-street parking spots with and average parking duration of 300 seconds. Notice that 300 seconds is the average duration of parking, however, not all of the time is used to load and unload passengers. The longer duration is attributed to the fact that some buses choose to dwell at these locations for longer than necessary to reduce the time they need to park at off-street parking locations. The locations of the 6 parking spots are shown in Figure 4-4.

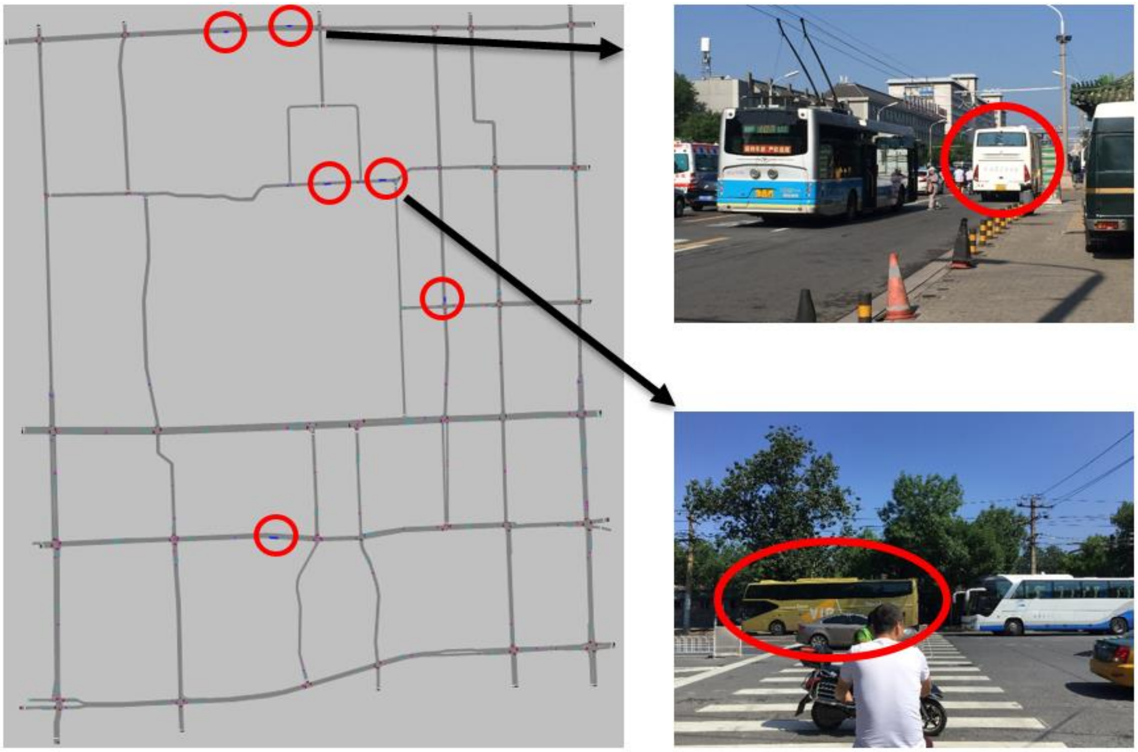


Figure 4-4 Current distribution of parking spots in Beijing downtown

By comparing Figure 4-3 and Figure 4-4, it can be seen that there are not parking spots near some attractions, like National Museum and Beijing Sihe Yuan. Hence, the current setting of temporary parking spots in downtown of Beijing does not meet the parking demand of tourist buses.

Field observations have shown that the current setting of the tourist bus parking spots leads to large delays on the general traffic, especially on the north-most street, which is too narrow to start with. Hence, the remainder of this thesis will attempt to replicate current conditions, and reduce the traffic delays by changing the bus parking spots' location, type, parking duration and parking length.

4.1.4 Assumptions

The simulation model of the total delay is based on the following assumptions:

(1) In the road network, the traffic vehicles are only composed of cars, public buses, and tourist buses.

(2) Cars with origin-destination information is known based on the study conducted by Beijing Transport Institute. Cars are free to change their routes within the network to avoid congestion.

(3) Tourist buses have fixed routes and fixed bus stops where they intend to drop off passengers or pick up passengers. If a tourist bust finds that the target parking spot is full, it will wait in line until an available parking space appears.

(4) Lane width is 3.50 meters.

(5) Urban (motorized) driver behavior is selected in the simulation [34].

(6) Simulation time is 3600 seconds per run.

(7) The number of runs is 20 [35].

(8) The free flow speed is 60 km/h for car and 40km/h for public bus and tourist bus.

(9) All vehicles run normally according to established rules and lanes [36].

(10) Pedestrians, non-motor vehicles are not considered in the simulation.

4.2 Bus Stop Relocation

To improve the setting of parking spots in a systematic matter, the simulation process includes three steps:

1) Determination of parking duration.
2) Determination of parking location.
3) Determination of type and size of parking spots.

The following sections will introduce these three steps.

4.2.1 Parking Duration

Section 2.3 has mentioned how to determine the parking duration for two types of parking spots. Based on field observations and *Beijing Parking Management Policy (2015)* as discussed in Section 2.3, the parking duration is specified as 120 seconds for on-street parking spots and 360 seconds for bay parking spots [37].

4.2.2 Location and Type for Parking Spots

The steps to determining the location and type of parking spots is done according to the following steps:

(1) Remove all existing parking spots

(2) Determine a zone of influence around each attraction as a circle with a 500-meter radius. Assume that within each zone of influence, there needs to be at least one parking spot per attraction it serves.

(3) Determine the number of parking spaces that should serve each attraction as a function of the parking supply shown in Table 4-3.

(4) Starting from attraction 1, for all feasible roadway locations within the zone of influence set-up different simulation tests with possible parking spot locations at 50-meter increments. Consider both on-street and bay parking spot at each considered location.

(5) Allocate tourist buses whose destination is attraction 1 to park in the parking spots determined in step 4. Assume that the remaining tourist buses operate at free flow speed within the network without parking. Calculate the total delays in the road network.

(6) Determine the combination of location and type of parking spot that minimizes the total network delay amongst all possibilities determined in step 4.

(7) Record the best setting of parking spots for attraction 1 and keep this setting for the next round of simulations. Change "attraction 1" to "attraction 2" in step 5, and repeat until all attractions are considered. The steps are described in more detail below.

<u>Step 1</u>

Remove all existing parking spots.

<u>Step 2</u>

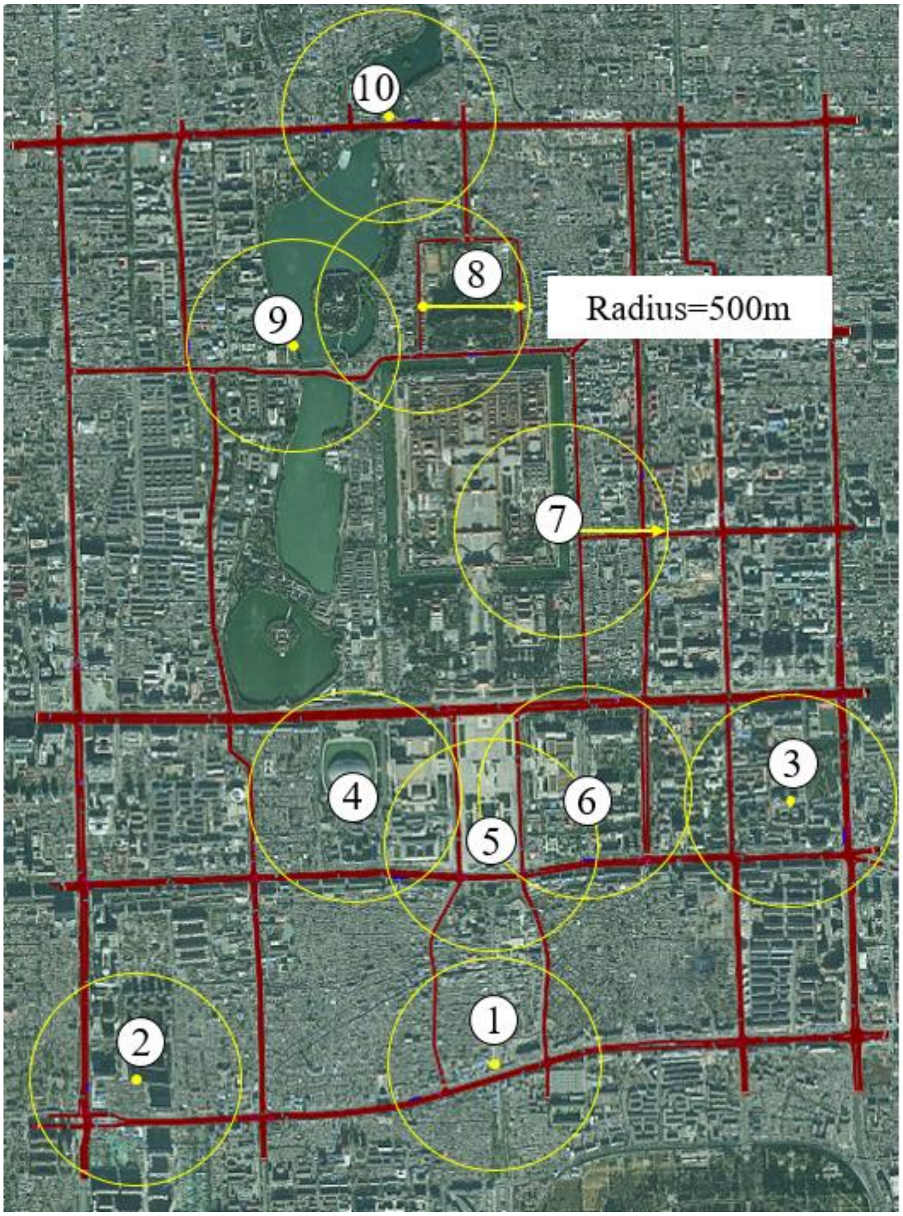


Figure 4-5 Zone of influence for each attraction

In the above described process, the radius of the zone of influence used in step 2 is based on the *Parking Design Code of China (2015)* [38]. The maximum distance from a parking spot to the entrance of an attraction is 500 meters. Therefore, in determining the parking area, the entrance of an attraction is used as the center and 500 meters as the radius to draw a circle. The area on both sides of all roads in the circle are possible locations for parking spots, as is shown in Figure 4-5.

Step 3

Considering attraction 1 as an example, the number of spots required to meet the tourist bus demand which is 30 buses/hour. Hence, given that the duration of parking is set to 120 seconds (2 minutes) for on-street bus stops and 300 seconds (5 minutes) for bus bays, using Equation 4-2 only one parking spot is required for on-street parking and three are required for bay parking spots.

Step 4

Again, take attraction 1, Beijing Dashilan District, as an illustrative example. First, all possible parking locations with 50-meter increments are determined within the zone of influence for attraction 1. This results in 60 optional locations for parking spots, as is shown in Figure 4-6. Either on-street parking or bay parking spots are placed at each location, resulting in 120 different cases.

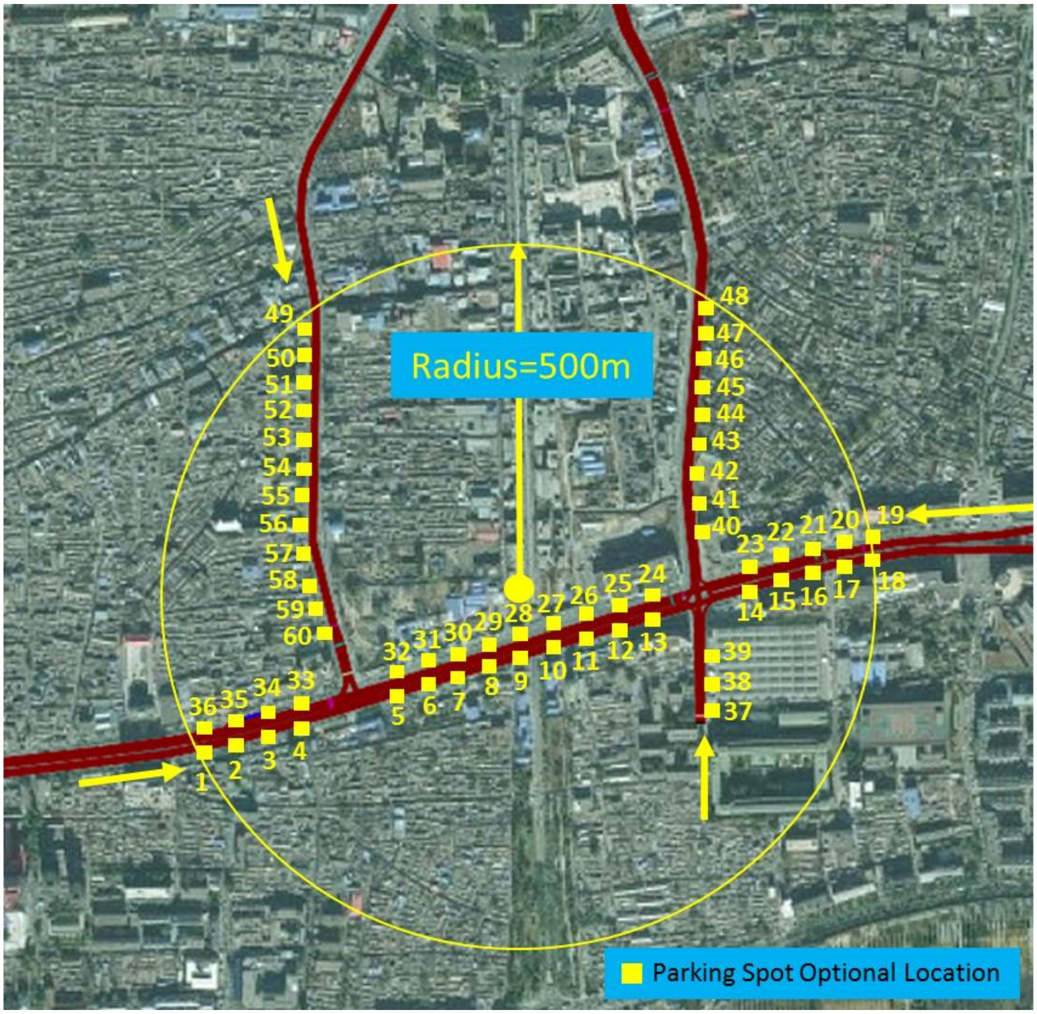


Figure 4-6 Optional locations of parking spots for attraction 1

<u>Step 5</u>

Using the input traffic and signal data, a simulation for every 120 cases is run. The total delays for all vehicles in each case are calculated and shown in Table 4-4.

Table 4-4 Simulation result for setting the parking spot of attraction 1

Optional Parking Location	Total Delay for all vehicles (hour) For bay parking spot	Total Delay for all vehicles (hour) For on-street parking spot
1	150.81	155.35
2	150.23	155.18
3	150.74	155.08

4	150.19	155.01
5	149.89	155.24
6	149.67	154.87
7	149.34	154.62
8	149.26	154.57
9	148.99	154.20
10	148.78	153.56
11	148.75	153.78
12	148.62	153.36
13	148.67	153.19
14	152.98	154.07
15	151.85	154.45
16	151.76	155.32
17	151.55	156.41
18	151.23	156.58
19	150.14	157.65
20	150.56	157.92
21	151.38	158.54
22	151.87	158.95
23	152.43	158.71
24	149.54	158.64
25	150.26	160.22
26	149.21	161.57
27	148.65	159.83
28	147.31	158.12
29	146.29	156.63
30	145.89	152.66
31	144.43	155.49
32	143.68	155.13
33	138.98	152.98
34	138.29	152.87
35	137.62	152.14
36	137.88	151.87
37	140.78	150.19
38	140.89	150.74
39	141.51	151.88
40	141.24	149.13
41	140.67	149.25
42	140.25	149.56
43	140.07	149.33
44	139.89	149.20
45	139.67	148.86
46	139.55	148.69

47	139.43	148.75
48	139.21	148.56
49	147.92	157.76
50	147.48	157.85
51	146.92	157.14
52	146.64	156.75
53	146.95	156.34
54	146.87	156.14
55	146.47	156.74
56	146.51	156.54
57	146.24	155.74
58	145.93	155.68
59	145.81	155.32
60	145.48	155.10

Step 6

From Table 4-4, we see that the lowest delay is 137.62 hours, which is observed when we set a bay parking spot at the location 35. However, a very small difference in delay is observed for setting a bus stop at locations 33, 34, 35 or 36. Actually, when considering the standard deviation of the delay for these 4 locations (shown in Table 4-5), one can observe that there is no statistical significance in delay among these locations. Therefore, we can conclude that the bus stop could be set at either 33,34,35, or 36 as depicted in Figure 4-6, i.e., a far side bus stop located in the southeast corner will minimize the delay.

Table 4-5 Standard deviation for the location 33, 34, 35 and 36

Optional Parking Location	33	34	35	36
Standard Deviation	1.282	1.145	0.922	1.057

Step 7

The bus stop location for attraction 1 is set at location 35 with a bay parking spot, keeping in mind that locations 33,34, and 36 will also result in similar delays. The setting of other parking spots will follow the same method. When two attractions have overlapping parking area, two parking spots may be considered to merge into one parking spot if the delay in the experiment is the lowest.

4.2.3 Length of Each Parking Space

Once the parking location and type are set, the length of each parking space is also determined. As mentioned in Section 2.4, the length of most tourist buses is between 10 and 11 meters. To find the most suitable length of parking space, we still take the experimental simulation, starting from 12 meters per parking space and adjusting the length by 0.5 meters to explore the impact on the total delay in road network. The experiment result is shown in Table 4-6.

Table 4-6 Experiment on the different length of each parking space

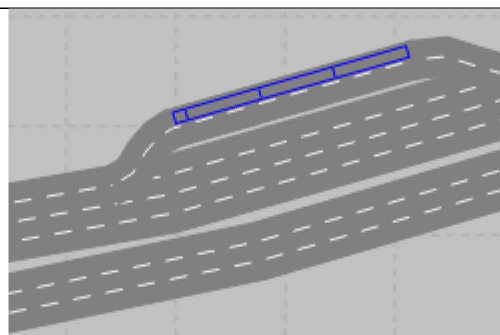
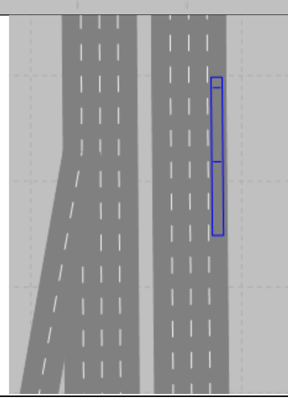
Length (m)	12	12.5	13	13.5	14	14.5	15
Total delays (h)	153.41	151.67	149.68	147.95	146.57	148.42	153.85
Standard Deviation	2.26	1.96	1.82	1.25	1.18	1.31	2.10

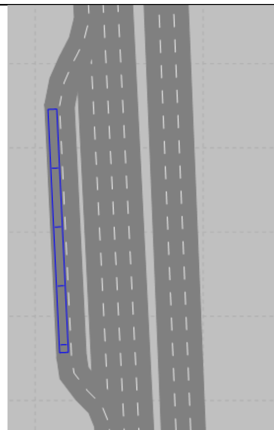
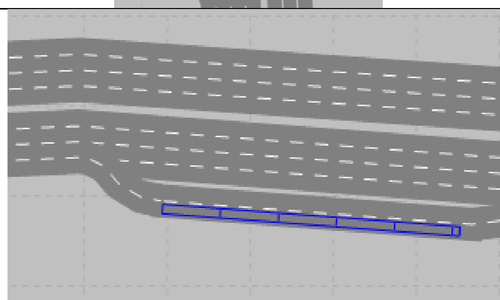
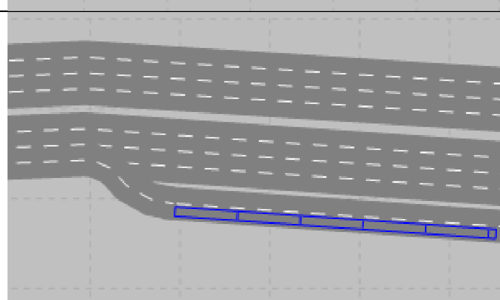
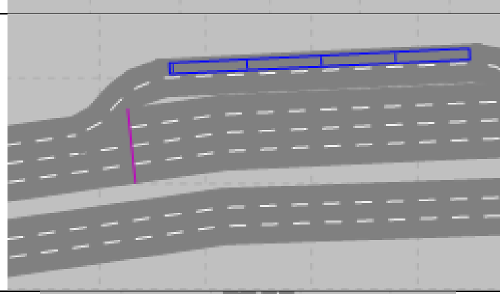
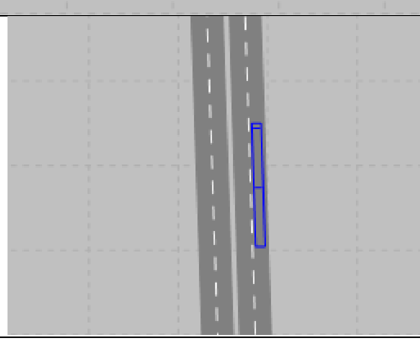
From Table 4-6, it can be seen that a parking space length of 14 meters result in the smallest delay, with 13.5 and 14.5 also providing similarly low delays. While a t-test reveals that the means of these two samples are statistically different with 99% confidence, practically they are not different. While for this thesis the length of the parking space is set to 14 (which provides the minimum delay), note that 13.5 to 14.5 meters would also be reasonable to use depending on the available space and road conditions.

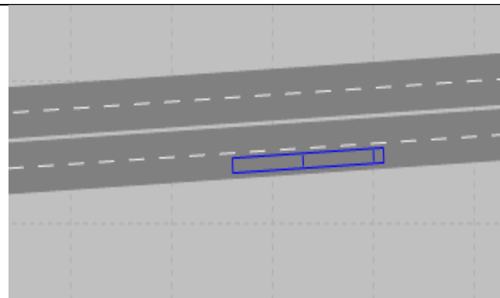
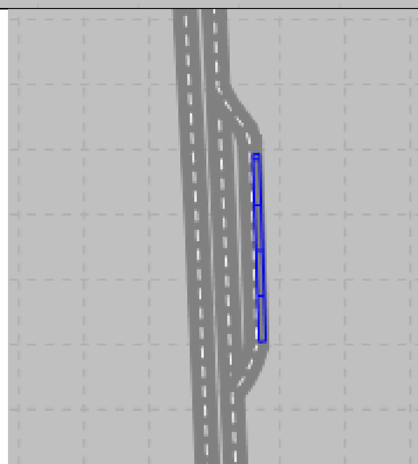
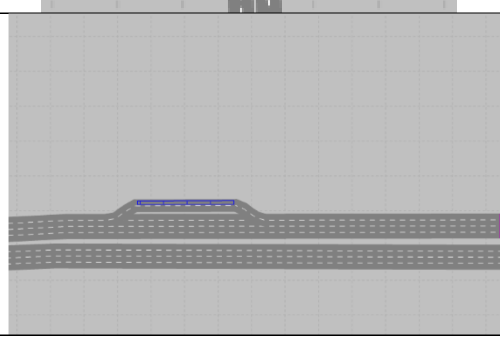
4.3 Simulation Result and Relocation Scheme

The above described procedure to relocate tourist bus parking spots to reduce car delays is conducted. Table 4-6 shows the location of each bus stop for each attraction considered in downtown Beijing after the relocation procedure.

Table 4-7 Location and type of parking spots for each attraction

Attraction Number	Parking spot	Location
1		Located on Zhushikou Street 116.6 meters west of Meishi street
2		Located on Xisi Street 80.947 meters north of Zhushikou street.

3		Located on Dongsi Street 108.424 meters north of Qianmen Street
4		Located on Qianmen street 647.154 meters east of Nanxinhua Street
5		Share the same parking spot with attraction 4
6		Located on Qianmen Street 281 meters east of Guangchang East Street
7		Located on Beiheyan Street 246.574 meters north of Jinbao street

8		Located on Jingshan front Street 236.249 meters east of Jingshan west street
9		Located on Xishiku Street 70 meters north of Jingshan front Street
10		Located on peace street 202.744 meters west of Dianmen street

The overall improvement in the network as a result of relocation is shown in Table 4-7.

Table 4-8 Simulation result before and after relocation

	Before relocation	After relocation
Total delays (h)	176.36	146.57
Total delays for cars (h)	153.78	125.73
Total delays for buses (h)	22.58	20.84

As can be seen, simply by improving the location and operation of the tourist bus stops (without changing the tourist demand), the total car delay in downtown Beijing can be decreased by 18.2% and the delay for buses can also be decreased by 7.7%. This also highlights the high impact of tourist buses on congestion in downtown of Beijing when a systematic approach to manage this mode efficiently is not used. The results show that significant improvements to congestion can be made with little investment in the infrastructure and regulation. Both cars and buses will benefit from this improvement and increased regulation.

Chapter 5 Contribution and Future Work

5.1 Contribution

The major challenge of this research is the large number of factors related to tourist bus parking spots that need to be considered. Therefore, it is difficult to consider all factors in the improvement process. For example, the influence by non-motor vehicles and pedestrians are not considered in this thesis. The location of parking spots considered is every 50 meters so many possibilities have also been overlooked. Therefore, the setting proposed may not be the optimal one, however, given the limitations of this work it was the best one that could be found.

However, this research provides a new solution to the parking problem of tourist buses in many developing countries. After all, there was little research and literature related to the problem of tourist bus parking. Significant contributions of the research are:

(1) The research provides qualitative and quantitative discussion on factors which are related to the setting of parking spots.

(2) The analysis of the above factors can provide references and guidelines for the related improvement work in different cities.

(3) Taking Beijing downtown as a case study, a step-by-step illustration of how improvements to the traffic flow can be provided by the relocation of parking spots for tourist buses is illustrated.

5.2 Recommendations for Future Work

There are still many imperfections in the research and these imperfections can be improved in future research.

(1) Including pedestrians and bicycles in the research. These two factors will influence the location of harbor parking spot.

(2) Considering the delay of pedestrians and buses due to the different location settings to obtain a system-wide result.

(3) Dynamic vehicle input can be considered in the related projects in the future.

(4) In the research, the potential locations are 50 meters away. The lower interval can be adopted in the future work.

(5) Future work can analyze this problem with different driving behaviors.

(6) This research is based on the data in the peak hour. Future work can focus on whether the setting will waste land resources during off-peak hours.

References

1. Gibson, J., & Baeza, I., & Willumsen, L. (1989). Bus-stops, congestion and congested bus-stops. *Traffic engineering & control, 30(6).*

2. Kraft, W. H., & Eng-Wong, P. (1977). Passenger service time characteristics of street transit systems. In *Compendium of Technical Papers, Institute of Transportation Engineers, 47th Annual Meeting, Mexico City, Mexico*.

3. Guenthner, Richard P. Sinha & Kumares C. (1983). Modeling bus delays due to passengers boarding and alighting. *Transportation Research Record*.

4. Dueker K.J., & Kimper T.J., & Strathman J.G. (2004). Determinants of bus dwell time. *Journal of Public Transportation.*

5. Fitzpatrick, K., & K. Hall, & D. Perkinson, & L. Nowlin, & R. Koppa. (1996). TCRP Report 19: 10 Guidelines for the Location and Design of Bus Stops. *Washington DC: TRB, National Research 11Council.*

6. Fitzpatrick, K., & R. Nowlin. (1997). Effects of bus stop design on suburban arterial operations. 20 *Transportation Research Record: Journal of the Transportation Research Board*, No. 1571, 21 1997, pp. 31-41.

7. Luthy, N., & Guler, S.I., & Menendez, M. (2016). System wide effects of bus stops: Bus bays vs. curbside bus stops. *Presented at the 95th Annual Meeting of the Transportation Research Board. Washington D.C.*, USA, 10-14 January.

8. Herbert S.L., & Scott R, Eric B. (2002). TCRP report 90: Bus rapid transit, volume2: implementation guidelines. *Transportation Research Board*.

9. Tan, J., & Li, Z., & Li, L., & Zhang, Y., & Lu, L. (2014). Berth assignment planning for

Multi-line bus stops. Journal of advanced transportation, 48(7), 750-765.

10. Gu, W., Cassidy, M. J., Gayah, V. V., & Ouyang, Y. (2013). Mitigating negative impacts of near-side bus stops on cars. *Transportation Research Part B: Methodological*, 47, 42-56.

11. Gayah, V. V., Ilgin Guler, S., & Gu, W. (2016). On the impact of obstructions on the capacity of nearby signalized intersections. *Transportmetrica B: Transport Dynamics*, 4(1), 48-67.

12. Furth, P., & SanClemente, J. (2006). Near side, far side, uphill, downhill: impact of bus stop location on bus delay. *Transportation Research Record: Journal of the Transportation Research Board*, (1971), 66-73.

13. Chunhua Shi, & Xiaoguang Yang, & Song Zeng. (2000). Setting and design of urban bus lanes. *Shanghai: Tongji University*.

14. Tian Chunchun. (2009). Research on Establishment Optimization of Conventional Bus Stop. *Central South University*.

15. Taiqun Feng. (2012). The impact of the bus stop section capacity analysis. *Chengdu: Southwest Jiaotong University*.

16. Jing yuan. (2013). Impact of Bus Terminus on Road Capacity. *Chengdu: Southwest Jiaotong University*.

17. Bilin Han. (2011). Analysis of Factors Influencing Bus Stops Delay and Reduction Strategy. *Beijing: Beijing Jiaotong University*.

18. Moore, J. (2006). Coach parking. *Parking News, Issued 249.*

19. Kuanmin Chen, & Baojie Yan. (2003). Road Capacity Analysis. *Beijing: People's Communications Press.*

20. Boyle, D. K. (2015). TCRP Synthesis 1: Better On-Street Bus Stops: A Synthesis of Transit Practice. *In, Transportation Research Board of the National Academies, Washington DC,* 2015.

21. Baorui Han, & Li Lin, & Xiao Fan. (2004). Investigation and Analysis of Vehicle Delay at Bus Stops. *Nanjing: Nanjing Forestry University*.

22. Hongwei Ge, & Wei Wang, & Xuewu Chen, & Zhenyu Mei. (2004). The Design and Adaptability of Urban Bus Stop. *Modern city research.*

23. Hongwei Ge. (2006). Study on Traffic Impact Analysis and Optimization Technology for Urban Bus Terminus. *Nanjing: Southeast University*.

24. Chen M, & Liu X. (2005). Analyzing passenger activity and its impact on bus dwell time and travel time using AVL/APC data. *Journal of the Transportation Research Forum, 44(3): 131-142.*

25. Jaiswal, & Bunker, & Ferreira. (2009). Modeling the relationships between passenger demand and bus delays at busway stations. *The 90th Transportation Research Board Annual Meeting.*

26. Xi Wang. (2007). Statistical Analysis of Delay in Urban Public Transportations and Countermeasures. *Xian: Changan University*.

27. Furth P.G., & Rahbee, A.B. (2000). Optimal bus stop spacing through dynamic programming and geographic modeling. *Dept. of Civil and Environmental, Northeastern University*.

28. Shuqi Yang. (2002). Road Traffic Data Book. *Beijing Construction Industry Press.*

29. Koshy, R. Z., & V. T. Arasan. (2005). Influence of bus stops on flow characteristics of mixed traffic. *Journal of Transportation Engineering*, Vol. 131, No. 8, 2005, pp. 640-643.

30. Yang, X., & Z. Gao, & B. Si, & L. Gao. (2011). Car capacity near bus stops with mixed traffic derived by additive-conflict-flows procedure. *Science China Technological Sciences*, Vol. 54, No. 3, 2011, pp. 733-740.

31. Yang Qiu. (2007). Research on Improving Bus Stopping Ability. *Wuhan: Huazhong University of Science and Technology.*

32. Hongwei Ma, & Gangyan Li. (2006). Analysis and Countermeasures of Time Delay in Urban Bus Stop. *Wuhan: Wuhan University of Technology.*

33. LisaRene Schilperoort, & Doug McClanahan, & Ray Shank, & Mike Bjordahl. (2014). Protocol for VISSIM Simulation. *Washington State Department of Transportation*.

34. Srivatsa Srinivas, S., & Gajanand, M. S. (2017). Vehicle routing problem and driver behavior: a review and framework for analysis. *Transport Reviews*, *37*(5), 590-611.

35. Bohang Liu, & Tong Zhang, & Guijiang An. (2012). Traffic simulation experiment tutorial. *Beijing: People's Communications Press.*

36. Zhijun Zou. (2000). Urban Road Simulation Research. *Shanghai: Tongji University*.

37. Department of Transportation. (2015). Beijing Parking Management Policy. *Beijing People's Government.*

38. Department of Transportation. (2015). Parking Design Code. *Beijing People's Government.*