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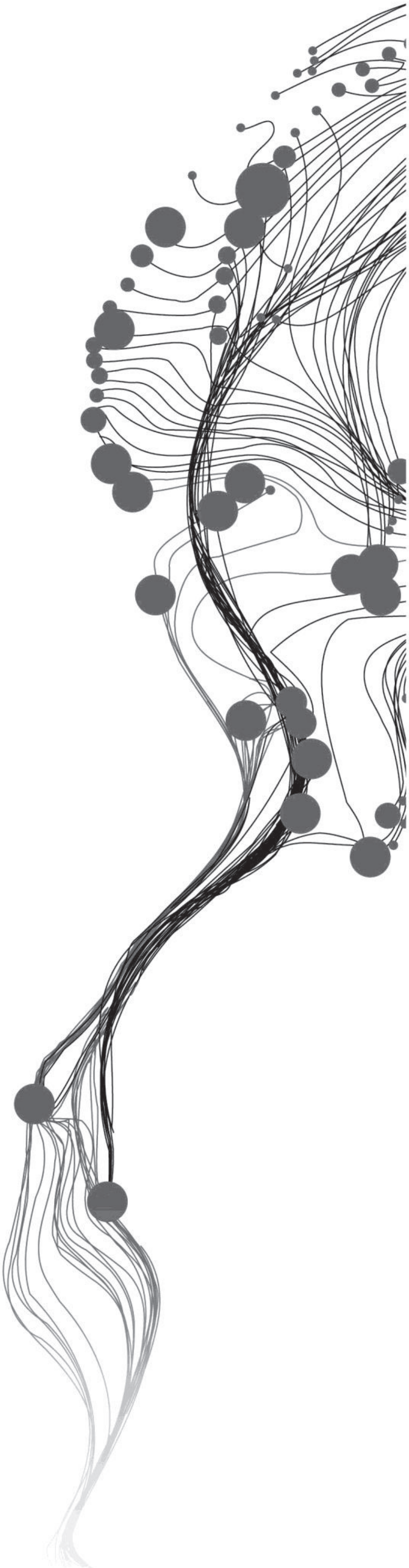

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# ABSTRACT

With the economic development all over the world, there is an increasing usage of automobiles, which has resulted in a series of urban and transport problems, such as global warming, air pollution and traffic congestion. Therefore, many countries have taken actions to improve these problems by encouraging the use of public transportation and green transport. In recent years, bike sharing system has become a mode of green transport, which has been adopting all over the world, to be used as a single transport or integrated with other public transport system.

This paper seeks to evaluate performance of bike sharing system in Wuchang district of Wuhan, in China, based on the existing problems of this bike sharing system. And method on the combination of GIS and multi criteria evaluation (MCE) was adopted to evaluate this system, by building a series of indicators which was assumed that would influence the performance of bike sharing system.

In this study, the research on bike sharing system mainly focused on bike users, bike stations, and bike lanes. Furthermore, the efficient "performance" of bike sharing system was defined as operation efficiency and spatial effectiveness of bike sharing system in this research.

The operation efficiency of bike sharing system aimed at understanding the characteristics of bike users, and evaluating the conditions of bike lanes from the perspective of bike users. Through the survey on bike users and investigation of bike lanes, a series of the characteristics of bike users and conditions of bike lanes were understood. While the spatial effectiveness of bike sharing system aimed at analyzing the characteristics of bike stations, and accessibility between bike stations and other facilities (e.g. bus stops/subway stations, residential communities, colleges..). According to the analysis on these two aspects, to find out whether the performance of bike sharing system is efficient, and to further improve the performance of bike stations in optimization model.

According to the results of performance evaluation of bike sharing system, a straightforward method on spatial analysis, which is based on the distribution of bus stops and population, was adopted to optimize the spatial location of bike stations, this aimed at improving the interconnection between bike stations and bus stops or residential community.



**Keywords:**
Bike sharing system, Performance, Evaluation, GIS, Bike stations, Bike users

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# 1. INTRODUCTION

With strong economic development all over the world, there is an increasing use of automobiles, which has resulted in global warming, air pollution, and traffic congestion. Consequently, many countries are trying to take action to attract more and more people to use public transport in order to improve these problems, but the accessibility has been a key determinant that hampers people to choose public transportation as their traffic mode. However, bicycle was designed with the goal of achieving more efficient transportation, and it is also a cheaper and green transport mode compared with other modes in developed countries and developing countries. So there is a trend to combine bicycle with public transportation to attract more customers, to relieve the traffic pressure and to promote green transport and sustainable development of transport.

## 1.1 Background and Justification

### 1.1.1 Current status of transport development in China

With the rapid development of the economy, urbanization and motorization in China during the past decades, there is an increase in the number of registered private automobiles (Wei 2010). Since 1978, the urban population has grown from 80 million to more than 560 million, an annual growth rate of 7.5% (Lin 2002). Vehicle ownership has increased at more than twice this rate (Cervero et al. 2008). From 2000 to 2003, China's roads absorbed nearly 14 million additional vehicles, namely an average of almost 13,000 new cars and trucks per day (Appleyard et al. 2007). According to Feng et al. (2009), studies show that pollutants resulting from vehicle emission contribute about 60% of the total urban air pollution in China. Next to air pollution, the urban transport system is also confronting significant challenges in traffic congestion and energy shortage.

To address these issues, promoting the wide use of public transport can be an effective and efficient solution. Many Chinese cities have made policies and increased the investment to promote public transport development. However, public transport development still lags behind (Li et al. 2010). According to Qiu(2010), public bus trip only accounts for 10% to 25% of the total residential travel trips in China. According to Li et al.(2010), public bus travel a shorter distance but take a longer time, especially waiting time and walking time which account for 36% of the total travel time. And sometimes single-model public transport has a weak accessibility, so customers would prefer to choose private car or taxi as traffic mode. In order to promote the public transport development, one of the determinants is to improve the accessibility. In recent years, many experts think of that it is rational and necessary to establish an integrated urban transport system, and come up with the idea of "green transport", for example, establishing bicycle renting system to induce the public to take public transport.

### 1.1.2 Bicycle sharing system in China

Cycling is high efficiency, environment friendly, healthy, low pollution, and could help to reduce congestion, parking needs and energy use; it is regarded as the bright future of the transportation system in our future cities. In 1980s, China was named "the kingdom of bicycles", though the number of bicycle users has decreased, cycling was and still is one of commuting modes in most Chinese cities (ITDP-China 2010; Tang et al. 2010).

Because of the increase in traffic and urban problems which have been mentioned earlier, bicycle sharing systems have been introduced to some Chinese cities to encourage the use of bicycles which are used as a separate transport or integrated with other public transports, and to facilitate green transportation. For example, in 2005, China's first bike sharing system began operating in Beijing. Within the concern to encourage green transportation, more and more Chinese cities show their interest to build their own bike sharing systems (*Figure 1-1*). So far, there are more than ten cities and city areas that have established bike sharing system (ITDP-China 2010; Tang et al. 2010) (*Figure 1-2*).

| | Start time | Number of Rental Locations | Number of Bicycles | Rent Times each bike per day |
|---|---|---|---|---|
| Shanghai(Pudong) | Sep-2008** | 80** | 1200** | 2.5** |
| Shanghai(Minghang) | Mar-2009** | 170** | 6000** | 5.5** |
| Beijing | Aug-2005** | 1000** | 10000** | 2.32** |
| Hangzhou | May-2008** | 800(Jun/2009)** | 20000** | 5~6** |
| Nanchang | Aug-2009 | 30 | 1000 | 4 |
| Wuhan | Apr-2009 | 718 | 20000 | 5 |
| Wuhan(Qinshan) | Nov-2008 | 66 | 3000 | |
| Guangzhou (concept stops) | Aug-2009 | 2 | 100 | |
| Dujiangyan | Apr-2010 | 52 | 500 | |

Source: **from the operator's website or their reports, the other Chinese cities' data from http://www.chinabikesharing.org/

*Figure 1-1 Overview of Chinese cities' bike sharing system*

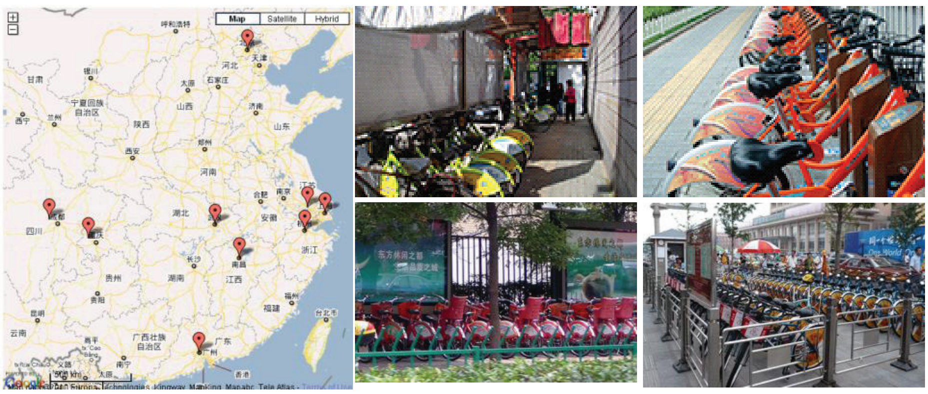


*Figure 1-2 Bicycle-Sharing System in China*

*(Source: http://www.chinabikesharing.org/)*

#### 1.1.3 Importance of developing a bicycle system integrated with public bus

Accessibility has been a key determinant related to transport choice. In general, single-model public transport sometimes have no capability to satisfy customers' demand that travel from one place to another place (Grotenhuis et al. 2007), in this case, customers would choose private car or taxi as their mode to avoid the weak accessibility of public transport. However, using bicycle as an access or egress trips can substantially reduce the door-to-door travel time of public transport trips (Martens 2007). Austroads(2005)also proposed that the interaction of bicycles and buses is more frequently seen to expand the catchments for public transport, when the bicycle is as a feeder mode.

Over the past decades, in many industrialized countries, the combination of public transport and bicycle has been a method to solve a key shortcoming of public transport (Martens 2007), namely the accessibility of public transport. As a feeder mode, the bicycle is considerably faster than walking, and more flexible than public bus or other public transports due to its "continuous character" (that is no travel time gap) which can eliminate the waiting time and scheduling cost (Keijer et al. 2000). And it offers a number of environmental and social benefits, including reduction in energy use, air and noise pollution, as well as lower congestion levels and access routes to bus stops. Last but not least, the combined use of bus and bike may promote the car free lifestyle, which can improve the development of the green mode of transport.

## 1.2 Research Problems

The study area is Wuhan, which is a metropolis in the central area of China and characterized by high population density and large urban scale. Although the public bus service is the major transit mode in Wuhan, the residents are still suffering traffic congestion, air pollution, and low quality of public transport service.

In order to relieve the transport problems, a bike sharing system was launched in 2009. This bike sharing system is built by Wuhan Transport Planning Institute in cooperation with Xinfeida Bicycle Company, 718 bike rental stations with 20,000 bicycles in eight districts (except Qinshan district) have been built up since 2009; and these bike rental stations are interconnected with bus stops, residential communities, large commercial area, colleges, and subway stations. Moreover, Wuhan Transport Planning Institute and Xinfeida Bike Company have taken some actions to extend the scale of bike sharing system.

Since the start of bike sharing system, this is always popular with inhabitants. However, there still exist some problems in the operation of bike sharing system. This is a new and first bike sharing system in Wuhan, and is still under construction, therefore this research mainly focus on evaluating bike sharing system based on the probably existing problems of bike sharing system from bike users' perspective in the reality.

### 1.2.1 Unbalanced supply and demand of bicycle sharing station

Supply and demand can be one of the important determinants that influence the quality of a bicycle sharing system. A balanced supply and demand can not only enhance utilization of bicycles, but also promote the development of the bicycle sharing system. According to Tang et al. (2010), unbalanced volumes will bring about a redistribution problem, which will cost a big amount of money and become the largest problem of the bike sharing system, especially in the peak hours when it is hard to find a bike in the hot spots and it is no room to return bikes. In this case, it definitely reduces the recycle use of bikes and decreases the quality of bicycle sharing system.

### 1.2.2 Irrational distribution of bicycle stations

Accessibility is an advantage of bike sharing system, and is deeply impacted by the distribution of bike rental stations. MacIntyre (2006) proposed that NMT users are sensitive to travel distance. With respect to the performance of the bike sharing system, which as an access or egress trips in the integrated public transport system, are impacted by the efficiency of transport network. According to Zuidgeest et al. (2009), the distribution of bicycle stations influences the efficiency of the bus-bike integrated system, when the access distance is short it is unlikely that users bike instead of walk to the facilitated bus stop, however , when the access distance is longer than a threshold it is likely that people choose another access mode instead of a bike. In order to enhance the accessibility and utilization of the bicycle system, a rational and efficient distribution of bike rental stations should be well integrated with bus stops and residents, that is to say, it has a suitable travel distance and travel time that contribute to a trip.

#### 1.2.3 Insufficient method for performance evaluation

In China, local public transport plans are made based on policies that are made by MOHURD (Ministry of Housing and Urban-Rural Development of the People's Republic of China ) cited by Wei (2010), which regulate the public bus system that including route length, route density, average transfer coefficient and net transit capacity. In the conventional planning, planners plan and design transport network just based on policies and qualitative analysis, but scarcely adopt quantitative methods and technical skills to analyze traffic demand and service coverage, which also results in traffic congestion and unbalanced demand and supply in real situation of transport.

In Wuhan, the distribution of bike rental stations are just based on the investigation of different institutes, which tended to distribute stations around bus stops, residential communities, large-scale commercial districts, colleges, metro stations (XFD 2010). There is no scientific analysis of traffic demand and coverage of bike rental stations based on GIS techniques. So, in the implementation of bicycle sharing system, there are existing problems of irrational distribution and insufficient capacity of bike rental stations. It is sensible to apply GIS techniques in the evaluation and optimization of bike sharing system, instead of single qualitative analysis.

Thus, this study mainly focuses on evaluating the performance of bike sharing system, based on a series of qualitative and quantitative methods and indicators, for example, the characteristics of bike stations, and the accessibility of bike stations. In addition, GIS techniques will be applied in the evaluation and optimization process.

### 1.3 Research Objectives and Questions

#### 1.3.1 Research Objectives

**Main objective:**

- To evaluate whether the performance of bicycle sharing system in Wuhan is efficient.

**Sub-objectives:**

- To understand the characteristics of bicycle users;
- To select and perform indicators for the evaluation of bike lane;
- To analyze characteristics of bike stations;
- To analyze accessibility between bike stations and other facilities;
- To establish and implement a model for spatial location optimization;

### 1.4 Research questions

- To understand the characteristics of bicycle users;

**Q1: what elements will be set as "characteristics" of bike users?**

- To analyze characteristics of bike stations;

**Q2: How to define and perform "characteristics" of bike stations for analysis?**

- To analyze accessibility between bike stations and other facilities;

**Q3: What method will be implemented for accessibility analysis?**

- To select and perform indicators for the evaluation of bike lane;

**Q4: what criterions can be set for evaluation?**

- To establish and implement a model for spatial location optimization;

**Q5: Which model will be set for spatial location optimization?**

### 1.4.1 Conceptual Framework

The benefit of a bicycle system is that it can offer door-to-door service, so the combined bus-bike system can enhance the accessibility of public transportation trips. However, the efficiency of bike sharing system' performance substantially determines the value of bike sharing system. In this research, the efficiency of bike sharing system's performance is defined as operational efficiency and spatial effectiveness of bike sharing system, and this will be introduced in more detail in section4.2.1. Therefore, the performance evaluation of bike sharing system will be operated from three aspects: first, to analyze the characteristics of bike stations; second, to analyze the level of accessibility between bike stations and other facilities including bus stops/subway stations, residential communities, colleges, and business area; third, to analyze bike lane network in study area. This research seeks to detect the performance of bike sharing system and improve the integration of public bus and bike sharing system. (*Figure 1-3*)

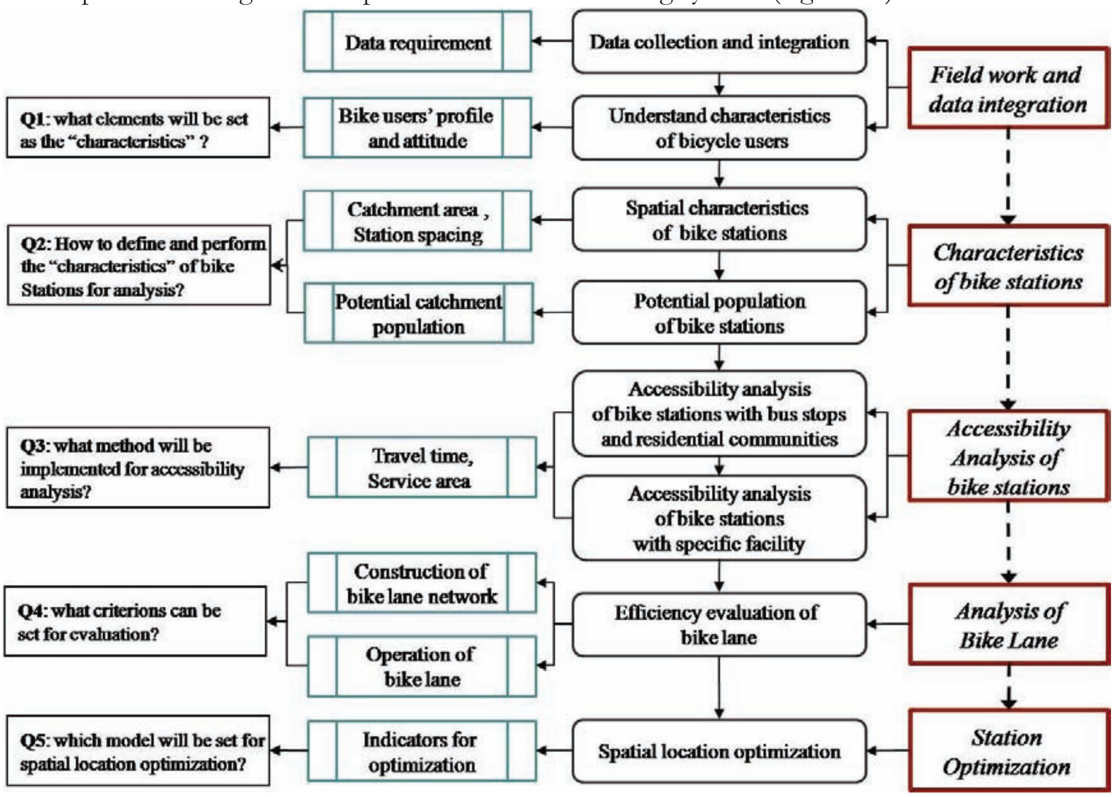



*Figure 1-3 Conceptual Framework*

## 1.5 Research Design and Methods

The main purpose of this study is to evaluate the efficiency of bicycle sharing system based on spatial analysis, which uses the bicycle sharing system in Wuchang district of Wuhan as a case study and optimize bike stations with poor efficiency. *Figure 1-4* outlines the methods proposed for answering specific questions under each of the sub-objectives identified in Section 1.3.1. *Figure 1-5* outlines the operational plan under which the whole study will take place. It incorporates five stages, including field work and data integration (stage1), analysis of characteristic of bike stations (stage2), accessibility analysis of bike stations (stage3), evaluation of bike lane (stage4), station optimization (stage5).

- **Understanding the characteristics of bicycle users**

Understanding characteristics of bicycle users aims to investigate bike users' profile and attitudes to bike sharing system, and this can be related to location and capacity of bicycle rental stations. With respect to the investigation of bike users' profile, it can be including travel mode and destinations of bike users, required time and cost of bike users, and so on. If there is no available data about the characteristics of bike users, it is necessary to do a survey in a small-scale area.

- **Analysis of the characteristics of bike stations**

The characteristics of bike stations incorporate two parts: spatial characteristic of bike stations, and non-spatial characteristic of bike stations. With respect to the spatial characteristic of bike stations, catchment area of bike stations in a certain time, and station spacing between bike stations will be analyzed. And for analyzing the non-spatial characteristic of bike stations, potential catchment population of bike stations will be calculated. Both of these indicators can reflect the characteristics of bike stations. After analysis, catchment area, station spacing and catchment population of bike stations can be obtained, which can be useful and necessary for the further analysis.

- **Accessibility analysis of bike stations**

In this stage, accessibility analysis is divided into two parts which are accessibility analysis between bike stations and specific facilities, and accessibility analysis between bike stations and bus stops or residential communities. Indicators which influence accessibility and methods for accessibility analysis can be derived from literature review. After accessibility analysis, bike stations with weak accessibility can be obtained.

- **Performance evaluation of bike lane**

The performance evaluation of bike lane aims to evaluate whether the performance of bike lane is efficient, which can be an important determinant that influence the performance of bike sharing system. And the performance of bike lane will include two aspects: the construction of bike lane network, and the operation of bike lane. Through analyzing the two aspects of bike lane, find out whether the bike lane is efficient and whether there is weak point of bike lane.

- **Station optimization**

Indicators and constraints for optimizing spatial locations of bike stations can be obtained from literature review. Data that used for station optimization can be prepared in the previous work. Selected station with poor performance will be upgraded related to characteristics and accessibility analysis of bike stations. A useful method for spatial location optimization will be selected and implemented.

| Research Question | Research Method | Data Required | Source | Stage in Conceptual Framework |
|---|---|---|---|---|
| Q1: what elements should be taken into consideration? | Literature review, survey in small-scale area | Literature | Field work | **FD** CB AA BL SO |
| Q2: How to define and perform the "characteristics" of bike stations for analysis? | Literature review, Catchment area analysis, Travel distance analysis, Catchment population | Bike station location, Census data, Network data | Basic data, Updated data | FD **CB** AA BL SO |
| Q3: what method will be implemented for accessibility analysis? | Literature review, Indicators and data analysis | Bike station location, Facility location, Bus stop, Network data | Existing data | FD CB **AA** BL SO |
| Q4: what criterions can be set for evaluation? | Literature review, Investigation of bike lane, Indicators analysis | Network data | Existing data | FD CB AA **BL** SO |
| Q5: which model will be set for spatial location optimization? | Literature review, Data analysis | Bike station , Bus stop, Community data, Net work data | Existing data | FD CB AA BL **SO** |

*Note: FD: Field work and Data analysis; CB: Characteristic of bike stations; AA: Accessibility Analysis; BL: Evaluation of bike lane; SO: Station Optimization.

*Figure 1-4 Research Method*

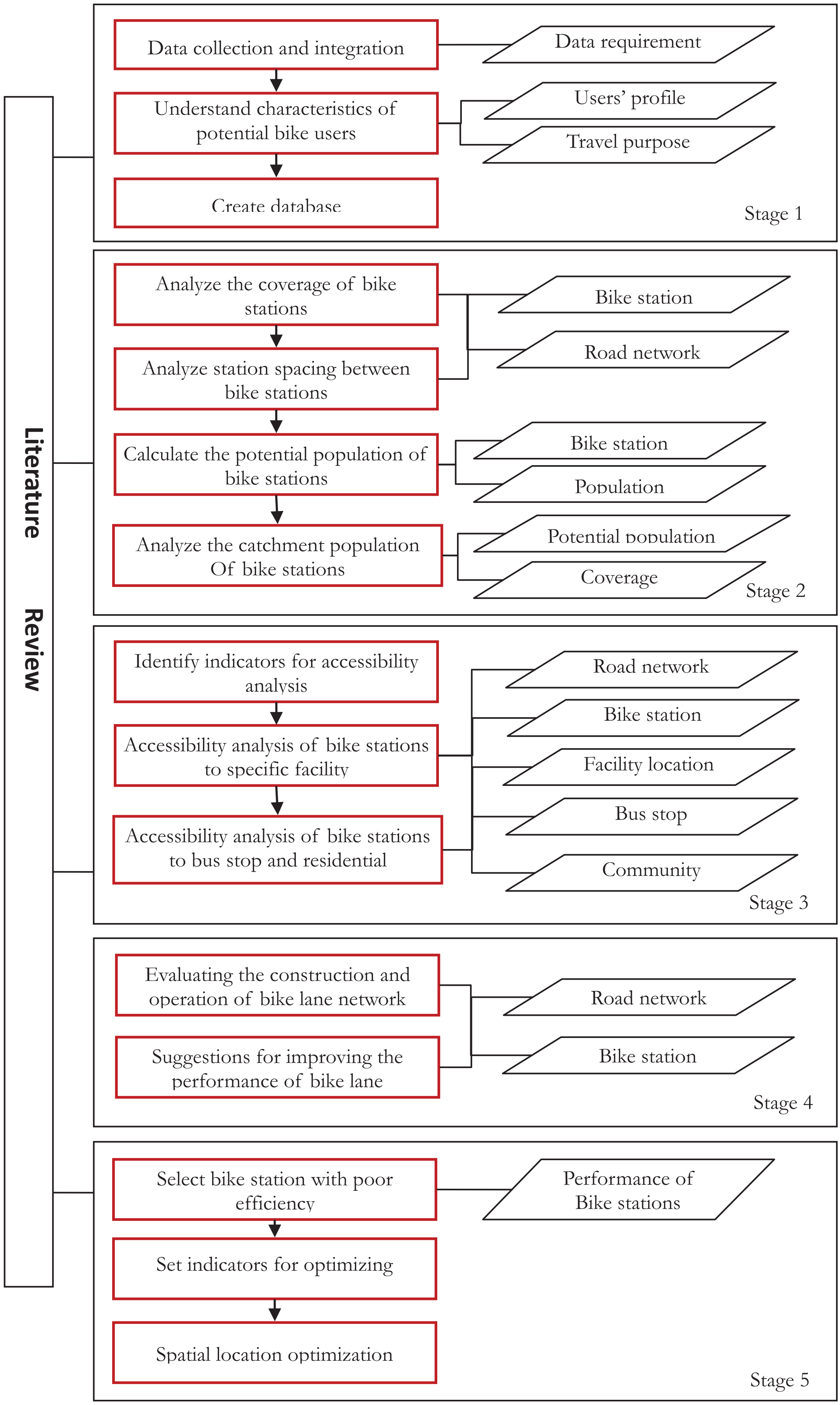



*Figure 1-5 Research Design*

# 2. LITERATURE REVIEW

## 2.1 The development of bicycle sharing system

Bike sharing systems have been appearing in more and more cities around the world in the last few years, which have received increasing attention in recent years with initiatives to increase bike usage and improve the last mile connection to other modes of transit and lessen the environmental impacts of our transport activities(DeMaio 2009). According to The Bike-sharing Blog(2009), based on an unscientific count of the bike sharing services listed on the bike-sharing world map, there was approximately 160 bike sharing systems globally at the end of 2009, which is up nearly 74% from 92 bike sharing systems at the end of 2008. Bike renting systems contain a large fleet distributed at high and medium density areas, and usually allow for one way trips and sometimes provide short-term access(PBOT 2010).Bicycles from a bike renting station are typically available in cities with other forms of public transportation to provide for intermodal transportation options for the public(UtilityCycling 2008). Users check out a bike by using credit card, membership card, or cell phone at a docking station.

As the development of better methods of tracking bikes with improved technology, this give birth to the rapid expansion of bicycle renting systems throughout the Europe and most other continents during the recent decades(DeMaio 2009).

According to Bührmann(2008), public bicycle systems are not only for free, but have a high added value in the long run if properly implemented. They can help to come to a real "bicycle culture" and to change people's travel behavior.

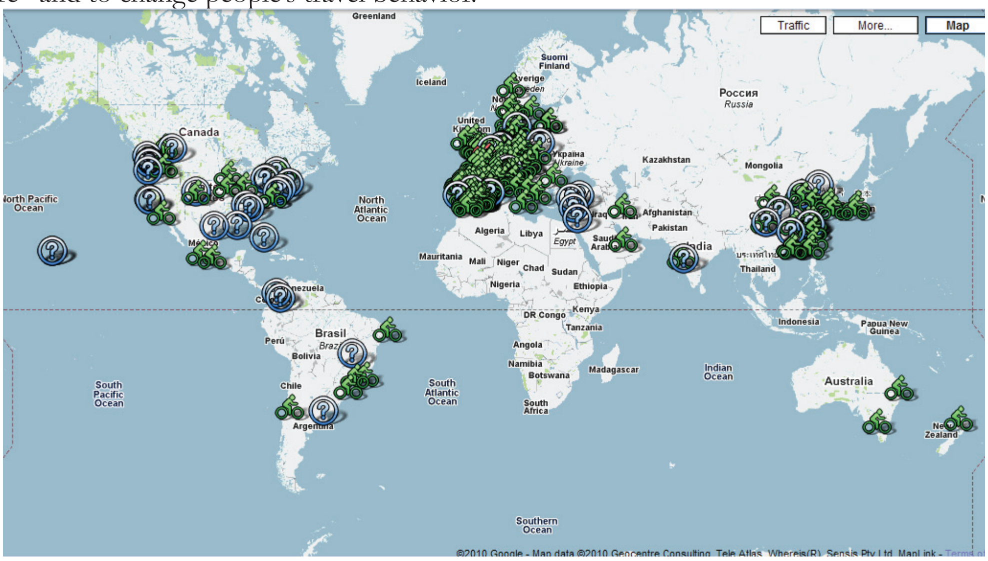



*Figure 2-1 Worldwide Distribution of Bike Sharing system*

### 2.1.1 The development of bicycle sharing system in European Countries

#### 2.1.1.1 History of European bike sharing system

Bike sharing system originated in Europe(UtilityCycling 2008).According to DeMaio(2008), there have been three generations of bike renting system during the past 40 years. The 1st generation began in 1964 in Amsterdam with the white bikes. The operators gathered a handful of bicycles, which they painted white and distributed around the city Amsterdam for providing bikes to public for free(UtilityCycling 2008). But things didn't go as planned, due to the bikes were thrown into canals or appropriate for private use, so this system collapsed within days(DeMaio 2008).while a strong memory or urban legend still lingers around the idea of the white bicycle in Amsterdam(UtilityCycling 2008).

Nearly 30 years later, in 1995, the 2nd generation was operated in Copenhagen called Bycyklen, with many improvements over the previous generation. That bike sharing system were specially designed, users could pick up and return bikes at specific locations throughout the central city areas with a coin deposit. While more formalized than the previous generation-with stations and organization to operate the program – these bikes still experienced theft due to the anonymity of the customer(DeMaio 2008).

The 3rd generation system is smartened with a variety of technological improvements including electronically locking rack or bike locks, telecommunication systems, smartcards, mobile phone access and on-board computers. Bike sharing system grew slowly in the following years until the launch of Velo'v in Lyon, France(DeMaio 2008).

In the past years, many cities in European countries have been successful in the project of bicycle renting system. According to PBOT(2010), the Velib system in Paris is generally considered successful. In two years, Velib's 20,000 bicycles generated over 54 million trips. On average, Parisians and its visitors generate 74,000 bike sharing trips a day. The Velo'v program in Lyon is arguably more successful with an average of 22,000 trips on a 3,000 bike fleet – or roughly seven trips per bike per day. And Barcelona's Bicing project planners projected to gain 2,000 bikes sharing member per month. After just four months, 82,000 people had joined (source: Clear Channel Outdoor). Barcelona has doubled the size of its program to 6000 bikes(PBOT 2010).

In recent years, Europe has been a real boom of public bicycle schemes, which make the bicycle accessible as part of the public transport system. The number of cities that already implemented or plan to do so, increased strongly. And the scale of the systems has also reached new heights. Beyond Europe, the interest in the concept of public bicycles is also rising, e.g. in the US, in Canada, Australia, Argentina, or Israel.(Bührmann 2008)

#### 2.1.1.2 European approaches to bike sharing system planning

The bicycle sharing system in European cities has already been mature in some aspects, compared to the system in Chinese cities. According to WANG et al.(2009), most of the European bike sharing system are public-private-partnership, and the users are required to register it by paying membership fee and members can use the bicycles free of charge within half an hour. And many modern techniques are applied in the 3rd generation of European bike sharing system, for example, network techniques, and wireless communication techniques etc.

With respect to the bike sharing system in some of the European cities, the bike users can obtain the data from the operator' websites and observe the dynamic change of capacity in each bike station over 48 hours on operator' websites, which are all in JavaScript *(Figure 2-2)*. To a large extent, this is great convenient for the users(Oliver 2010).


*Figure 2-2 Animation of bike sharing system*

The planner of bike sharing system in London also developed a visible technique – BikeGrid which is a very sophisticated and data-rich visualization that provides a detailed overview of the actual performance of the Barclay Cycle Hire scheme. It shows the real-time and historical availability of the "Boris bikes", which are located in over 300 docking stations spread around central London. On this dynamic websites, the initial map view shows all docking stations are rectangles, sized by the capacity of the station. Darker stations are full, while lighter stations are empty. A unique "grid view" reveals the status of each docking station more clearly: the proportion of bikes at each station is indicated by the height of the blue bar. Very full or very empty stations are shown with a lighter or darker border respectively. In addition, the actual status of each bike station over the last 24 hours can be seen as a line graph, highlighting the urban dynamics of bikes going in and out the city centre over a time span of a typical day(Barclays 2010).

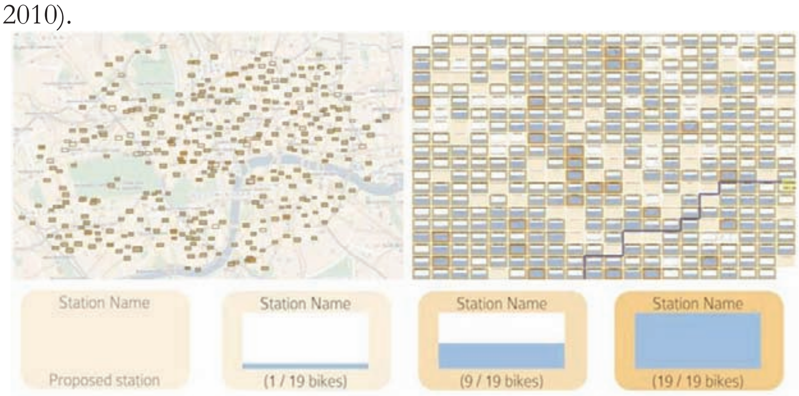



*Figure 2-3 BikeGrid (London)*

#### 2.1.2 The development of bicycle sharing system in China

##### 2.1.2.1 Overview of Chinese bike sharing system

Bicycle sharing system has also become popular in China, which is a number of bicycles made available for shared use amongst individuals who do not own the bicycles(Schroeder 2010; WIKIPEDIA 2010). According to ITDP-China cited by Schroeder (2010), over 60% of people use public bike because it is more efficient than the transport they used earlier.

In China, the first bike sharing system was launched in Beijing in 2005, it was not a big system compared with such a big city and without governmental involvement. And there was no digital information technology used in this system(ITDP-China 2010; Tang et al. 2010). In addition, there are other cities also show there interest in building bike sharing system, such as Shanghai, Hangzhou, Guangzhou, Wuhan, and so on; moreover, the bike sharing system in some of these cities are working well(*Figure 2-4*).


*Figure 2-4 Bike Sharing System in Chinese cities*

Bike sharing system was started in Hangzhou in May 2008, which is operated by Hangzhou Public Transport Bicycle Service Development Co; and 2,204 bike rental stations with 50,000 bikes are built. Moreover, some bike stations are open for 24 hours, and citizens can use bikes in one hour without charge. Hangzhou bike sharing system has been the most successful scheme in China, where the bike rental stations can be found every 100 meters, compared to the 300 meters in Paris. And during the first year operation, no bikes were stolen and few bikes were broken or vandalized compared to the half of that were stolen or broken in Paris(ITDP-China 2010; WIKIPEDIA 2010).


*Figure 2-5 Bike Sharing System in Hangzhou*

In order to cater for the 2010 WorldExpo, Shanghai has also launched a bike sharing program in March 2009, which is operated by Shanghai Forever Bicycle Company. And bike rental stations are open for 24 hours. This bike sharing system can be accessible by RFID cards. Users can purchase 100 ride credits for about 30 dollars. Short rides are rewarded credits and longer rides subtract credits once the bike has been re-docked. Shanghai plans to expand to 3,500 bicycle hot spots throughout the entire city by 2010(ITDP-China 2010; WIKIPEDIA 2010).

Guangzhou launched the bike sharing system in June 22nd 2010, which is initiated by Guangzhou government and operated by Guangzhou Public Bicycle Operation and Co., and ITDP (Institute for Transportation and Development Policy) was asked to provide assistance with issues such as station distribution, hardware technical support and operational recommendations. This bike sharing project contains 3 phases, providing 15,000 bicycles, to along BRT corridor and nearby living and business area, and to set stations around bus stops and in Jinshazhou and Daxuecheng. The bike sharing project adapt automatic charging system by using Yangchengtong IC card (can also be used on metro and bus) or a Public Bicycle Service card to activate either manual or self service, and citizens can use public bike free of charge within one hour. Since the first day of starting, the public bike project has been welcome by the citizens and media. In only 2 months, the number of rental per day has reached 5000 and keeps growing(Warrier 2010).

In addition, Wuhan is the first city that launches a free public bike sharing system in China since 2009. Till now, more and more Chinese cities start to build a public bike sharing system, such as Shenzhen, Suzhou, Chengdu, and so on. The bike sharing system has been widely spreading to more and more Chinese cities.

#### 2.1.2.2 The profile of Chinese bike sharing system

According to Schroeder(2010), the evidence derived from bike sharing system in Beijing, Shanghai and Hangzhou shows that public bike is public transit, of which vast majority trips are commuter and utilitarian trips. And public bike also improves the usage of other public transports, when it is combined with other public transports. Furthermore, public bike is faster than bus or rail for short trips and flexible route, and runs 24 hours in some Chinese cities.

- ***Technology system***

In China, there are differences in technology system of bicycle sharing system in different cities. That is to say, there are high technology system and low technology system. For the bike sharing system which is of high technology, it needs higher initial capital costs and lower maintenance cost, but it is easier to integrate with other transports (e.g. bus, metro, car paring). While in relation to the bike sharing system which is of low technology, it needs lower initial capital costs, but needs higher operating costs and to create employment due to there is no auto locking mechanism, and to distribute more bikes per square meter of pavement space(Schroeder 2010).

To some extent, the low technological bike sharing system is inconvenient for users to rent bikes and also results in some problems. For example, bike stations without good quality docking stations so that the bicycles look disorderly and messy, and there is long waits for service due to the system is not automated(Schroeder 2010).Therefore, it is necessary to improve the construction and management of bike sharing system with low technology system.

- ***Financing***

In some Chinese cities, there are two approaches to deal with the financing of bike sharing system. One is that capital costs are usually absorbed by the government. The other one is to gather money from operational revenue which includes system sponsorship, advertising revenue, annual membership fee, usage fee, retail revenue, etc (Schroeder 2010).

| | |
|---|---|
| **Guangzhou** | Completely paid for by the government |
| **Shanghai** | Packaged in with the total operational cost of RMB 1500/bicycle/year |
| **Hangzhou** | Completely paod for by the givernment |
| **Wuhan** | Xinfeida (operating company) paid for the capial costs |

*(Source: http://www.slideshare.net/rgadgi/guangzhou-bike-share-nitin-warrier)*

*Figure 2-6 Financing - Capital Cost*

- ***Operation***

In China's bike sharing system, a public bicycle card is provided to citizens, which also can be used on metro and bus in some Chinese cities, to rent bikes. And bike users need to put a deposit into public bicycle card to activate it which is used for renting and returning bikes in either manual or self service. In some Chinese cities, the temporary card is provided to people who want to use public bike temporarily.

In most of the Chinese cities, bikes can be borrowed and returned at any bike station in opening time, and 24 hours are available in some cities or stations(ITDP-China 2010).

- ***Pricing***

Apart from the free bike sharing system in Wuhan and credits system in the bike sharing system of Shanghai and Beijing, most of the Chinese cities adopts a same pricing model for using bikes in bike sharing system. That is to say, users can rent bikes without charge in the first one hour, but need to pay for renting bikes in additional hours with certain money. The goal of the pricing model is to encourage short trips and promote the recycle use of bikes, instead of maximizing revenue. For example, in Hangzhou, 95% of the trips are less than 1 hour, so they are free(Schroeder 2010).

| Time Used | Price |
|---|---|
| 1 hour | 0 RMB |
| Additional 1 - 2 hours | 1 RMB |
| More than 3 hours | 3 RMB |

*Figure 2-7 Pricing Model in some Chinese cities*

- ***Marketing and maps***

The website and marketing is a platform to inform users and keep them up to date on new developments in the bike sharing system(Schroeder 2010).

## 2.2 Advantage and challenge of developing bicycle sharing system

### 2.2.1 Advantages of bike sharing system

Bicycles have several advantages as a mode of transportation for short-distance urban trips: they reach underserved destinations, require fewer infrastructures and generally do not add to congestion. In addition, they are relatively inexpensive to purchase and maintenance, do not create pollution in their operation, and provide the user with exercise. Their value is undeniable when one also considers that these bicycles may increase trips on other modes of public transportation by expanding the reach of trains and buses(DeMaio 2008).

The implementation of a public bicycle scheme brought about many benefits. It provides a fast, convenient and flexible inner urban transport option, and can be a "door opener" to increase the acceptance of cycling as urban transport mode in cities which still lack a good level of bicycle use. It also makes sense in cities that have a good level of cycling as it increases sustainable mobility choices at low cost when compared to other public transport measures. Furthermore, it encourages intermodal travelling(Bührmann et al. 2008).

According to PBOT(2010), the bike sharing system has the potential to introduce new people to urban cycling, reduce peak-hour pressure on transit, reduce automobile trips, and improve livability. And achieve a change towards a more sustainable multimodal travel behavior ("the right mode for the right trip"). If the systems are properly implemented, they can be part of the "bigger puzzle" of an integrated urban transport strategy, which enables cities to reduce motorized traffic and its environmental impact(Bührmann 2008).

#### 2.2.2 Challenges of bike sharing system

According to PBOT (PBOT 2010), the bike sharing system have also faced a few of challenges, that is theft and vandalism, maintenance of bicycles and docking stations, helmet use and cost. Some of these challenges are also emerging in China, like vandalism, maintenance of bikes and docking stations and cost.

There are also other manifold challenges for the implementation of a public bicycle system. First, getting it started is not as easy as it seems (need for integrated approach, infrastructure, scale of scheme and layout, traffic safety etc.). Cities need advice to avoid mistake. Second, financing model is a key aspect. There are many options, which should be thoroughly evaluated by a city before tendering and contracting a service. For example, outdoor advertisement contract (e.g. Rennes, Lyon); Service paid through parking revenues (e.g. Barcelona, 10 years – 22,3Mio.); advertisements on bicycles (e.g. OYbike, Next); and others (e.g. backed-up by operator).

Furthermore, automatic systems are often not very suitable for small and medium cities, which are well known the bicycles as urban transport mode. Last, achieving real long term impact needs continuous development of urban transport strategies. The direct impact bicycle schemes regarding the reduction of motorized traffic in the city centers and of $CO_2$ emissions is limited. In the mid-to long run, however, public bicycles can be an important building block towards a multi-modal and more sustainable travel behavior(using the right mode for the right trip)(Bührmann 2008).

### 2.3 Benefits of GIS

Geographic Information Systems (GIS) were initially developed as tools for the storage, retrieval and display of geographic information, which is capable of the geographic analysis of spatial data which were either poor or lacking in these early systems. Moreover, the potential of GIS to become a powerful tool for spatial analysis in general and for spatial data analysis in particular is by now commonly accepted in the research literature. Following the needs for better integration of GIS and the methods of spatial analysis, various alternatives have now been suggested(Anselin 1993; Fotheringham et al. 1994).

A capability for GIS to integrate digital maps and spatial analysis has made it a powerful tool for public transit planning. Parallel with the wide adoption of GIS technology in the transportation has grown rapidly, which dates from the earliest interest in GIS in 1960. With respect to the application of GIS in transportation, a wide variety of researches have been done, ranging from transit route selection to market potential evaluation to potential bus stop placement to transit GIS data model design(Goodchild 2000; Lao et al. 2009)

The reason that GIS should be used in public transportation planning can be seen from two perspectives. The one perspective is using a GIS for different spatial analysis; a quite common opinion is that these systems often lack sufficient tools for studying mobility. Therefore, the aim of this perspective is to include such modeling tools in an existing GIS. Another perspective is that of transport modelers wanting to use a GIS as an aid to visualize modeling results or to input data to such a tool; and the aim of this perspective is to simply transform data from planning tools to a GIS, and vice versa(Hall 2006).

With respect to the non-motorized travel, GIS can be used to enhance bicycle demand forecasting and facility analysis by permitting spatially-based analysis, otherwise, which might be difficult or impossible. Moreover, GIS can also be used to display and communicate information relevant to bicycle planning(U.S.DTFHA 1999). In this study, GIS based spatial analytical method would be used to evaluate the performance of bike sharing system.

## 2.4 Service Location Model

### 2.4.1 Location set covering model & Maximal coverage location model

Coverage of location has been an aspect of influencing service location. Many methods have been developed to solve coverage problems. Location set covering problem (LSCP) proposed in Toregas et al. cited by (Murray 2001), and Maximal coverage location problem (MCLP) propose in Church and ReVelle (1974) cited by (Murray 2003) are two common models used for analyzing stop placement efficiency.

- ***Location set covering problem***

The LSCP was originally utilized for locating a minimum number of emergency service facilities and has also been suggested for identifying a minimum number of express bus stop locations. The use of the LSCP for assessing redundancy in service coverage for an existing public transportation system does not appear to be a previous application area(Murray 2001). In the LSCP, the optimum number of facilities is one aspect of the solution to the problem, and the constraint requires for all demands must be covered by at least one facility(cited by MAHMUD et al.(2009)).

- ***Maximal coverage location problem***

The MCLP was proposed to seek the maximum population that can be served by a limited number of facilities within a stated service distance or time(MAHMUD et al. 2009). In the MCLP, the number of facilities is known a priori and the objective becomes to maximize services for demands (cited by MAHMUD et al.(2009)).

### 2.4.2 Maximal service area model

Conventional facility location models only define a facility's service area simply as a circular-shaped region based on a specified radius. Such definition might be appropriate for facilities which are not influenced by topographical barriers. But for bike station, accessibility is an important requirement. Therefore, road accessibility should be taken into account in emergency facility (e.g. bike rental facility) location problem to improve emergency services (e.g. bike renting service). GIS can serve this requirement through network analysis. Network analysis in GIS takes into account network attributes such as road width, speed limit, barriers, turn restriction and one way restriction. This advantage provided by GIS should be incorporated in the service area calculation to obtain a more realistic model(MAHMUD et al. 2009).

The maximal service area problem (MSAP) is created as a modification of the MCLP which makes use of the capability of GIS to generate service areas of facilities as travel time zones. In the travel time zones, service area polygons are generated based on the network through a network analysis in a vector GIS environment. Network analysis in GIS takes into account network attributes, such as road width, speed limit, barriers, turn restriction and one way restriction. The MSAP does not take into consideration capacity constraints of facilities in calculating the service area. It is designed as a discrete model where a specified number of facility sites that achieves the best objective function value of the problem are selected out of a finite set of potential sites. The actual area of coverage can be calculated in the GIS once the set of facility sites has been selected.

### 2.5 Previous Research on optimizing service location

Service location has played an important role in developing and planning a multimodal transportation system (Murray 2001; Rybarczyk et al. 2010). And many methods on optimizing and planning service location have been proposed. Murray(2001) proposed a model that supports strategic analysis of service coverage inefficiency and stop spacing optimization along a route to address strategic aspects of service access. In Chien et al.(2002)'s study, a mathematical model was developed to improve the accessibility of a bus service by optimizing the number and locations of bus stops. MAHMUD et al.(2009) also present and discuss the new developed model to maximize total service area of a fixed number of facilities. In order to reduce redundancy bus stops, a muticriterion buffer analysis was performed using ArcGIS to identify suitable locations for bus stop, considering the parameters of distance, importance of location, willingness to walk and junction points (Alterkawi 2006).Ziari et al.(2007) concluded that past research on optimizing location of bus stops can be classified into three categories.

Apart from methods on optimizing bus stops, many methods on bicycle facility planning also have been proposed. According to Rybarczyk and Wu (2010), typical bicycle facility planning models can be divided into two groups: supply-and demand-based models. And supply-based bicycle facility planning relies on two overarching theories: (a) all major arterials and collectors should have bike facilities, or (b) a quantitative model, such as bicycle level of service, hazard score analysis, or bicycle compatibility index should be calculated prior to bicycle route planning.

Service location models concern the provision of a service to satisfy a spatially dispersed demand. A demand for the service exists at a large number of widely dispersed sites, it is impossible to provide the service anywhere(MAHMUD et al. 2009). It is important to apply a suitable method in the research of a specific study area.

### 2.6 Conclusion

Because of the increasing environmental issues and transport problems, bike sharing system has become a reigning project in all over the word. And the overall bike sharing systems in Chinese cities are in building and improving phrase.

In this research, GIS technique is applied in analysis. And service location model – especially the maximal service area model- is used for analyzing and optimizing bike stations. Moreover, optimization of bicycle station mainly focuses on the efficiency of service coverage and station spacing of bike stations.

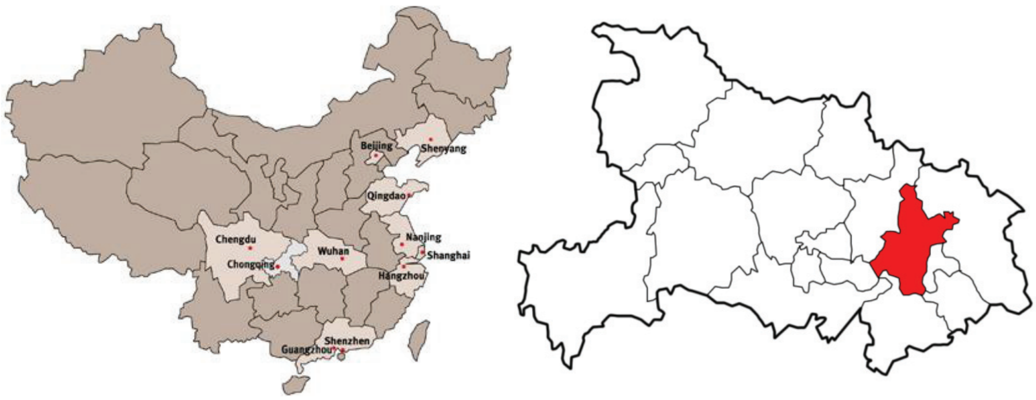
# 3. BACKGROUND OF STUDY AREA

## 3.1 General description of Wuhan city

### 3.1.1 An profile of study area

The study area is urban area of Wuchang district in Wuhan city. Wuhan is the capital of Hubei province, China, and is the most populous city in central China. It is situated in the middle of Hubei Province, at the east of Jianghan Plain, and the confluence of the middle reaches of the Yangtze River and Hanshui River. The metropolitan area comprises three parts – Wuchang, Hankou, and Hanyang, commonly called the "Three Towns of Wuhan". The consolidation of these three cities occurred in 1927 and Wuhan was thereby established. These three parts face each other across the rivers and are linked by bridges, including one of the first modern bridges in China, known as the "First Bridge". It is simple in geographical structure – low and flat in the middle and hilly in the south, with the Yangtze and Han rivers winding through the city.

Arising out of the conglomeration of three boroughs, Wuchang, Hankou, and Hanyang, Wuhan is known as "the nine provinces' leading thoroughfare"; it is a major transportation hub, with dozens of railways, roads and expressways passing through the city. The city of Wuhan, first termed as such in 1927, has a population of approximately 9,100,00 people(2006), with about 6,100,000 residents in its urban area. Now Wuhan is recognized as the political, economic, financial, culture, educational and transportation center of central China.




a. Wuhan in China b. Wuhan within Hubei Province

*Figure 3-1 the Location of Wuhan in China and Hubei Province*

### 3.1.2 Description of transportation in Wuhan

#### 3.1.2.1 Current status of transportation in Wuhan

Although the speed of constructing major infrastructures has been accelerated and the integrated transportation system has been improving, the inhabitants are still experiencing that electric bicycles are faster than cars in urban area of Wuhan(WHTPI 2010).

Nowadays, the car owners are consistently increasing at the speed of more than 10,000 vehicles per month in Wuhan. In 2009, the number of private cars has been up to 402,000. Therefore, the travel demand is increasing quickly, and the traffic congestion in central urban area is still serious and has been spread to the peripheral area. In 2007, during the peak hours, there are 48 intersections where the traffic volume is more than 5,000 vehicles per hour. But in 2009, the numbers of intersections have been up to 74, in which the traffic volume of 18 intersections is between 10,000 and 15,000 vehicles per hour. Now, the Hangkong road in Hankou district has become the most serious traffic congested area, the traffic volume in peak hours has broken through 20,000 vehicles per hour. In 2009, the new increased length of urban roads is 198 kilometers, which is equal to a big "parking lot"(WHTPI 2010).

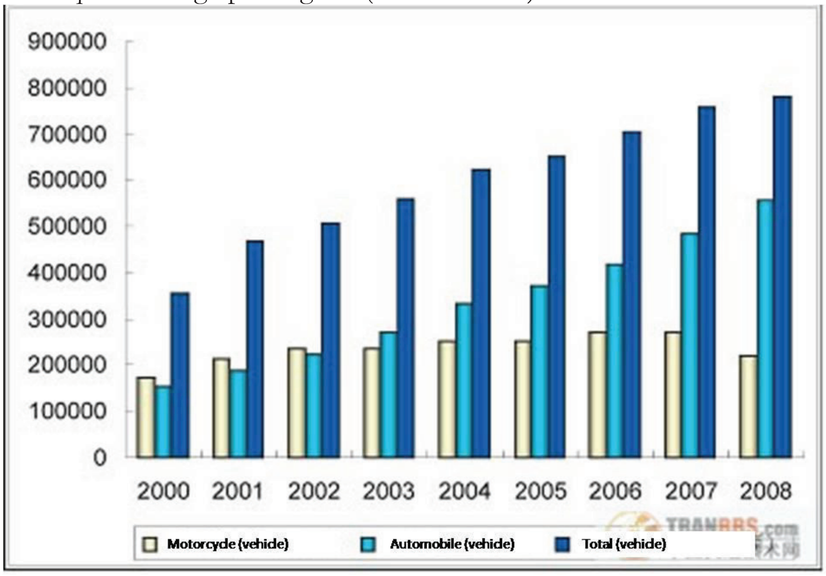



*Figure 3-2 Ownership of Motor Vehicles in Wuhan*

(source: cited from(WHTPI 2009))

In 2008, the average traffic velocity is 23.8 k/h within the third ring route, and the average traffic velocity of main road is 25.5 k/h (WHTPI 2009) (*Figure 3-3*). In 2009, within the third ring route, the average traffic velocity is 20.4 k/h which is close to threshold of traffic jam (20 k/h). Compared to 2008, the average traffic velocity is decrease of 2.9 kilometers per hour. By comparing the traffic velocity of three districts in Wuhan, the fastest traffic velocity is 22.6 k/h in Hanyang district, and the faster one is 22.2 k/h in Wuchang district. So the slowest traffic velocity is 18 k/h in Hankou district which is of traffic jam in the whole area, and the traffic velocity of some routes in Hankou district is lower than 15 k/h(WHTPI 2010).

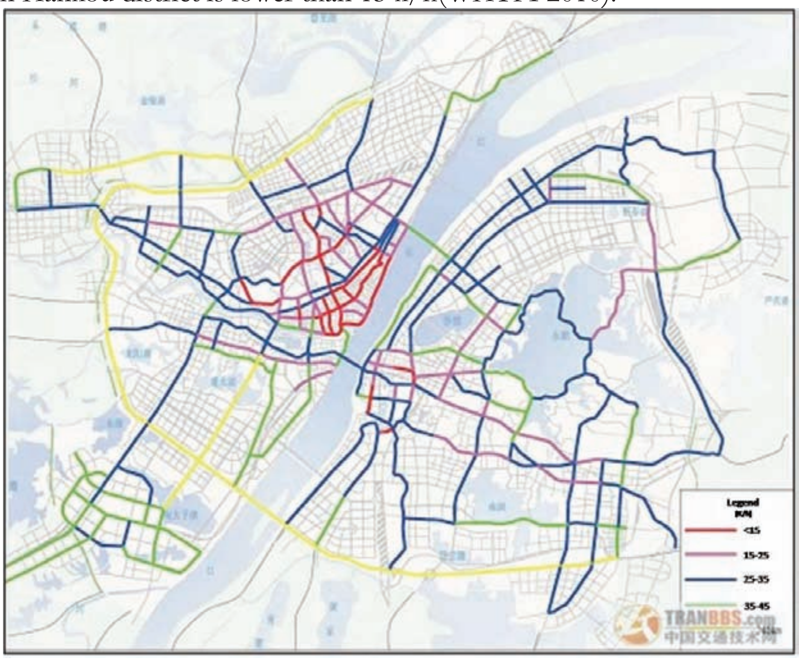



*Figure 3-3 Traffic Velocity in Wuhan*

(source: cited from(WHTPI 2009))

Until to 2008, the total investment of transportation construction has been up to 269.2 billion RMB which accounts for 6.8% of the total GDP. Compared to 2007, the investment has increased 29.4% in 2008. Within these investments, the total investment for constructing rail traffic has achieved 27.5 billion RMB, which has increased 248% more than that of last year. The investment of constructing transportation infrastructure has increased quickly, which is positive to improve transport environment and economic development(WHTPI 2009).

#### 3.1.2.2 Public transport development in Wuhan

In 2008, there are 20 billion public transport passengers all the year, which is an increase of 20% more than that of last year. Within these passengers, regular public bus and tram account for 71.7% which are 14.3 billion passengers; the passenger of rail and small public bus yearly account for 0.55% and 6.9% of the total public transport passengers respectively; the passenger of taxi and ferry yearly account for 20.1% and 0.79% of the total public transport passengers respectively. Therefore, the regular public bus and tram are still the major public transportation in Wuhan(WHTPI 2009).

In recent years, the investment in public transportation is still increasing in Wuhan. In the first phase of constructing the line 1 of rail transit, the proportion of investment is continuous increasing. And as the construction of the first phase of line 2 and line 4, and the second phase of line 1, the proportion of investment in public transportation is still gradually increasing(WHTPI 2009).

#### 3.1.2.3 Blueprint of transport development in the next 5 years in Wuhan

In Wuhan, 12 million parking spaces will be built annually in the next 5 years. The total number of new increased parking spaces will be up to 60 million, which would basically meet the needs of extra parking spaces. Additionally, in order to strengthen the construction of public parking lots in central urban area, 8.5 million public parking spaces will be built in old city of Hankou and Wuchang district, and other areas. This can gradually make up for the insufficient parking spaces in city, and relieve the conflicts between supply and demand of parking lots in central city area(WHTPI 2010).

With respect to the transportation access across the Yangtze River, Two-seven Bridge, Parrot Island Bridge, the access across river of metro line 2 and line 4 will be built in the next 5 years; and some of the new bridges also will be built. All of these will form the pattern of Yangtze River access — “ten bridges, one tunnel, three rails” and construct the pattern of fast road network, which aims to achieve smooth of the road in 30 minutes, and basic construction of fast road network within major urban area(WHTPI 2010).

## 3.2 Characteristic of bike sharing system in Wuhan

### 3.2.1 Introduction of Wuhan’s bike sharing system

Wuhan launched the bike sharing system in April, 2009 which aims to satisfy people who demand for access to “the last mile” easily. This system is operated by Xinfeida Bicycle Company in cooperation with Wuhan Transport Planning Institute, which has been extended to 718 stations with 20000 bicycles in eight districts (expect Qingshan district). And the final objective is to reach 2000 bicycle stations to cover the center city area in Wuhan, and the average distance of these stations is 300 meters. *Figure 3-4* shows the general information of bike sharing system in Wuhan.

| | | | |
|---|---|---|---|
| Government constructed and owns station | ○ | Control Center managing demand | ● |
| Payment integration with other transport modes ( bus, BRT, metro) | ○ | Website | ● |
| Advertising is the main source of revenue | ● | Maps with station locations | ● |
| Deposit Required | ○ | Adjustable Saddle Heights | ○ |
| Opening hours over 12 hours | ● | RFID Equipped | ○ |
| Smart Card integration | ● | GPS Equipped | ○ |
| Automated self-service ( at least majority of stations) | ○ | Front Basket | ● |
| Free initial time period ( at least 30 – 1 hr) | ● | Reflectors ( front and rear) | ● |
| Charge for additional time | ○ | Child seats on some bicycles | ○ |
| Government initiated | ● | Lock | ● |
| Annual Subscription | ● | Fenders | ● |
| Temporary Subscription | ○ | Multiple speeds | ○ |

( Note: "●"–yes; "○"–No)

*Figure 3-4 Wuhan Bikesharing System*

### 3.2.2 Implementation of Wuhan's bike sharing system

Since 2010, the sites selection of the new bicycle stations was operated by municipal urban management bureau in cooperation with other institutes. In order to satisfy the different demands of people and make the bike stations can be fully connected with other facilities in city area, these stations are set up around bus stops, residential communities, business area, recreational area, colleges and metro stations (*Figure 3-5*).


*Figure 3-5 Bike rental stations in Wuhan (Wuchang)*

### 3.2.3 Pricing of Wuhan's bike sharing system

Because this is a convenient system for citizens, people can use this bicycle free of charge in two hours which aims to improve the recycling use of bikes. But if people cannot return bicycle in two hours three times, or people cannot return bicycle in 24 hours, they will be disqualified from renting bicycles. The bicycle company supports this sharing system by advertising in the bike stations and bikes (*Figure 3-5*).

### 3.2.4 Operations of Wuhan's bike sharing system

This bicycle sharing system is a "manual + self-service" system (*Figure 3-6*) *to* achieve 24 hours service; users need a "public bike card" which you can get freely by using your ID card or other valid documents. There is an intelligent box that you can pick up and return key by yourself.

Bikes can be borrowed and returned at any stations between 7:00 – 21:00. The workers of bicycle stations in kiosks have to report to the bicycle company that the number of bikes in their stations every night at the close time of bike stations.

*Figure 3-6 Manual & Self-service system of Wuhan's bike sharing system*

#### 3.2.5 Feedback since operations began

Since the first day of starting, the bicycle sharing system is popular with citizens and media organizations. In a investigation, 52% people think that it is necessary to build bicycle sharing system; 43% people think that it is important for bicycle sharing system to build two-oriented society (resource saving society and environment friendly society); with respect to the best benefit of bicycle system, 32% people think that is to relieve the transportation pressure in the city, 28% people think it can save the energy consumption, 26% people think that it is convenient for short trip. 79% people are satisfied with the service of bicycle sharing system.

But some problems are still present in this bike sharing system: the number of bicycle stations is not sufficient, the distribution of bike stations is irrational, unbalanced capacity of bike stations, and the equipments and bikes in bike stations are broken.

#### 3.2.6 Future development

Bicycle Company and Wuhan Transport Planning Institute have made a plan to improve the new added bicycle stations. First, to build newly modernized bike stations to provide public service information; Second, to set bicycle location scientifically. Furthermore, to achieve 24 hours for borrowing and returning bikes.

# 4. DATA COLLECTION AND METHODOLOGY

## 4.1 Data collection

Based on the literature review, the research questions will be solved, and the availability of data, road network data, land use pattern data, data on population distribution, existing bike stations, bus stop locations, metro stations were collected. Road network provides the conditions for evaluating the performance of bike sharing system, because the bike stations are located along the roads and bike users can go on a trip through the road network. Concerning the land use pattern, especially business and college area, this can be used to analyze the accessibility between bike stations and other facilities (e.g. business, college, residential communities), based on the idea used for planning bike sharing system. Meanwhile, because the advantage of bike sharing system is as a feeder of public transportation, data on bus stops and metro stations will be used to analyze the accessibility between bike stations and them. In addition, population density is closely related to travel demand and in proportion with the amount of trip production and attraction. With regard to these collected data, in addition to be used for evaluating the performance of bike sharing system, these can also be used to optimize the bike sharing system The obtained data are described as Figure 4-1.

| Data category | Feature type | Purpose | Data source |
|---|---|---|---|
| Road network | Poly line | Analysis of characteristics and accessibility of bike stations | Wuhan Transportation Planning Institute |
| Bike stations | Point | Performance evaluation of bike sharing system | Field work |
| Population distribution | Raster | Catchment population calculation, accessibility analysis | Wuhan Transportation Planning Institute |
| Land use pattern | Polygon | | |
| Bus stops | Point | Accessibility analysis | |
| Subway stations | Point | | |

*Figure 4-1 Data description*

In order to understand the characteristics of bike users, a survey should be operated. In this study, a series of bike users' characteristics are obtained based on questionnaires survey, see chapter 5.1.

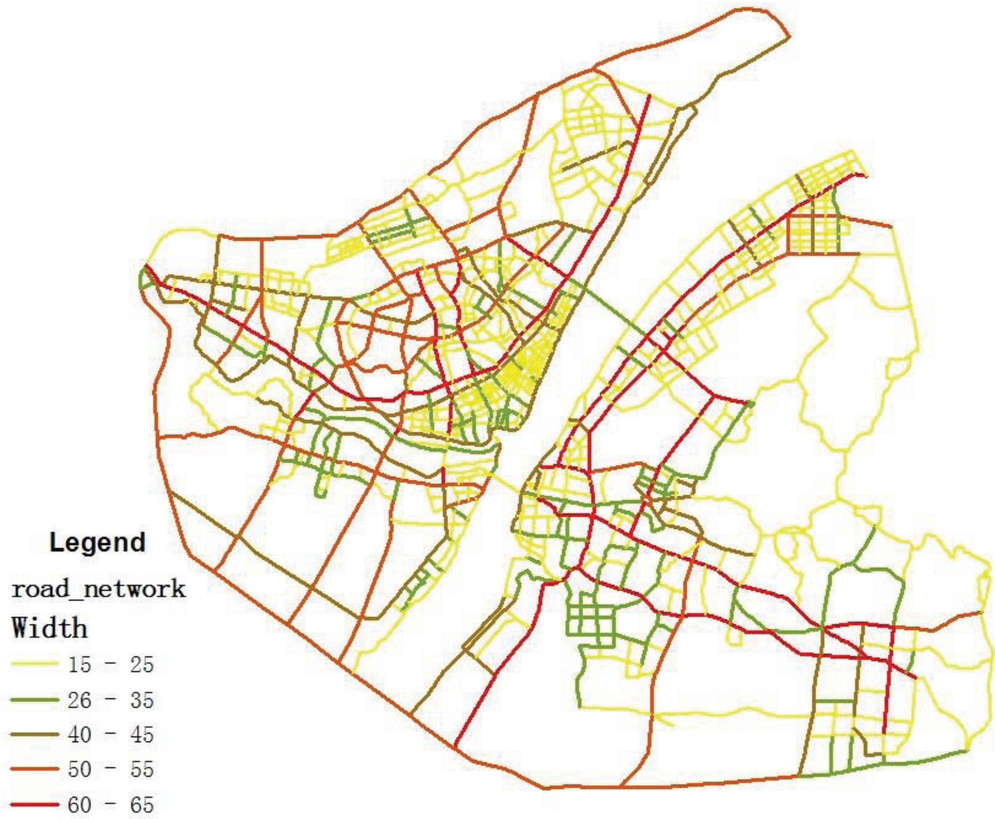



*Figure 4-2 Road Network of width in Wuhan*

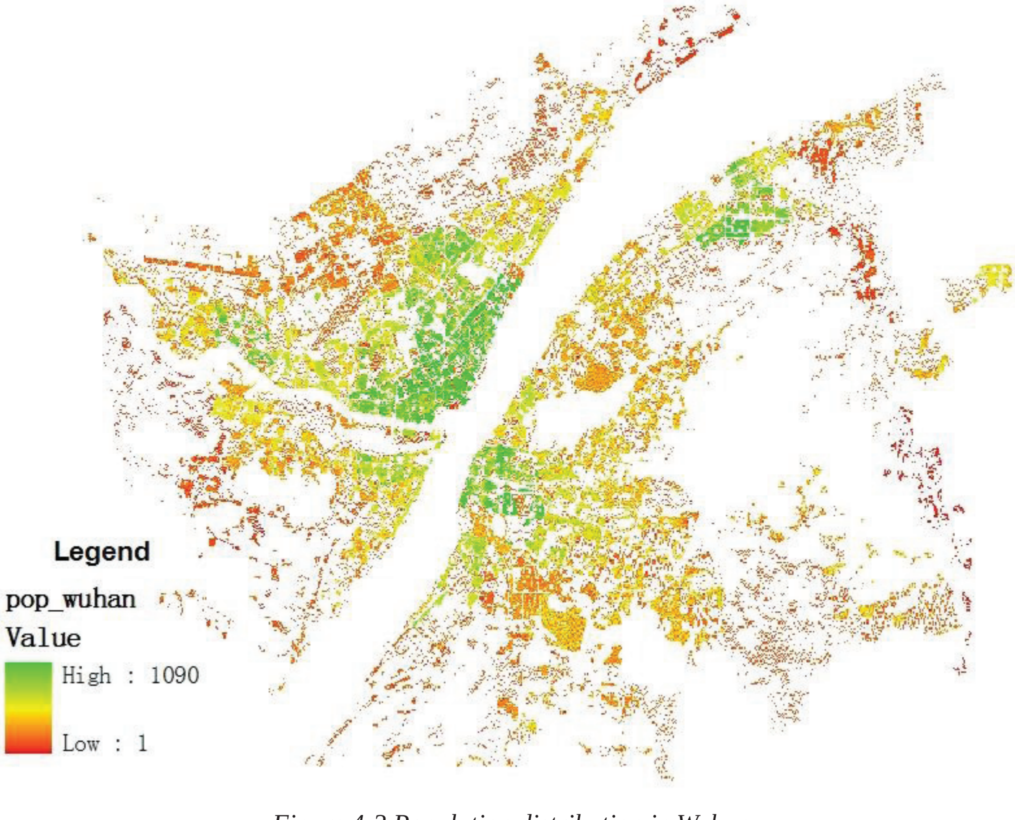



*Figure 4-3 Population distribution in Wuhan*

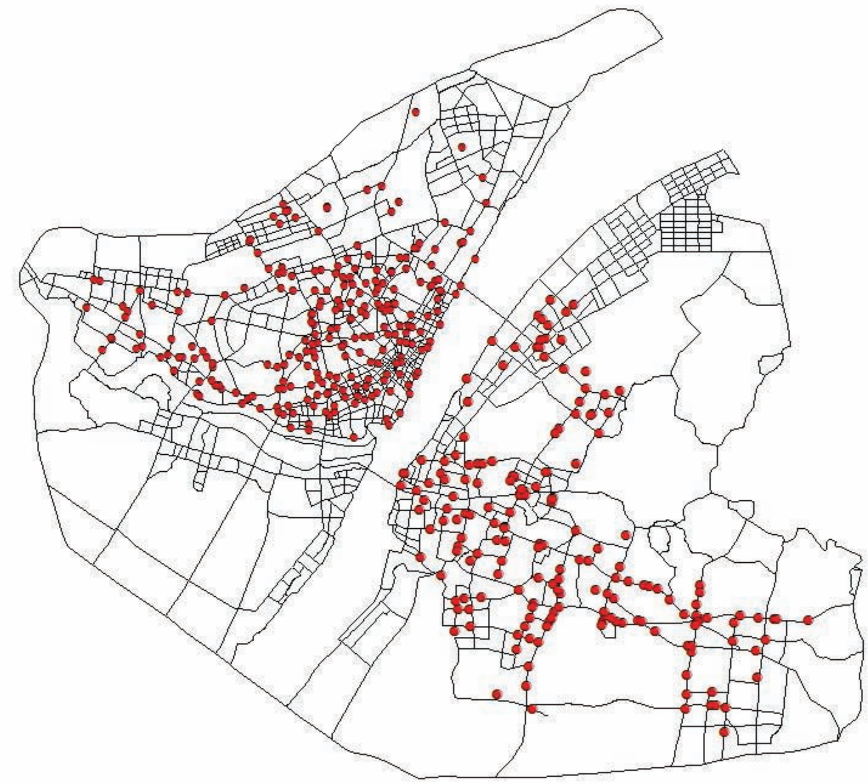


*Figure 4-4 Distribution of bike stations in Wuhan*

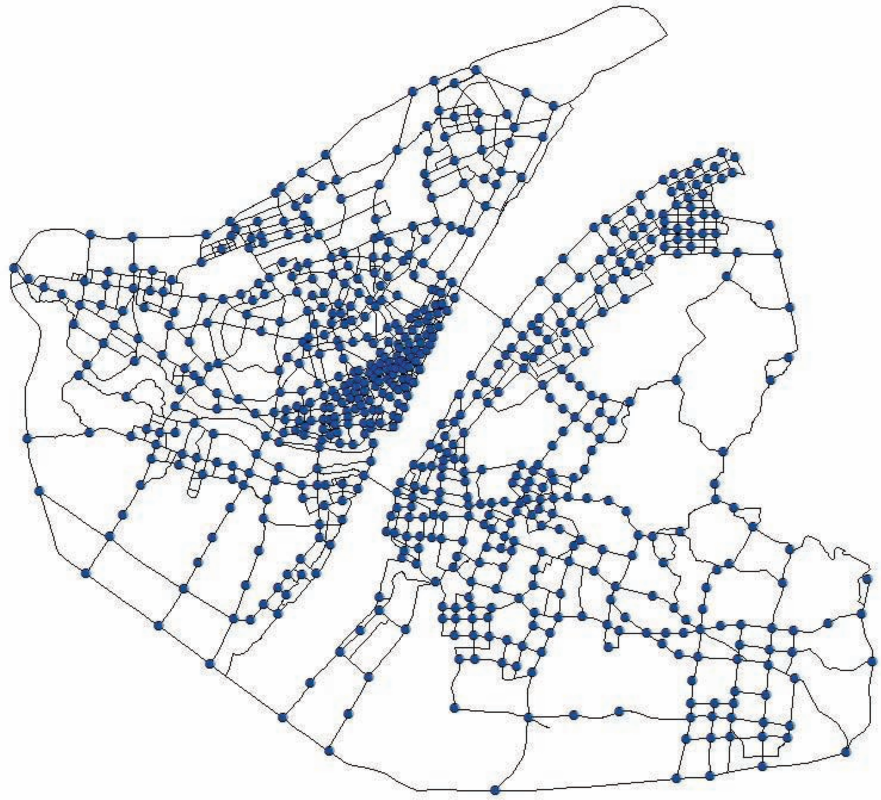


*Figure 4-5 Distribution of bus stops in Wuhan*

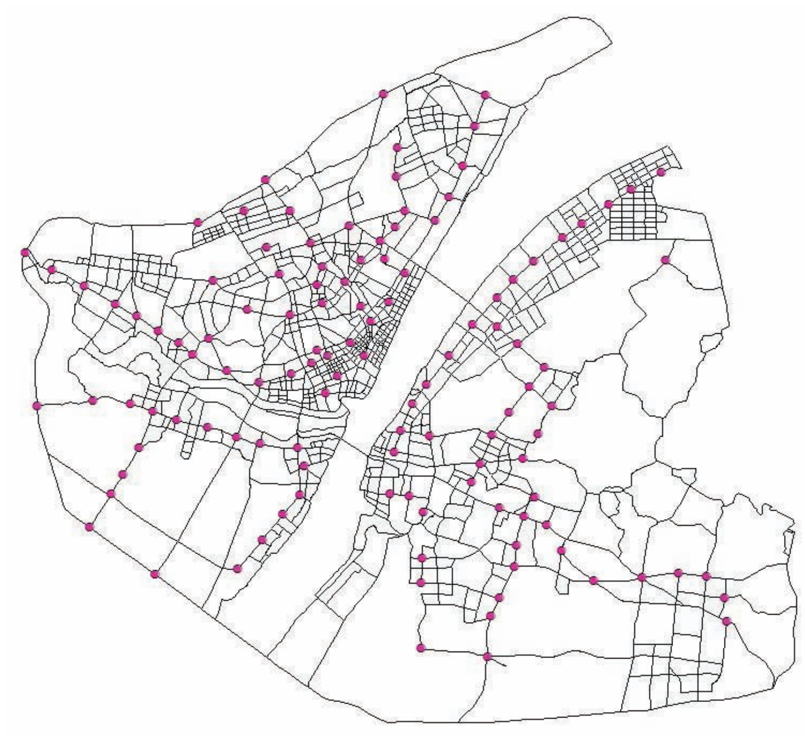


*Figure 4-6 Subway stations in Wuhan*

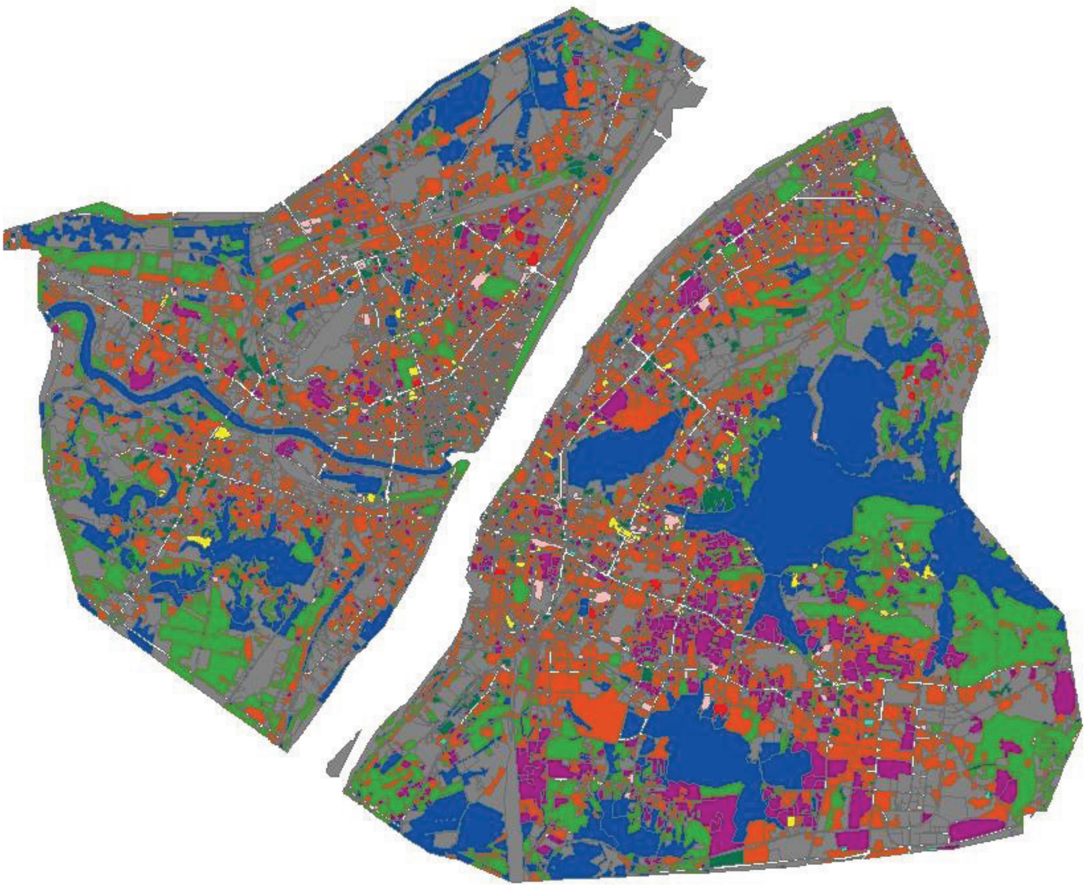


*Figure 4-7 Land use pattern in Wuhan*

## 4.2 Methodology

This paper focuses on evaluating the performance of bicycle sharing system in Wuchang district, based on the existing problems of bike sharing system in Wuhan. And method on combination of GIS and multi criteria evaluation (MCE) is adopted to comprehensively evaluate the overall performance of bike sharing system, by building a series of indicators which would influence the "performance" of bike sharing system. Moreover, the bike stations with poor performance will be optimized.

After data collection, research process were performed in according with conceptual framework (*Figure 1-3*) and research design (*Figure 1-5*)

### 4.2.1 The concept of "performance" on evaluating bike sharing system

Public transit is an important component of local transportation system. Moreover, assessing transit system performance has been one of the most widely investigated areas of research within the transit industry(Karlaftis 2004). According to Lao et al.(2009), the majority of existing researches focus on evaluating the performance of transit agencies from management perspectives, little attention has been given to the spatial aspects of a public transit, such as the characteristics of local population, transportation network, and commuting patterns. Furthermore, Murray(2003) proposed that accessible and efficient service are vital features of well-utilized public transit system.

In the light of these theories and researches, in this study, the "performance" evaluation is operated in two dimensions: operational efficiency and spatial effectiveness. As follows:

- Operational efficiency—— this will be evaluated from the perspectives of bike users to focus on knowing the characteristics of bike users and the conditions of bicycle lane. The objective of this dimension is to evaluate whether the operation of bike sharing system is efficient.
- Spatial effectiveness —— this will be implemented from spatial perspective of bike stations to focus on analyzing characteristics of bike stations and accessibility between bike stations and other facilities. This dimension aims at evaluating the spatial effectiveness of bike sharing system.

### 4.2.2 Methodology for evaluating "performance" of bike sharing system

#### 4.2.2.1 Understanding the characteristics of bike users

The objective of understanding the characteristics of bike users is to detect operational efficiency of bike sharing system by knowing travel purpose, travel behavior and profile of bike users, and their attitudes to bike sharing system; these factors would be closely related to location distribution and capacity of bike stations. In order to know of this information and data, a survey based on questionnaires and interview with bike users and managers of bike stations was carried out.

In this study, 24 bike stations were selected in wuchang zone of Wuchang district in field work. In order to get a overall understanding, these stations were selected based on about 2km space of bike stations, and different land use patterns, i.e. business area, residential community, college, cultural entertainment area (cinema, bookstore, park, and so on), enterprise, metro stations/bus stops. The results of field work are displayed in Section 5.1.

#### 4.2.2.2 Methodology for the evaluation of bicycle lane

Because of the development of bicycle sharing system and the construction of bicycle stations, the bicycle lane has been an important determinant that influences the operational performance of bicycle sharing system. This paper focuses on evaluating bicycle lane from two aspects: construction of bicycle lane, and operation of bicycle lane. The former focuses on evaluating whether the network of bicycle lane is mature. And the later focuses on evaluating the right-of-way. The more detail of analysis will be performed in section 5.2.

#### 4.2.2.3 Methodology for analyzing characteristics of bike station

The objective of analyzing the characteristics of bike station is to deal with one aspect of spatial effectiveness of bike sharing system. Analysis on the characteristics of bike station will be performed by insight into spatial characteristic and non-spatial characteristic of bike stations. With respect to spatial characteristic, it includes catchment of bike station and travel time between bike stations. Both of catchment and travel time are closely related to the total travel time in a trip. And non-spatial characteristic of bike station is concerned about potential population of bike station.

- ***Spatial characteristic of bike station***

The catchment of bike station reflects the estimated tolerance time that a person would likely be willing to walk to a bike station. According to Krygsman et al.(2004) the catchment area is not only a function of the absolute access and egress time but also the relative share of total trip time. Therefore, the catchment of bike station should be calculated by using maximal tolerance time and average walk speed, which are limited by local transportation policy and actual traffic conditions. The results of calculation can be performed in ArcGIS

Furthermore, the travel time between bike stations reflects the interconnection of bike stations which along the road network. And analysis of travel time is based on shortest distance and average bike speed. Moreover, the average bike speed is defined by local transportation policy. By using average bike speed and Network Analyst in ArcGIS, the results of travel time between bike stations can be achieved and performed in ArcGIS.

- ***Potential population of bike station***

Due to unavailable data on the population of using bikes, potential population is obtained by calculating the catchment population of bike stations. And the premise of calculating catchment population is that assume all of the inhabitants as potential population who would use bicycles. Catchment population is calculated based on catchment area of bike station and population distribution in study area. The result of catchment population of each bike station can be achieved by aggregating the data of catchment area of bike station and population distribution of study area.

#### 4.2.2.4 Methodology for evaluating accessibility between bike stations and other facilities

Another aspect of spatial effectiveness that influences the performance of bike sharing system is accessibility between bike stations and other facilities. Accessibility evaluation aims at evaluating whether the spatial interaction of bike stations and other facilities (i.e. bus stops, communities…) is effectiveness. And the accessibility is evaluated in terms of travel time.

Because the major feature of bike stations is to be integrated with bus stops, in order to deeply detect the spatial interaction between bike station and bus stops, a method similar with 2SFCA method (Radke and Mu (2000)) is applied in this research.

- "Bike station availability" —— calculating the catchment area of bike station in maximal travel time, and searching how many bus stops around each bike station in certain catchment area.
- "Bus stops availability" —— calculating the catchment area of bus stop in maximal travel time, and summing up the bike stations around facility's location in certain catchment area.

Before these two steps, the suitable travel time between bike station and bus stops should be identified. Moreover, the theory on MSAP (maximal service area problem) will be considered to deal with service area of facilities. The analysis can be operated by using Network Analyst in ArcGIS, and the results would be performed in ArcGIS.

According to the principle of planning and building bike stations— bike stations are built around specific facilities, and 57.3% of respondents in investigation who use bikes for commuting trips (see section 5.1.3), it is necessary to analyze the accessibility between bike station and specific facilities (i.e. business, college, entertainment) or residential communities. Due to there is no detailed data on the location of specific facilities, the data on land use pattern is used to deal with this problem. The following flowchart explains the operational process of accessibility analysis on bike stations and specific facilities.

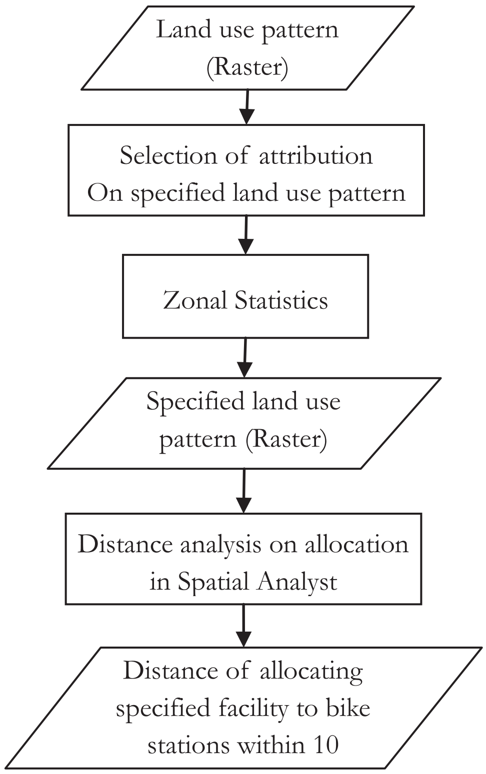



*Figure 4-8 flowchart of analyzing accessibility between bike stations and specified facilities*

#### 4.2.3 Optimization model

##### 4.2.3.1 Optimization of bike stations

In this study, the method of optimizing bike stations is a straightforward method based on spatial analysis, which focuses on access and accessibility analysis. In this study, the bike stations are seen as terminal stations and transfer stations. The optimization will be performed by the combination of coverage model and reduction model. The objective of coverage model is to optimize the locations of some existing bike stations, and to locate new bike stations in areas where there are insufficient bike stations. And then, reduction model is used to reduce redundant new bike stations. Both coverage model and reduction model are performed based on population distribution, maximal service area, and station spacing. ArcGIS is used in the setting up of the model.

- ***Coverage model***

In this study, during the investigation of bike users, there are 57.3% of respondents that use bike for commuting trips, and 55.1% and 35% of respondents using bikes integrated with public bus and walking respectively (see section 5.1.3). Therefore, the optimization and allocation of bike stations are completely based on the population distribution, selected bus stops which are not covered by bike stations in certain time, and maximal service area; and make sure that every selected bus stop and distributed population are served by bike stations, and station spacing is lower than 30 minutes. The coverage model will be performed compliance with the following flowchart (*Figure 4-9*). The more detail of coverage model will be described in section5.4.

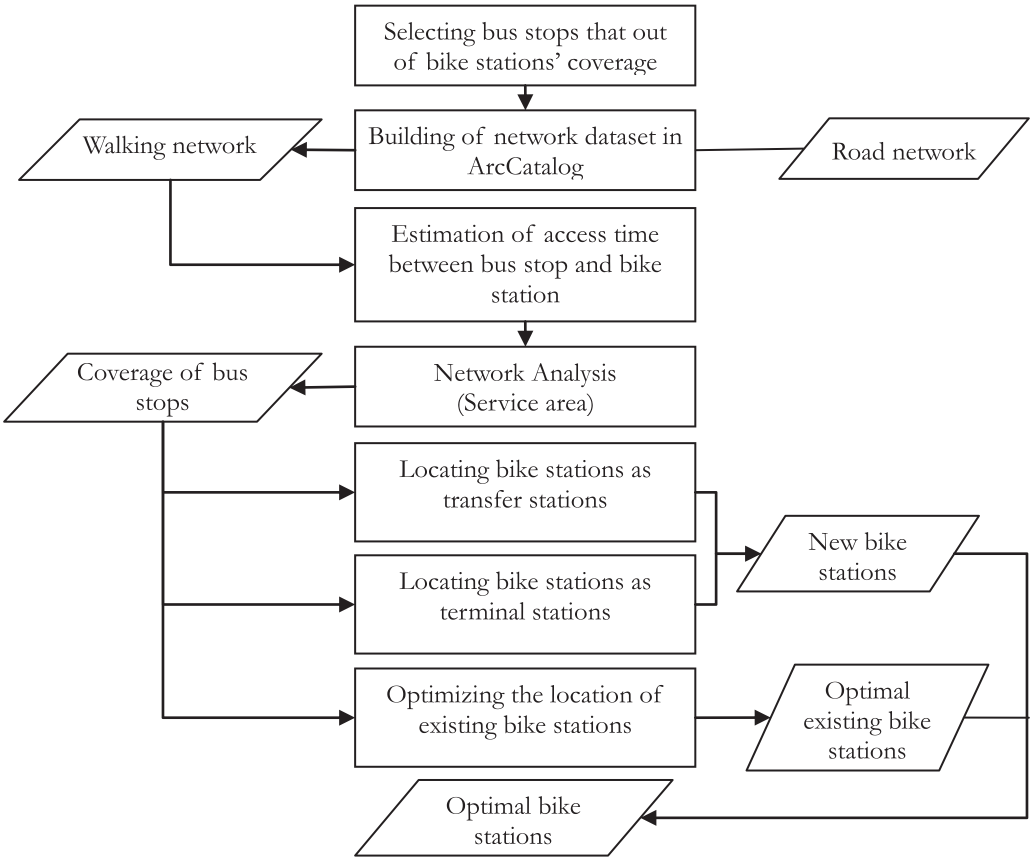



*Figure 4-9 Flowchart of Coverage Model*

- ***Reduction model***

In order to get the optimal bike stations (including original bike stations and new added bike stations) required for covering bus stops and population distributed in study area, a reduction model is adopted in removing the redundant bike stations (new built bike stations). The reduction model will be operated in accordance with the following two criterions.

- There is no bike station on express way, according to MOC(1995).
- There is no bike station as transfer station around bus stop, if there is no population distributed in the maximal service area of bus stop.

The more detail of reduction model will be performed in section5.4.

# 5. ANALYSIS AND RESULTS

### 5.1 Characteristics of bike users

In this study, the survey was carried out based on 24 bike stations which within different land use patterns and around different facilities, i.e. business area, residential community, college, entertainment area (cinema, bookstore, park, and so on), enterprise, subway stations/bus stops. And due to several reasons (e.g. limited time…), only 200 samples of questionnaires were distributed in 24 bike stations, including weekdays and weekend. In order to know the overall characteristics of bike users, the questions on profile of bike users and their views to bike sharing system were included in the designed questionnaire.

#### 5.1.1 Profile of bike users

In this survey, the profile of bike users includes users' age, job, income, travel purpose, rental time, the integrated travel mode, the reason for renting bikes.

According to the results of questionnaire survey, the major bike users are belong to the major group of 20 to 29 years old (*Figure 5-1*), company staff ( *Figure* 5-2), the income lower than 3,000 RMB (*Figure 5-3*). And main travel purpose is commuting trips ( *Figure* 5-4); majorities rent bikes between 10 and 30 minutes ( *Figure* 5-5). The major travel modes integrated by bike users are bus and walking *(Figure 5-6)*. During the survey, most of the bike users say the main reason for using bikes is convenience of bikes (*Figure 5-7*).

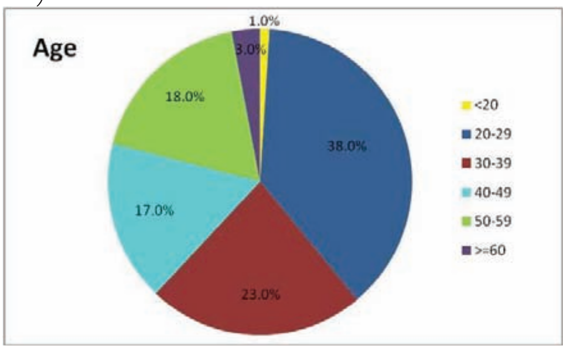



*Figure 5-1 Bike Users' age*

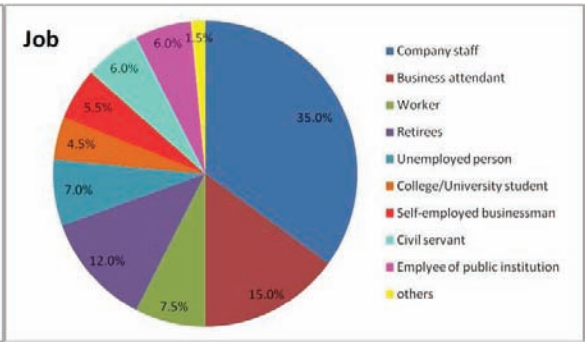



*Figure 5-2 Bike Users' job*

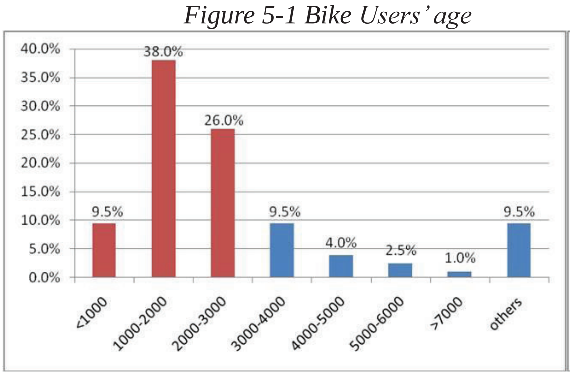



*Figure 5-3 Bike Users' income*

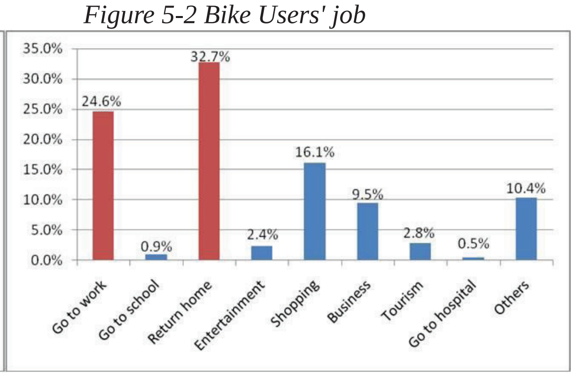



*Figure 5-4 Travel Purpose*

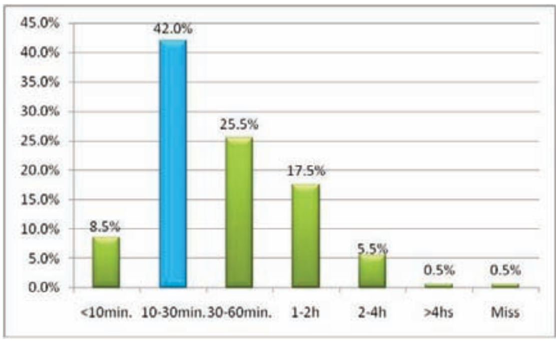



*Figure 5-5 Rental Time*

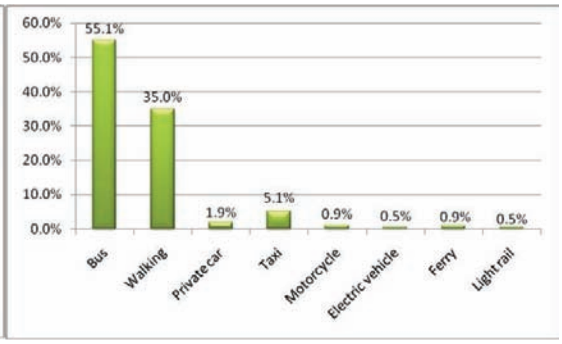



*Figure 5-6 Integrated Travel Mode*

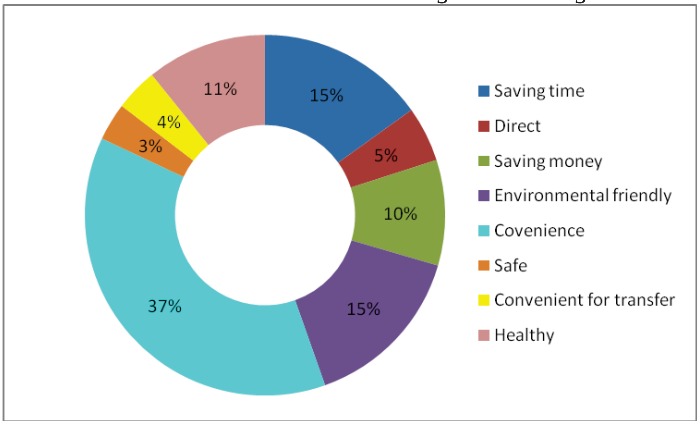



*Figure 5-7 the Reason for Renting Bikes*

### 5.1.2 Bike users' views to bike sharing system

In the questionnaire, there are five problems of bike sharing system listed:

- ( Ⅰ ) The quality of bikes is not good, and some bikes are broken;
- (Ⅱ) Insufficient bike stations leads to the difficulties of renting and returning bikes;
- (Ⅲ) Irrational distribution of bike stations leads to unbalanced utilization of bikes;
- (Ⅳ) Inadequate capacity of bike stations leads to the difficulty of renting bikes in peak hours;
- (Ⅴ) There is deficient in transit information and service in bike stations;

In the light of the results, the major problems are ( Ⅰ ), (Ⅱ) and (Ⅳ) (see *Figure 5-8*). Apart from these problems, other feedbacks were given by bike users. For instance, reducing the rental time to improve utilization of bikes, location of bike station is not apparent, and it is difficult to get a 'public bike card'.

With regard to the bike sharing system in Wuhan, it is satisfied by 29.5% bike users. While 53.0% bike users say there is a lot of space to improve this system, including location and capacity of bike stations, and managing the bike system. There are 17.5% users dissatisfied with this system, and most of the reasons are still about bikes' quantity and quality (see *Figure 5-9*).

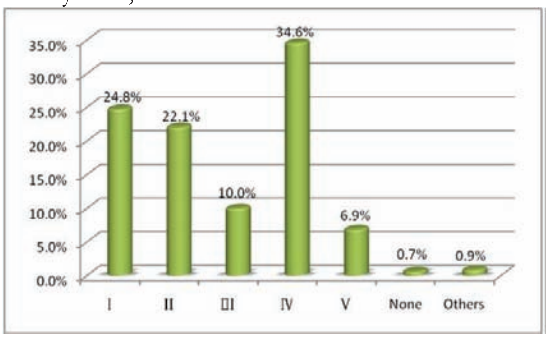



*Figure 5-8 Problems of Bike Sharing System*

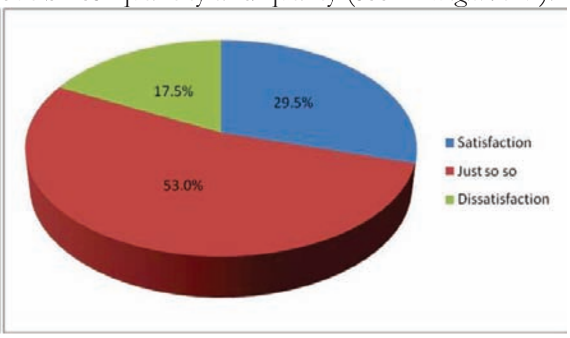



*Figure 5-9 Attitudes of users to bike sharing system*

#### 5.1.3 Conclusion

Given that questionnaire and interview with respondents and bike stations' managers, some basic information on bike users and bike sharing system of Wuhan is concluded:

- Major age group is between 20 and 39 years old (61%);
- Major users' job is white-collar worker (35%);
- The income of main users is lower than 3,000RMB (73.5%);
- Major travel purpose is commuting trips (57.3%);
- Rental time is between 10 and 30 minutes (42%);
- Bike users often using bikes integrated with bus (55.1%) or walking (35.0%);
- Saving time, environmental friendly, and convenience of bikes are the major reason that users renting bikes (67%);
- 91.5% of respondents say the bike sharing system with the problems on bikes' quality, and bike stations' quantity, distribution and capacity;
- 70.5% of respondents do not satisfy the bike sharing system, and say there is a lot of space to improve the bike sharing system of Wuhan;
- Most of the bike users responded that they wanted to find a bike station not further than 10 minutes by walking from their home, or work place, and in 5 minutes is better.

### 5.2 Analysis of bicycle lane

#### 5.2.1 Performance evaluation of bicycle lane

As discussed in section 4.2.2.2, bicycle lane is a key determinant that influences the good operation of both bike stations and bicycle sharing system. This paper will evaluate bicycle lane from following two aspects.

- ***Construction of bicycle lane network***

The good operation of bike sharing system depends on the good and completed bike lane network. This paper mainly focuses on evaluating the construction of existing bike lanes by investigating which roads have bike lanes, to analyze whether the bike lanes network is mature.

According to MOC(1995), three-board road has two dividing strips which divide the road into three parts. The median road is vehicle lane, and both sides of the median road are non-motor vehicle lanes. And this rule is applied in the area with more non-motor vehicles. Due to there is no enough data about bike lanes, this paper will identify bike lanes through finding out three-board roads by using Google Map, and extracting these three-board roads from the data of road network in ArcGIS. Finally, the results of data on road network with bike lanes can be obtained (see *Figure 5-10*).

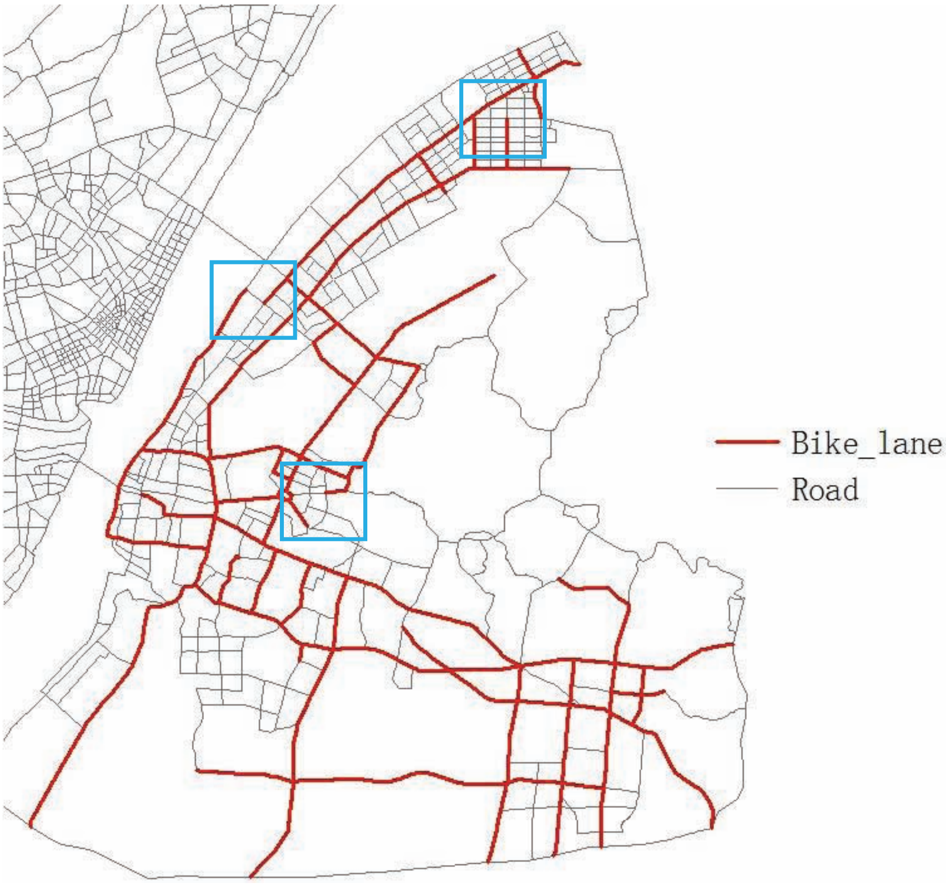



*Figure 5-10 Bike Lane Network*

In light of the results, the bike lane network is not completed and connectivity. There are discontinuous bike lanes in blue box, which is unsafe and inconvenience for bike users to travel, because bike users would bike on vehicle lanes and pavement if without bike lanes. Therefore, it is necessary to build new bike lanes to make the bike lane network be improved.

- ***Operation of bicycle lane***

The operation of bike lane is a factor that influences the performance of bike lane, which would influence the operation of bike sharing system. The analysis on operation of bike lane will be performed by considering the Right-of-Way of bike lane.

In Wuhan, before the operation of bike sharing system, a burning problem needs to be solved is the Right-of-Way of bike lane, and this is the premise and basis for advocating bike sharing system. However, the right of way of bike lane in study area has always been neglected in the past few years. Due to the increase of motor vehicles and intensity of traffic congestion, vehicles roads widening has been a solution to solve these problems, and this only emphasized the right of way on motor vehicles. But the right of way on bicycles has been lost gradually.

In order to improve the Right-of-Way of bicycles, Wuhan municipal design institute has decided to invest 55.36 million RMB to build bike lanes in 2010. Although some of the bike lanes have been built, there are problems existing on the operation of bike lanes.

- There is no bike lane in new roads. So bicycles and motor vehicles have to been mixed on roads.
- "Harbor bus stations" take up the space of bike lanes. A few years ago, a concept on "harbor bus stations" was proposed, so there are some bus stations on vehicles roads have been moved to bicycle lanes, this results in some bicycles have to be traveled on pavement or mixed with motor vehicles on vehicle roads.

- Bike lanes are occupied by motor vehicle parking. Many motor vehicles park on bike lanes; this result in people has to travel on vehicle roads and brings about the unsafe of bicycle travel.


#### 5.2.2 Suggestions for improving the performance of bicycle lane

In order to solve the problems of bicycle lane network and improve the actual situation of bicycle lane, some of the suggestions are given related to the construction and operation of bicycle lane network. As follows:

- The bicycle lane network should be completely constructed. Because the bicycle is short-trip transportation (less than 6km in metropolis), the bicycle lane network should be constructed by considering OD of trip, or the location of residential communities. This is not only convenient for bike users traveling, but also for integrating with other transportation systems.
- Management of bicycle lane should be strengthened. Because the space of bicycle lane is taken up seriously in reality, citizens should enhance their awareness on traffic regulations, which has a great impact on the working and operation of bicycle lane. In order to ensure the existence of the right-of-way, the punishment for breaking traffic rules should be strengthened.
- Improvement of the environment around bicycle lane. To design a beautiful environment and travel space for bicycle lane, by combining the bicycle lane with surrounding environment, pavement and motor vehicle lanes. This can not only provide a comfortable space for bike users to travel, and to avoiding bad weather. In a word, to build a comfortable and safe environment and space for bike users to travel.

### 5.3 Spatial analysis on bike stations

#### 5.3.1 Characteristics of bike stations

Characteristics of bike stations play a key role in spatial effectiveness of bike sharing system. The characteristics not only determine the performance of bike sharing system itself, but also influence the performance of integrating with external systems (e.g. public transport system). The elements in characteristics of bike stations can be important indicators to evaluate the performance of bike sharing system.

##### 5.3.1.1 Spatial characteristics of bike stations

- ***Catchment area of bike stations***

In this study area, following questionnaire survey, 57.3% of respondents' travel purpose is commuting trips, and 90% of respondents use bikes integrated with walking and public bus (see section 5.1.3), and most of the respondents responded that the access/egress time of 10 minutes is maximal if they walk to bike stations. Apparently, bike trip has been performed as an access/egress trip in resident trips. According to Krygsman et al.(2004) the propensity for use of public transport deteriorates with increase in access/egress time. In the case of Wuhan, with regards to walk to bike stations, it is assumed that people who want to walk there within 5 minutes instead of further than 10 minutes (this is derived from communicating with bike users in my survey). In terms of the travel speed is 4km/h for walking; the threshold of travel distance is 333m and 666m for 5minutes and 10minutes respectively.

By executing service area analysis in Network Analyst in ArcGIS, the catchment area of bike stations within 5 minutes and 10 minutes can be obtained, see *Figure 5-11*. This result will be used to calculate the potential population served by each bike station.

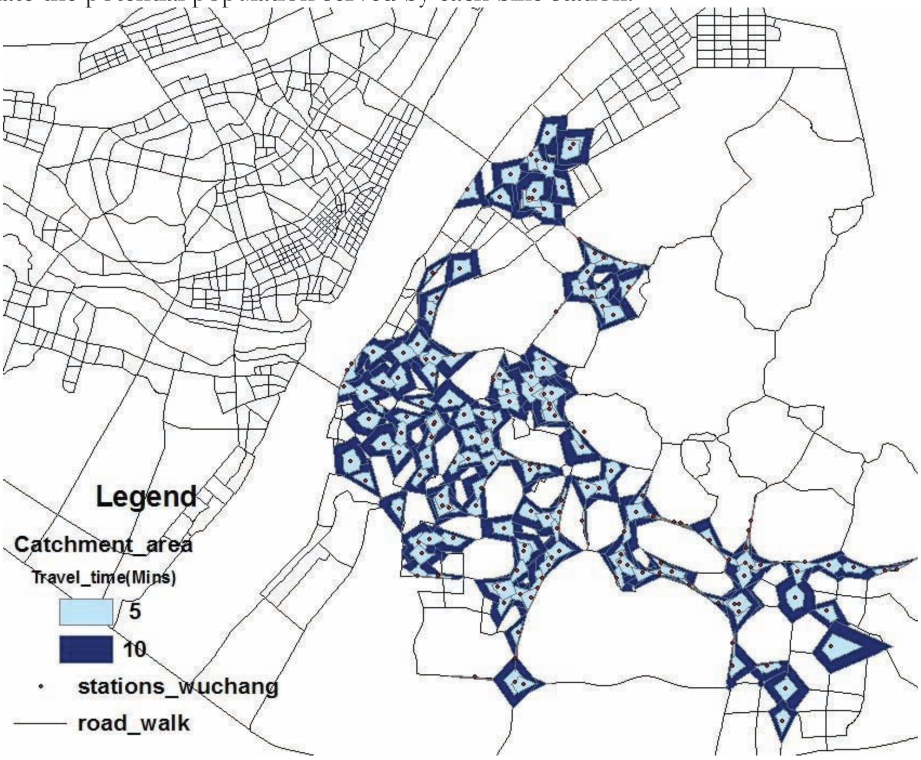



*Figure 5-11 Catchment area of bike stations of Wuchang*

- ***Station spacing of bike stations***

Given that the survey on Wuchang district in Wuhan, 62% of respondents use bike to transfer to public transportation, and 36% of respondents use bike as an only mode of transportation (see *Figure* 5-5). Station spacing of bike stations can be determinant to measure the efficiency of bike stations for travel, and the convenience for renting and returning in limited time. According to MOC(1995), the standard bicycle speed for calculation is 11-14km/h, and it is necessary to use minimum value in area of traffic congestion and poor road condition. Therefore, the bicycle speed is 11km/h in this research, due to the study area is serious traffic congestion. MOC(1995) also proposes that the longest travel distance of bicycle should be 6km in large and medium-sized city, and 10km in small city. Based on above standard, the tolerate travel time should be around 30 minutes in this study area.

The whole analytic process is performed in ArcGIS. First, the network dataset should be built in ArcCatalog based on road network. Second, to operate “closest facility analysis” in Network Analyst, bike station is defined as facility as well as incident. There is no clear network of bike route, so the travel route is selected based on shortest route along road network. In order to detect how many bike stations can be reached by each bike station in 30 minutes; the value of “facility to find” should be change to 168 (total number of bike stations).In the table of “layer properties”, the impendence is set as travel time (minutes), and default cutoff value as 30. After the automatic running of analysis, the results of travel time between bike stations are derived. The statistic results of analysis are shown in the following tables.

| Travel Time (Minutes) | No. of bike station (Incidents) | No. of reached bike station (Facilities) |
|---|---|---|
| 0 — 5 | 160 | Min: 1<br>Max: 9 |
| 5 — 10 | 167 | Min: 1<br>Max: 15 |
| 10 — 15 | 168 | Min: 1<br>Max: 25 |
| 15 — 20 | 168 | Min: 2<br>Max: 31 |
| 20 — 30 | 168 | Min: 7<br>Max: 58 |

*Figure 5-12 Bike stations find other stations in certain time stage*

| Travel Time (Minutes) | No. of bike station (Incidents) | ID of bike station |
|---|---|---|
| 0 — 5 | 8 | 26, 36, 43, 45, 76, 96, 110, 134 |
| 5 — 10 | 1 | 95 |

*Figure 5-13 Number of bike stations without finding other stations in certain time*

Based on the combination of above two pictures, 160 bike stations can find other bike stations in 5 minutes (see *Figure 5-12*). Although there is a bike station without reaching other bike stations from 5 to 10 minutes (see *Figure 5-13*), this bike station has already reached another bike station within 5 minutes. So, it is obvious that all of the bike stations can reach each other within 10 minutes (see *Figure 5-13*).

With respect to the bike stations (see "ID" in *Figure 5-13* and *Figure 5-14*) which cannot reach other bike station within 5 minutes, they can reach one or more other stations within 10 minutes (see "No. of reached bike stations" in *Figure 5-14*). And minimal travel time is just around 6 minutes (see "Travel Time" in *Figure 5-14*).

| ID of bike stations (Incidents) | Travel Time (5 – 10 minutes) | | No. of reached bike stations (Facilities) |
|---|---|---|---|
| | Minimum | Maximum | |
| 26 | 5.1 | 7.5 | 3 |
| 36 | 6.3 | 9.4 | 8 |
| 43 | 5.4 | 9.8 | 6 |
| 45 | 6.0 | 7.2 | 3 |
| 76 | 5.7 | 8.2 | 2 |
| 96 | — | 5.4 | 1 |
| 110 | 5.2 | 9.9 | 5 |
| 134 | 6 | 9.3 | 3 |

*Figure 5-14 Changes of 8 bike stations from 5 to 10 minutes*

Therefore, 95% of bike stations can reach the nearest bike stations in 5 minutes; only 4.7% of bike stations can reach the nearest bike stations around 6minutes. To sum up, the travel time between bike stations is in accordance with the code for transport planning (which was mentioned earlier in this section) in study area.

#### 5.3.1.2 Catchment population of bike stations

For calculating catchment population of bike stations, data on catchment area of bike stations (*Figure 5-11*) and population (*Figure 4-3*) has been got. However, it is necessary to aggregate the data to get the catchment population. First, the raster data of population should be converted to feature data—polygon, which makes the fowling activities more simple; Then, intersection of population and catchment area, and intersected population can be obtained. After that, summarizing the intersected population per catchment and calculating population density per catchment. With regard to calculation of population density, first to calculate the intersected area of intersected population per catchment, but the intersected area is just the aggregated area of total polygon of population with intersected size instead of full size, due to intersection of catchment area and polygon of population; then, to calculate the aggregated total area of complete polygon of population with full size in each catchment; after these two steps, the population density per catchment can be obtained by dividing aggregated total area by intersected area of population. Finally, catchment population can be got by multiplying sum of intersected population and population density per catchment (*Figure 5-15*). Figure 5-16 shows a general result of potential catchment population of bike stations, it is easier to find that the number of population served by each bike station is great different; therefore, it is necessary to distribute bikes in according with the catchment population of bike station in reality.

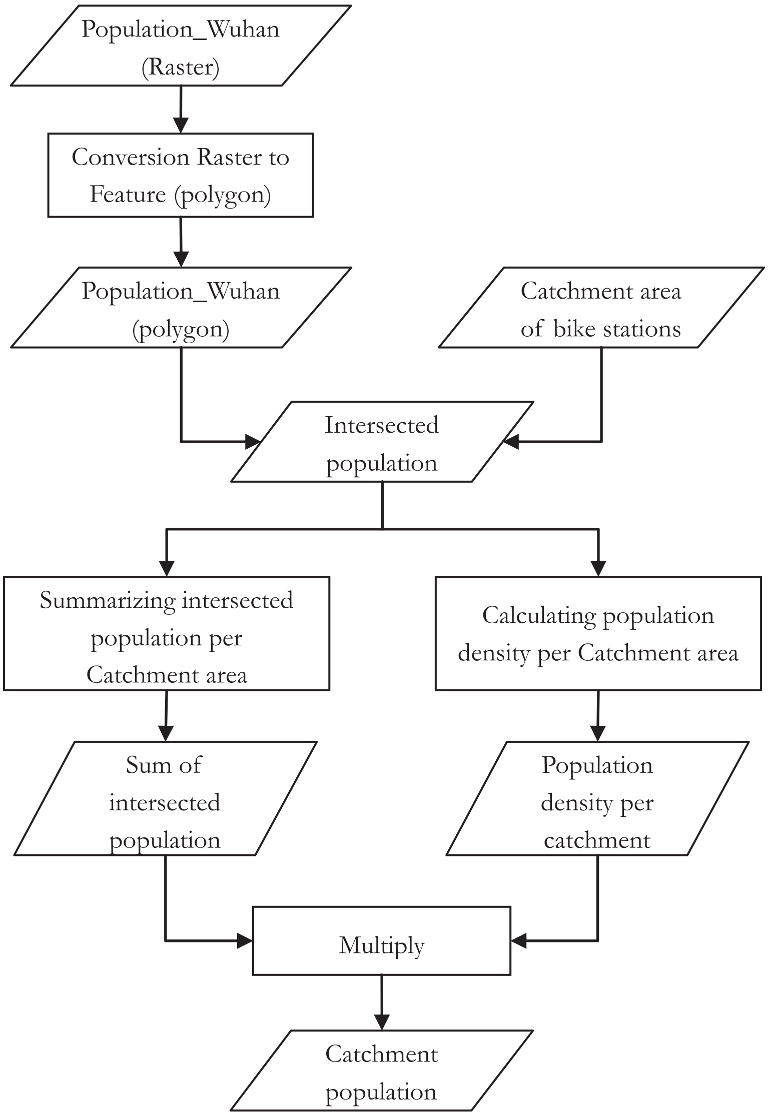



*Figure 5-15 flowchart of calculating catchment population*

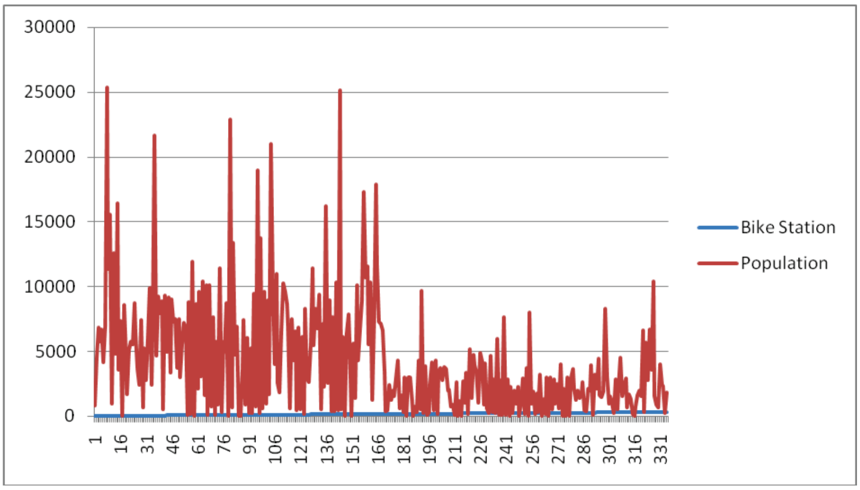


*Figure 5-16 Distribution of potential catchment population per bike station*

### 5.3.2 Accessibility analysis

#### 5.3.2.1 Bike station and bus stops

In the light of investigation on bike users of Wuhan, the maximal time of walking to a bike station is 10 minutes (see section 5.1.3); and the main feature of bike is as an access or egress transportation integrated with public bus. In this research, the maximum of traveling time between bike stations and bus stops is 10 minutes, and waking speed is 4km/h. A service area within 10 minutes can be generated in ArcGIS by using Network Analyst.

The method on analyzing accessibility between bike station and bus stops is totally in accordance with description in section4.2.2.4. Additionally, subway stations are already contained in the bus stops (*Figure 5-17*).

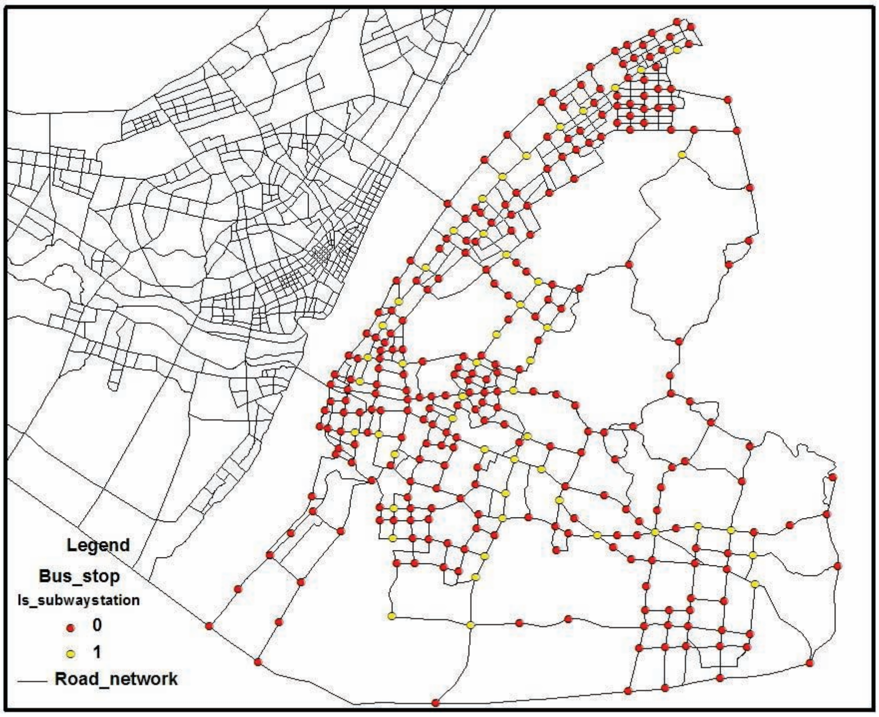


*Figure 5-17 Bus stops containing subway stations*

- ***Bike station availability***

In this phase, the analysis is operated from the perspective of bike stations, and service areas of bike stations are obtained by applying Network Analyst in ArcGIS. Because the maximal walking time is 10 minutes, the search tolerance is set up as 670 meters which is equal to multiply walking speed by 10 minutes; and settings of default breaks in "Layer Properties" is 5 and 10 minutes (see Figure 5-18). After setting up of parameters, the results of maximal service area of bike stations can be derived (see *Figure 5-19*).

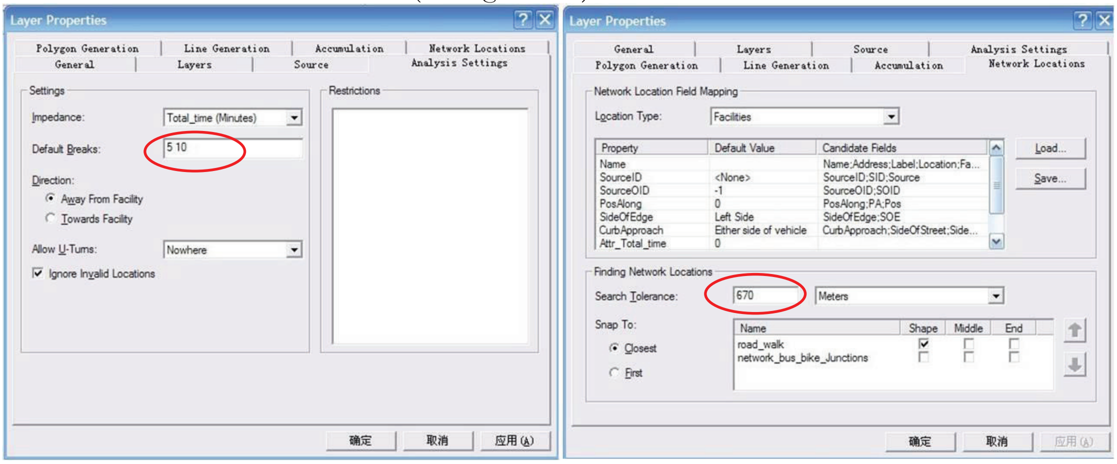



*Figure 5-18 Settings of Layer Properties in service area analysis on bus stops*

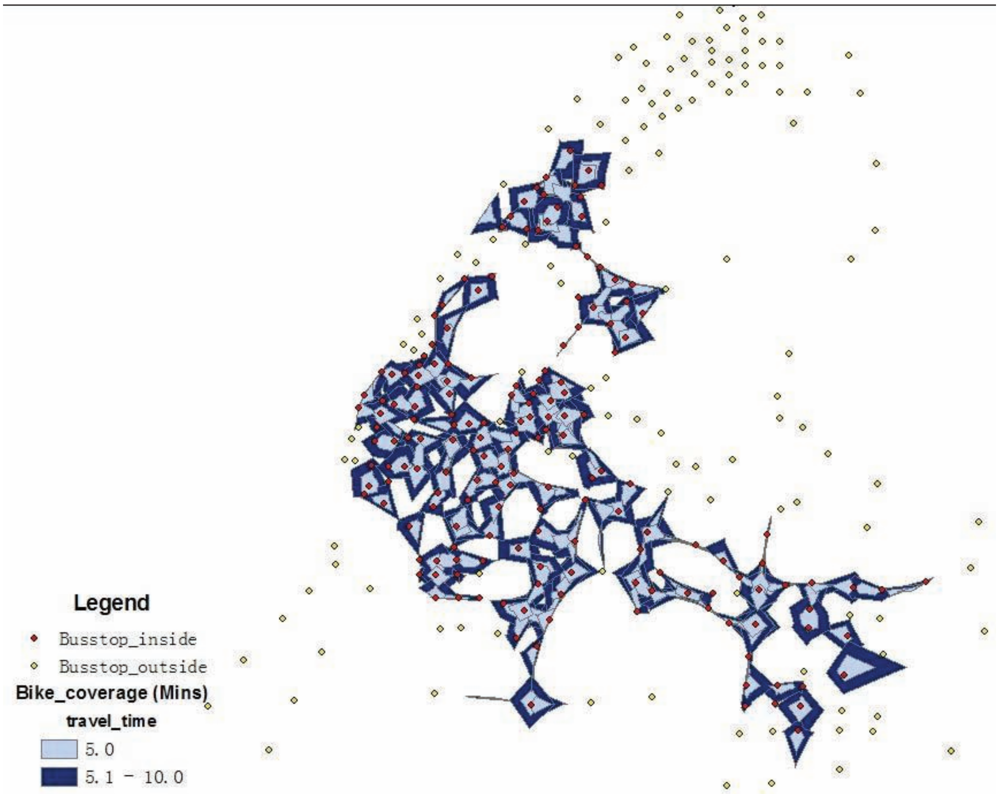



*Figure 5-19 Distribution of bus stops within bike stations' coverage*

In the results, the number of bus stops covered by each bike station is lower than 7 (*Figure 5-20* and *Figure 5-21*). Moreover, during 10 minutes, there are still 174 bus stops within service area, and 141 bus stops out of the service area of bike stations (*Table 5-1*), so more bike stations are necessary to be built. Furthermore, some of the bike stations cover 1 bus stop, while some cover 2 to 6 bus stops, therefore, the distribution of bike stations seems sort of irrational.

*Table 5-1 The results of bike station availability in 10mins*

| Facility | Results |
|---|---|
| Service area of Bike stations (in 10minutes) | 165 bike stations cover bus stops |
| | 3 bike stations not cover bus stops |
| Bus stops | 174 bus stops within service area |
| | 141 bus stops out of service are |

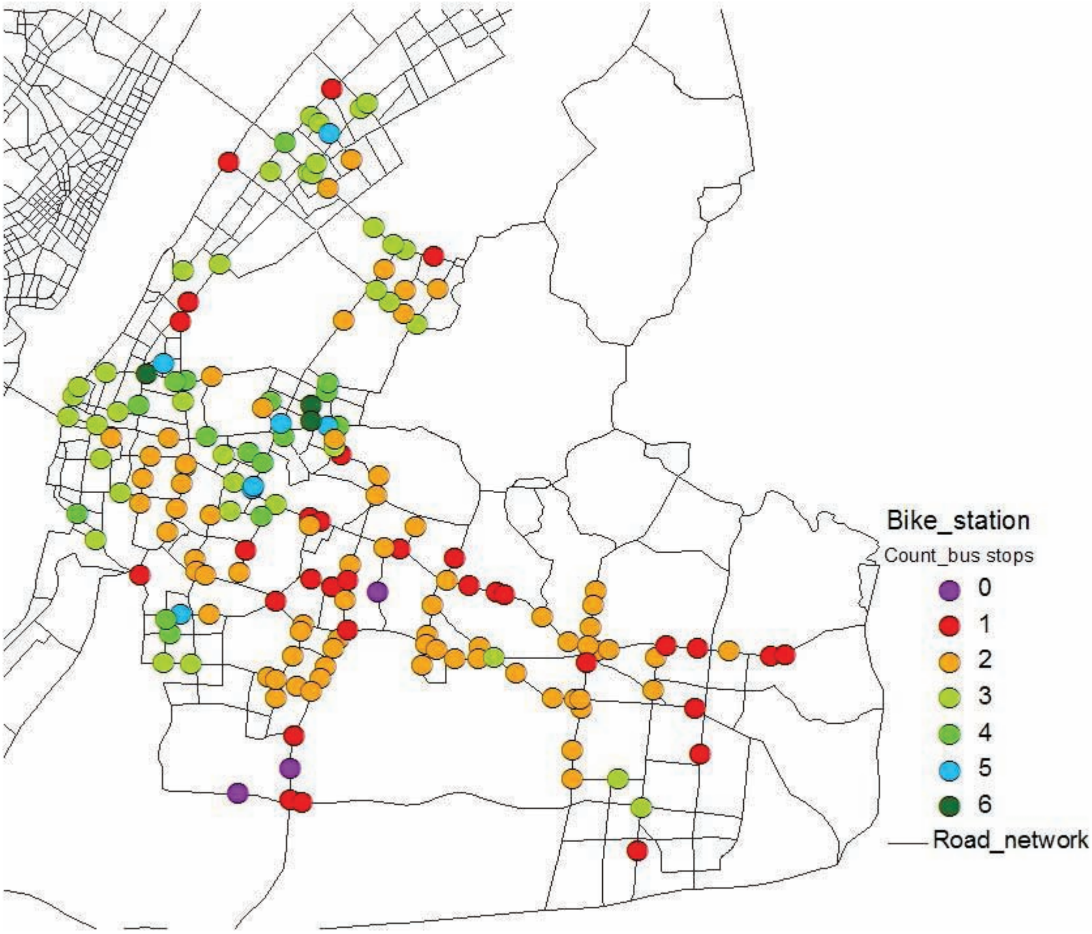



*Figure 5-20 Number of bus stops covered by per bike station in 10 minutes*

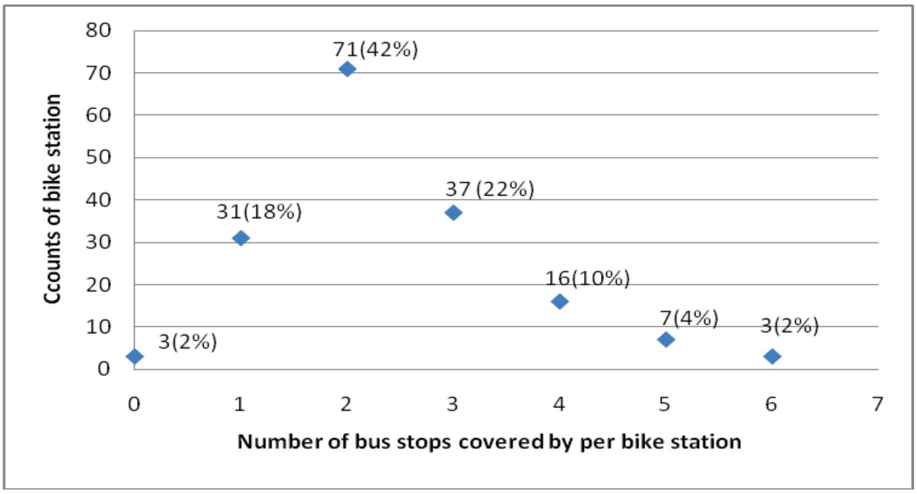



*Figure 5-21 Relationship between bike stations and bus stops (bike station avaliabity)*

- ***Bus stop availability***

Maximal service area of bus stops is also derived from network analysis in ArcGIS, which is similar to the previous analysis on bike stations. *Figure 5-22* shows the results of maximal service area of bus stops.

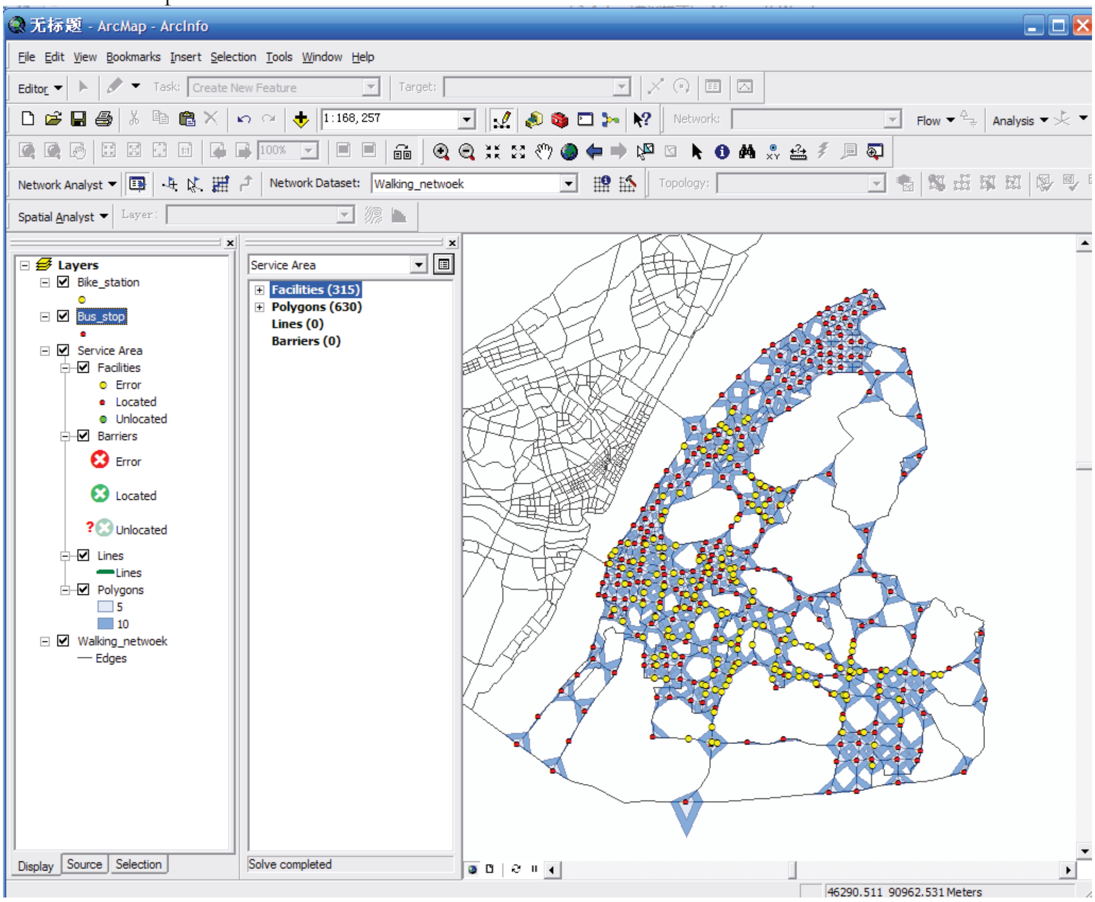



*Figure 5-22 Distribution of bike stations within coverage of bus stops*

*Table 5-2 The results of bus stop availability in 10mins*

| Facility | Results |
| --- | --- |
| Service area of Bus stops (in 10minutes) | 172 bus stops cover bike station |
| | 143 bike stops don't cover bike station |
| Bike stations | 165 bike stations within service area |
| | 3 bike stations out of service area |

With respect to the 165 bike stations which covered by bus stop in 10 minutes, there are 135 bike stations covered by bus stops within 5 minutes, and 33 bike stations covered by bus stops during 5 and 10 minutes. Moreover, the number of bike stations covered by per bus stop is lower than 7 (*Figure 5-23*), and 45% of bus stops do not cover bike stations within 10 minutes (*Figure 5-24*).


*Figure 5-23 Number of bike station covered by per bus stop in 10mins*

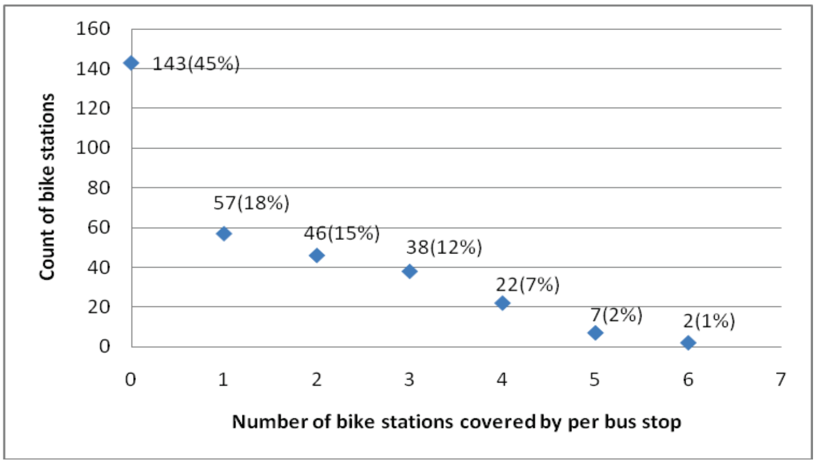



*Figure 5-24 Relationship between bike stations and bus stops (bus stop availability)*

#### 5.3.2.2 Bike station and Residential community

Because the raster data of population is collected based on residential community, the raster data of population is used as that of residential community for accessibility analysis. And the process of accessibility analysis is in compliance with the flowchart (*Figure 4-8*) showed in section 4.2.2.4.

During the investigation of bike users, they said it is best to arrive at a bike station in 10 minutes (see section 5.1.3). Therefore, in the distance analysis, all of the facilities are allocated to bike stations within 10 minutes.

According to the results of analysis, it is obvious that there are deficient bike stations in study area, see red box in *Figure 5-25*.

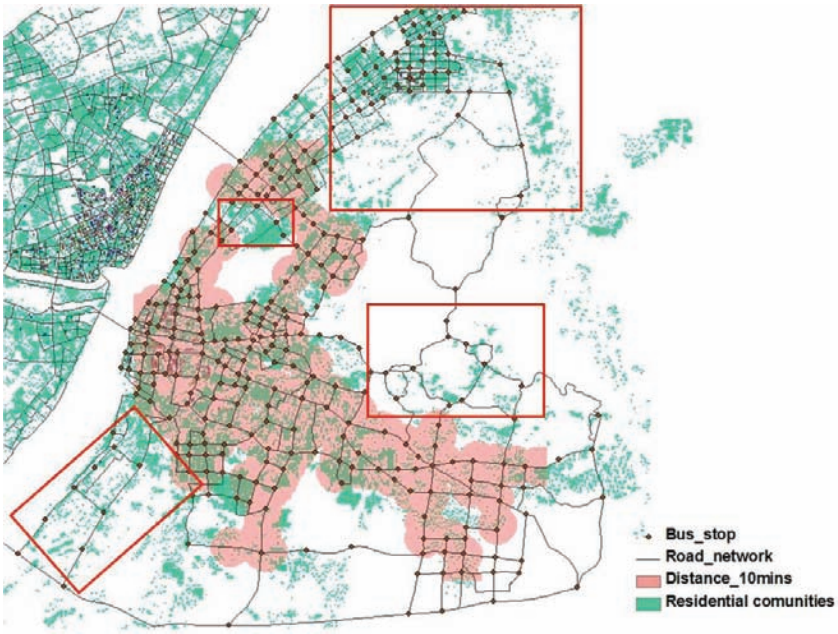



*Figure 5-25 Distance of allocating residential communities to bike stations within 10 minutes (in Wuchang)*

#### 5.3.2.3 Bike stations and specified facilities

As discussed in section 4.2.2.4, the accessibility between bike stations and specific facilities (e.g. business area, college, entertainment) should be analyzed. And the operational process of analysis is in accordance with the flowchart (*Figure 4-8*) in section 4.2.2.4. As described in section 5.3.2.2 the maximal walking time between bike station and specific facility is defined as 10 minutes.

- ***Bike stations and business area***

The data of business area is derived from raster data of land use pattern, based on "DESCR" in attribute table. In the results of analysis, of all the business in center area of Wuchang district are allocated to bike stations during 10 minutes, and business in red box(*Figure 5-26*) are not serviced by bike stations.

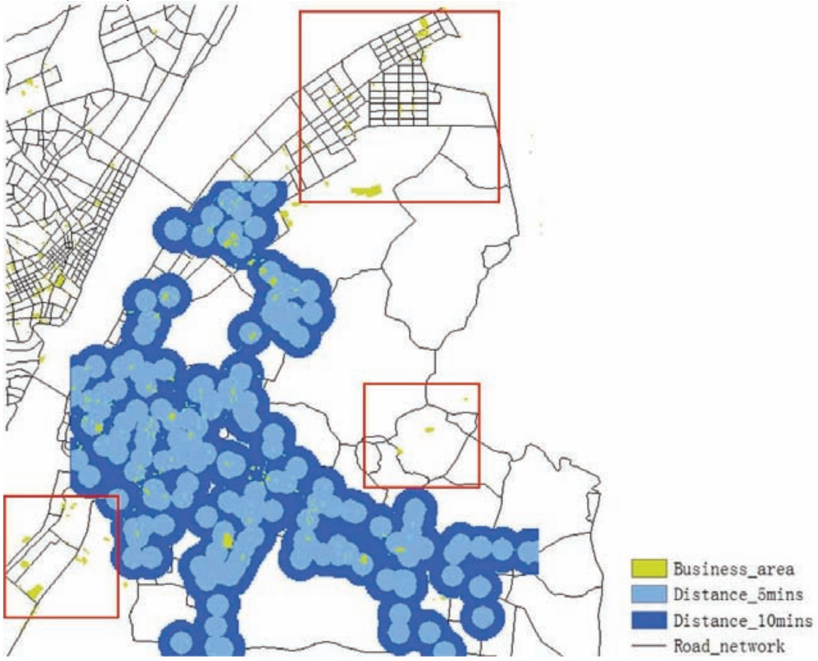



*Figure 5-26 Distance of allocating business to bike stations in 10mins (in Wuchang)*

- ***Bike stations and colleges***

The data of colleges are derived from raster data of land use pattern based on variety of colleges in “DESCR” of attribute table. The selected varieties of colleges are higher education institution, secondary specialized school, and adult and continuation school.

The colleges in red box (Figure5-27) reflect that there is no adequate bike station to service that area.

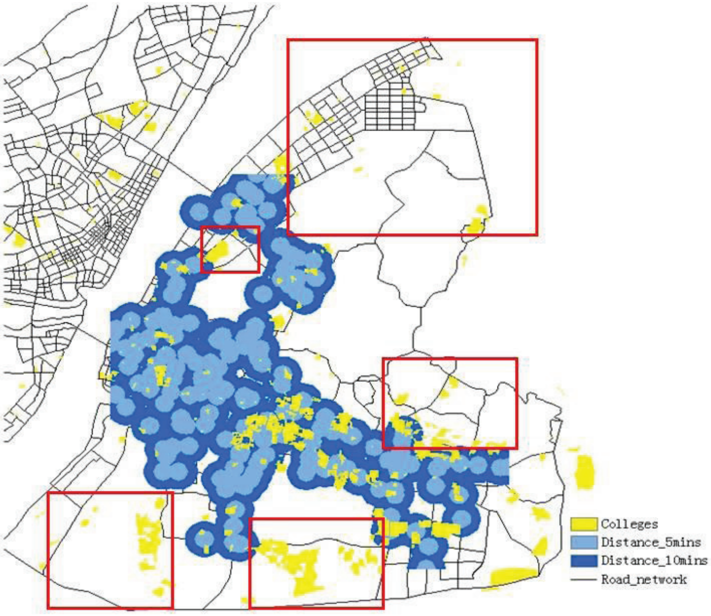



*Figure5-27 Distance of allocating colleges to bike stations in 10mins (in Wuchang)*

- ***Bike stations and entertainment***

The method on extracting data of entertainment from raster data of land use pattern is similar with college, and the selected varieties of entertainment are book stores, cinemas, recreation, stadiums and parks. The entertainment in red box (Figure5-28) indicates that there is an insufficient bike station.

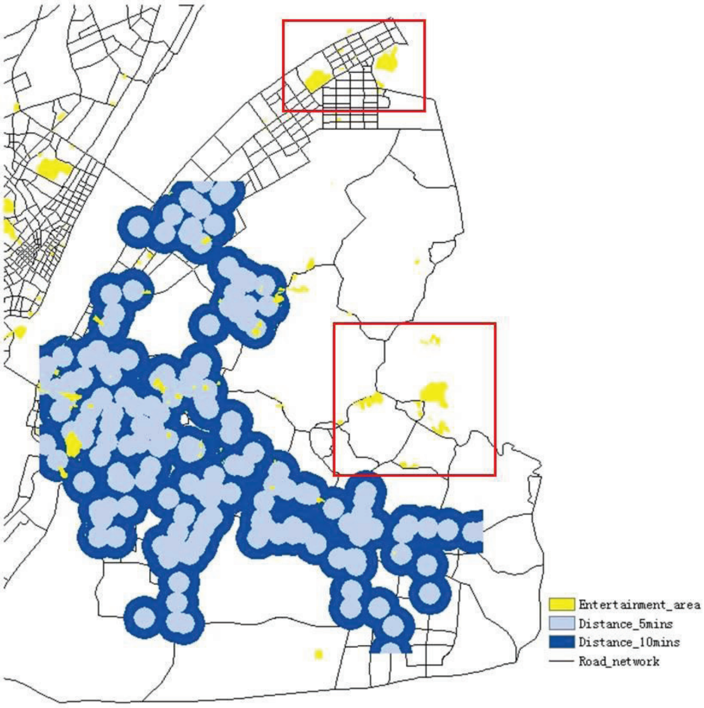



*Figure5-28 Distance of allocating entertainment to bike stations in 10mins (in Wuchang)*

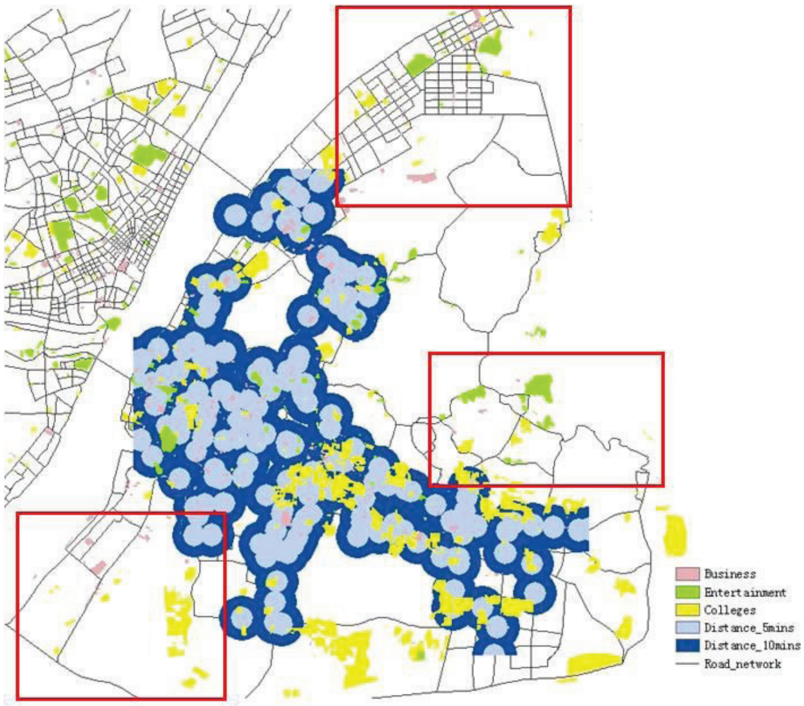



*Figure 5-29 Distance of allocating specific facilities to bike stations in 10 minutes (in Wuchang)*

- ***Conclusion***

According to the results of accessibility analysis between bike stations and business, college and entertainment, in general, the areas that no adequate bike stations are almost the same part in Wuchang district (see *Figure 5-29*). And there are existing problems on the locations of some bike stations, due to the spacing of two stations is too close, so it is necessary to optimize the location of these bike stations. The more detail optimization will be shown in chapter 5.4.

#### 5.3.3 Discussion

Based on the accessibility analysis, to some extent, it is easier to find that the interconnection between bike stations and bus stops, residential communities, colleges is poor. Almost half of the bus stops are not served by bike stations in 10mins (see section 5.3.2.1). And there are deficient bike stations in some areas with high population density (see section5.3.2.2). Moreover, by analyzing the accessibility between bike stations and specific facilities, it is easier to find that the areas with insufficient bike stations are nearly the same part in Wuchang district (see section5.3.2.3 ). Consequently, it is necessary to implement a optimization model to improve the performance of this bike sharing system.

Furthermore, in this research, the data of bike stations in Wuchang district only incorporates the bike stations which are within third ring, and which are operated by Xinfeida Bicycle Company (main operator of Wuhan's bike sharing system). Because the bike stations in Qingshan zone of Wuchang district are operated by another company which only builds the bike sharing system of Qingshan zone, then these bike stations are not included in this research. Because the two bike sharing systems are two separate bike sharing systems, bike users cannot rent bikes mixed. Moreover, the bike sharing system which is operated by Xinfeida Bicycle Company is the main bike sharing system in Wuhan. Therefore, this research only focuses on the bike sharing system operated by Xinfeida Bicycle Company.

## 5.4 Spatial location optimization for bike stations

As described in section4.2.3.1, the optimization will be performed in the combination of *Coverage model* and *Reduction mode*. Coverage model is used for locating new bike stations in the area with insufficient bike stations, and optimizing the existing bike stations. Reduction model is used for reducing the redundant new bike stations. Moreover, the analysis process of optimization is in accordance with the theoretical framework described in section4.2.3.1. According to the theoretical description, the procedures of optimization as follows:

- **Step 1**: Selecting bus stops which are out of the coverage of bike stations, based on section 5.3.2 Accessibility analysis.


*Figure 5-30 Bus stops which do cover and not cover bike stations in 10mins*

Bus stops which do not cover bike stations will be selected to be used for optimizing bike stations.

- **Step 2**: Building of network dataset based on road network.

Because bike sharing system integrated with public transport system, people walk between bus stops and bike stations. Because the walking speed is determined by physique, it is hard to identify an accurate value of walking speed. In this study, the walking speed is defined as 4km/h (Zuidgeest et al. 2009).

Therefore, in order to build network dataset in ArcCatalog, in the attribute table of road network, the travel time is calculated by dividing shape length by walking speed.

- **Step 3**: Estimation of access time to bus stops and subway stations.

In this study, during the investigation on bike users, they said that the suitable walking time between bike stations and bus stops is within 10 minutes. Therefore, the maximal access time is defined as 10 minutes.

- **Step 4**: Network Analysis —— to calculate maximal service area of bus stops and subway stations.

Service area analysis of Network Analyst in ArcGIS is used to calculate service area of bus stops. Road network dataset has been created in step 2. In the service area analysis, bus stops are defined as facilities to create service area. Because maximal access time is defined as 10 minutes, in “Layer Properties”, the search tolerance is set as 670 meters which is equal to multiply maximal access time by walking speed. In the previous accessibility analysis on the bus stops and existing bike stations, 80% of bike stations were covered by bus stops within 5 minutes. Moreover, a standard distance threshold of 0.4km was used for walking to bus stops (Zuidgeest et al. 2009). With respect to the optimization, in order to balance the walking time between bike station and bus stop, the "Settings of Default Breaks" in "Layer Properties" is defined as 6 and 10 minutes.

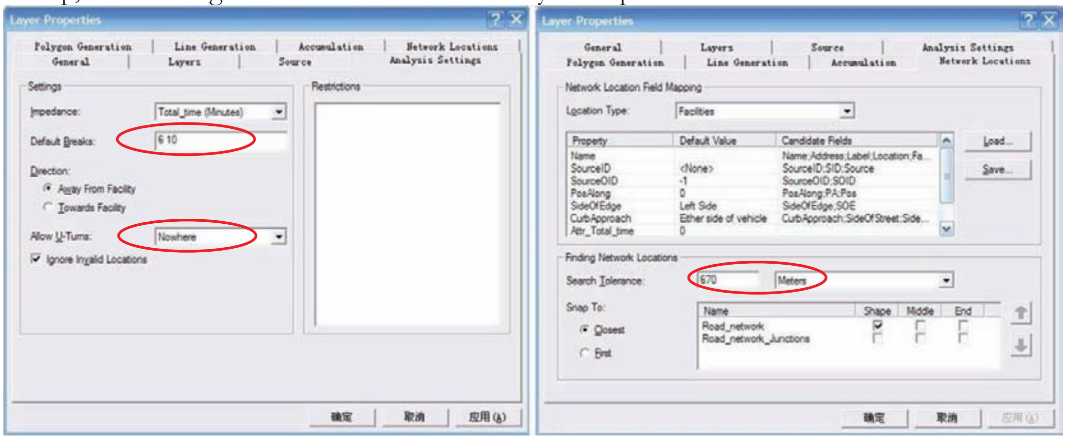



*Figure 5-31 Settings of Layer Properties in Service area analysis*

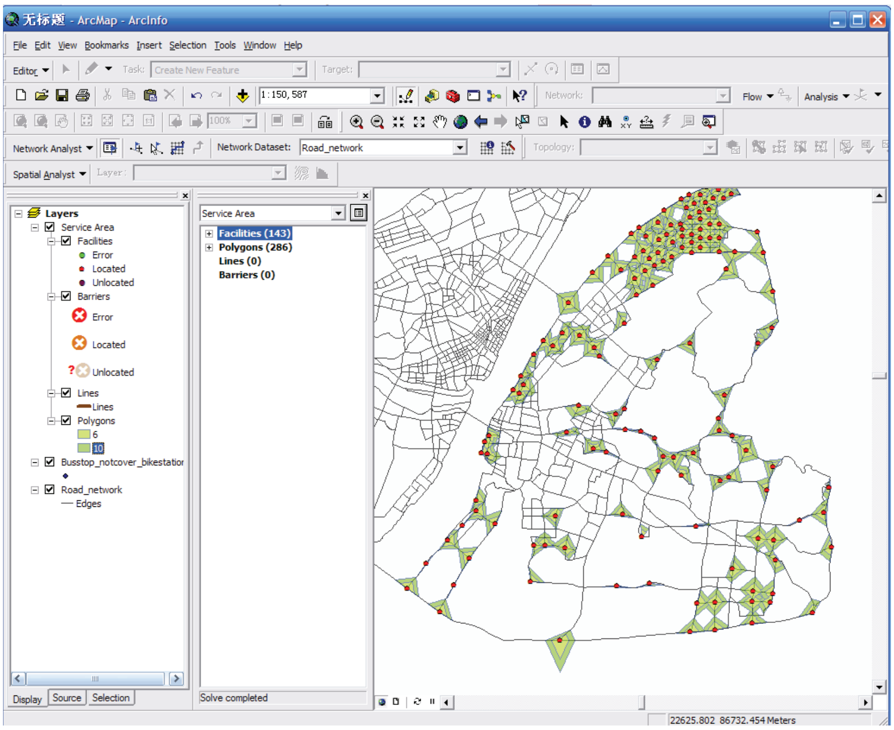



*Figure 5-32 Service area of bus stops in 10 minutes*

- **Step 5**: Optimizing location of some existing bike stations, and locating new bike stations within service area of bus stops along road network, based on station spacing, and population distribution in the study area.

In the perspective of bike stations which is divided into existing bike stations and new bike stations, the operation of step5 will be implemented in accordance with the following parts.

- Existing bike stations —— because the locations of some bike stations are too close which results in a bus stop is served by two or more bike stations, and some bus stops are not served by a bike station (see red circle in *Figure 5-33*), this will result in irrational utilization of bike stations for bike users. It is necessary to adjust the locations of these bike stations slightly based on population distribution.

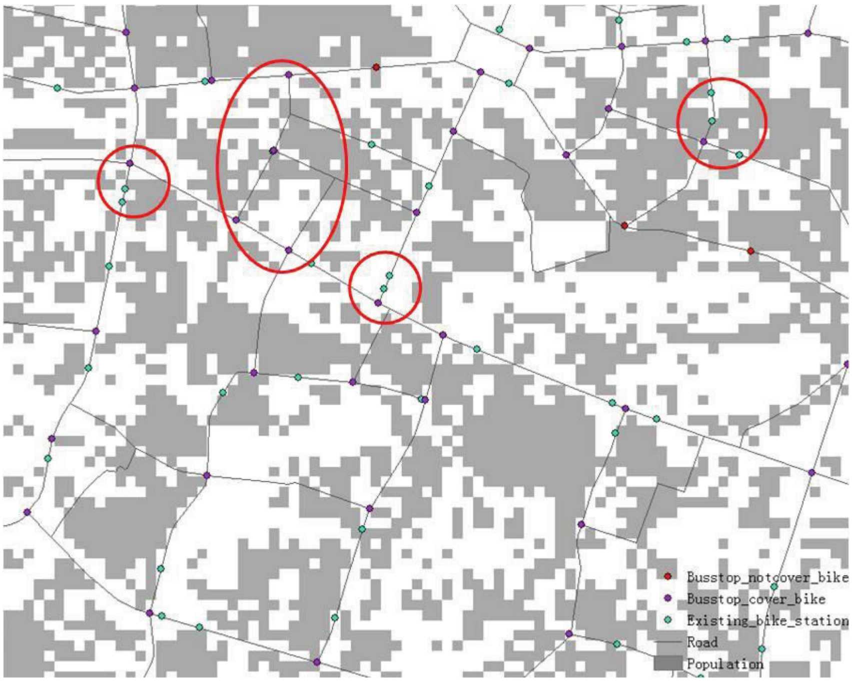



*Figure 5-33 Problems of existing bike stations' locations*

- New bike stations —— the objective of allocating new bike stations is to deal with the problems about the insufficient bike stations in some area. With respect to locating new bike stations, two aspects are taken into consideration. First, to locate bike station as transfer station in maximal service area of each bus stop. Second, to locate new bike stations as terminal stations, if the spacing of two bikes stations beyond 30 minutes by biking, or if there is unbalanced between bike station and population distribution in the area.

After the analysis, the new bike stations are allocated, and existing bike stations are optimal. However, according to the measures to locate new bike stations, lots of bike stations are located, but some of them are redundant. In order to make the bike stations can be efficiency and effectively utilized, it is necessary to reduce the redundant bike stations based on reduction model.

- **Step 6**: Reducing redundant bike stations based on reduction model.

According to two criterions described in section4.2.2, the redundant bike stations are removed.

The first criterion is to remove the bike stations which are along express way, because MOC(1995) provide that bike stations cannot be built on express way. In study area, there is only third ring of road network is express way, so the bike stations on the third ring are removed.


*Figure 5-34 Express way of Road network*

The second criterion is to remove bike stations which around bus stops, if there is no population distribution in the maximal service area of bus stops. As figure shown (Figure 5-35), there is no population distributed in the service area (see "blue circle" in Figure 5-35), so it is unnecessary to build bike station around bus stop as transfer station.

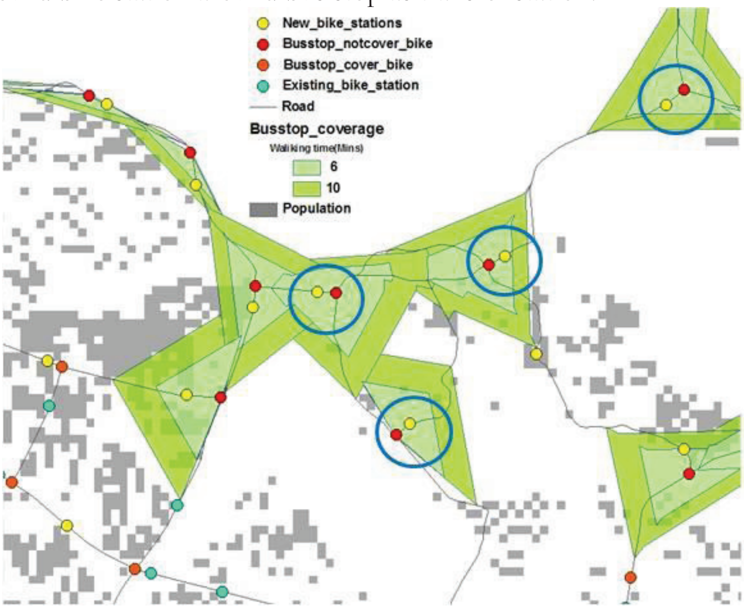



*Figure 5-35 Population and bus stops distributed in study area*

Therefore, of all the bike stations satisfy these two criterions will be removed. After removing redundant bike stations, the number of new additional bike stations is 174, and the total optimal bike stations are 342. *Figure 5-36* shows optimal bike stations including new bike stations and existing bike stations. *Figure 5-37* shows the distribution of bus stops and optimal bike stations.

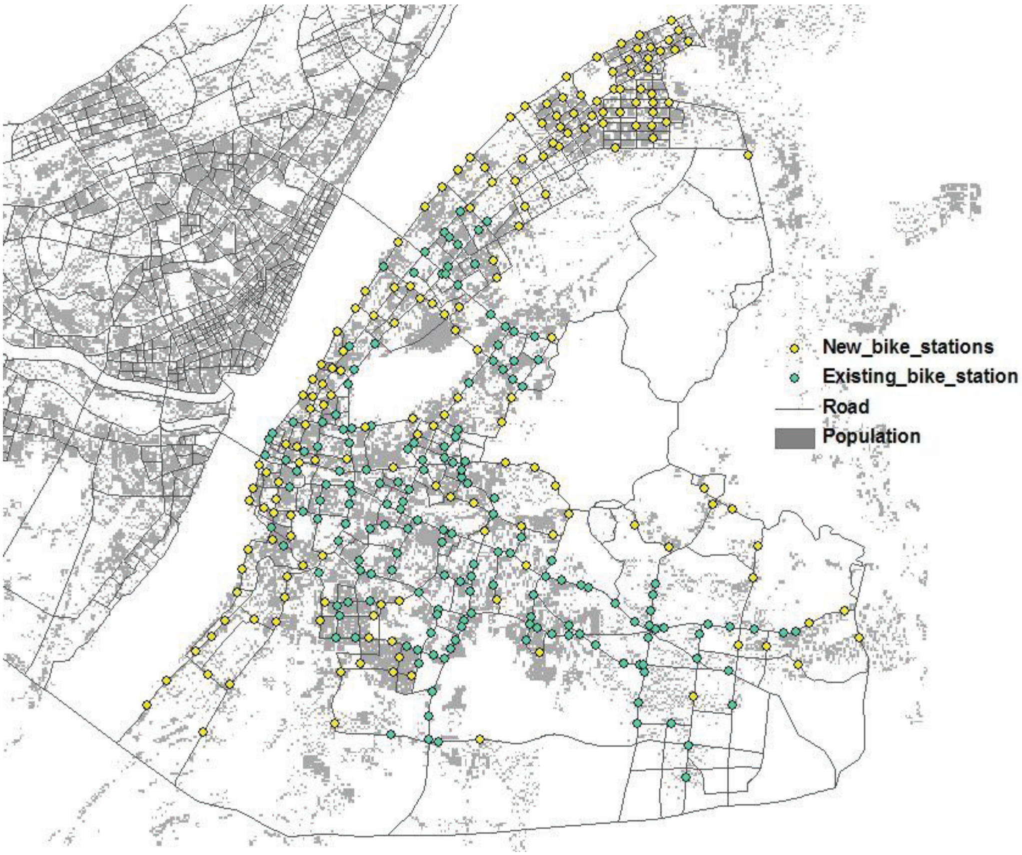



*Figure 5-36 Optimal bike stations*


*Figure 5-37 Bus stops and Optimal bike stations*

# 6. CONCLUSIONS

The objective of this research is to evaluate the performance of bike sharing system in Wuhan in order to detect whether the bike sharing system is efficient. And based on the results of evaluation (see section5.3.2), a method is implemented for spatial location optimization of bike stations (see section5.4). A series of research questions have been addressed accordingly, following the research method (see section4.2) has been proposed.

The results of performance evaluation of bike sharing system and optimized bike stations are finally achieved following the proposed research methodology, the research questions (see section 1.4) are answered consequently.

## 6.1 Achievement of this research

- ***Q1: what elements will be set as "characteristics" of bike uses?***

Understanding the characteristics of bike users aims to detect the operational efficiency of bike sharing system; this is closely related to the rationality and suitability of bike stations' location and capacity. In this study, the characteristics of bike users are understood by knowing the profile of bike users, and bike users' views to bike sharing system. Therefore, the "characteristics" of bike users are set as travel profile of bike users, and bike users' view to bike sharing system. Moreover, the profile of bike users including bike users' age, job, income, travel purpose, rental time, and integrated travel mode, and the reason for renting bikes. A series of results are obtained from a survey. The more detailed results are shown in section 5.1.

- ***Q2: How to define and perform "characteristics" of bike stations for analysis?***

The objective of analyzing the characteristics of bike station is to analyze the spatial characteristics and non-spatial characteristic of bike stations, both of which have an effect on the spatial effectiveness of bike sharing system. With respect to spatial characteristic, it includes catchment of bike stations and station spacing between bike stations; and the station spacing is performed in terms of travel time. And non-spatial characteristic of bike station is concerned about potential catchment population of bike stations.

Furthermore, the analysis of catchment and station spacing of bike stations are operated in ArcGIS, by using network analyst. And a computation method is implemented for calculating catchment population of bike stations. The procedure and results are performed in section 5.3.1.

- ***Q3: What method will be implemented for accessibility analysis?***

Accessibility of bike stations is an aspect of an aspect of spatial effectiveness that influences the performance of bike sharing system. In this study, the accessibility analysis aims at evaluating whether the accessibility between bike stations and other facilities (i.e. bus stops, metro stations, residential communities, colleges, business area, and entertainment area) is effectiveness, and the accessibility is evaluated in terms of travel time.

Accessibility analysis between bike stations and other facilities is divided into two parts; one is for analyzing the accessibility between bike stations and bus stops or metro stations, another is for analyzing the accessibility between bike stations and the rest facilities. And the procedure of method on accessibility analysis was operated in ArcGIS. In light of accessibility analysis (see section 5.3.2), it is easy to find that the accessibility between bike stations and other facilities needs to be improved, because some of the other facilities are not covered by bike stations in certain time.

- ***Q4: what criterions can be set for evaluation of bike lane?***

Bicycle lane is a part of bike sharing system, and it has a great influence on the performance of bike sharing system. In this study, the "performance" of bike sharing system is defined as operational efficiency and spatial effectiveness, so the evaluation of bike lane is focused on the aspects that influence the operational performance of bike sharing system. Consequently, the criterions for the evaluation of bike lane are set as: construction of bike lane, and operation of bike lane. The more detailed analysis is shown in section 5.2.

- ***Q5: Which model will be set for spatial location optimization?***

In this study, the method of optimizing bike stations is a straightforward method based on spatial analysis, which focuses on access and accessibility analysis. In this study, the bike stations are seen as terminal stations and transfer stations. The optimization is performed by the combination of coverage model and reduction model. The objective of coverage model is to optimize the locations of some existing bike stations, and to locate new bike stations in areas where there are insufficient bike stations. And then, reduction model is used to reduce redundant new bike stations. Both coverage model and reduction mode are performed based on population distribution, maximal service area, and station spacing. ArcGIS is used in the setting up of the model.

## 6.2 Limitation of this research

The analysis on the performance evaluation of bike sharing system and optimization of bike stations were presented gradually from data collection and analysis procedures to the analysis results. Due to the limitation of research time and unavailable data, there are some of deficiencies in this research, as follows:

- ***The survey on bike sharing system is not detailed***

In this study, the survey on bike users is general, which aims to overall understand the characteristics of bike users. Due to the limited time of investigation, the survey was mainly operated in peak hours and focused on bike users. However, if there were enough time, the survey can be implemented by investigating bike users evenly in peak hours and off-peak hours, and recording the information of renting and returning bikes in survey period at the same time. In this way, the detailed actual information of bike sharing system can be received.

- ***Insufficient data impair the accuracy of analysis results***

In this study, only the data of road network, bus stops, metro stations, population distribution, and land use pattern are available. The data of bike stations, colleges, community, and business are unavailable. Due to this reason, the data of bike stations were vectorized by combining the information of location of bike stations and Google map. And the data of business and colleges were extracted from the raster data of land use pattern. Therefore, in the accessibility analysis between bike stations and other facilities, the data of other facilities were not the location of these facilities, instead of polygon data which were extracted from the raster data of land use pattern.

Furthermore, in this research, the data of bike stations in Wuchang district only incorporates the bike stations which are within third ring, and which are operated by Xinfeida Bicycle Company. Because the bike stations in Qingshan zone of Wuchang district are operated by another bicycle company which only builds the bike system of Qingshan zone, then these bike stations are not included in this research.

To some extent, with respect to the accessibility analysis between bike stations and other facilities, this could impair the accuracy of analysis results.

- ***Optimization method has an effect on the results of optimization***

The optimization model was operated by combining coverage model and reduction model, as discussed in section 4.2.3. Due to the limited research time, for locating new bike stations and reducing redundant bike stations, a straightforward method – by manual – was proposed instead of working out automatically by running software. Hence, in this study, the optimization model was performed in ArcGIS based on the constraint conditions step by step, and some of the subjective ideas were inevitable when locating new bike stations and reducing redundant bike stations. However, adoptions of running software to operate coverage model and reduction model automatically maybe achieve more detailed or simple results of bike stations' distribution.

## 6.3 Recommendations for further research

- ***Quantitative traffic flow data is need to analyze the demand of bike station***

Because of the unavailable data of traffic flow, the demand of bike stations was analyzed by calculating the catchment population of bike stations and being focused on the potential bike users. The results of analysis of catchment population could only get the general result of the demand of bike stations. But the results cannot be seen as the actual situation of bike stations' demand. Therefore, it is better to analyze the demand of bike stations by using traffic flow data, which can be more practical for improving the balanced supply and demand of bike stations.

- ***Method of spatial location optimization of bike stations can be improved***

Due to the limited research time, a straightforward method was used for optimizing spatial location of bike stations, and it has a little limitation to generate new bike stations and reduce redundant bike stations, and also to the results of bike stations' location. In future research, a spatial analysis method combined with simulation software can be used to optimize the spatial location of bike stations, to avoid the limitation of the optimization method proposed in this research.

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