GI Based Performance Evaluation of Bike Sharing System in Wuhan, China

1 RESEARCH BACKGROUND

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 (Figure 1), 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). 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 1 Worldwide Distribution of 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).Now, more and more Chinese cities start to build a bike sharing system, such as Shanghai, Hangzhou, Guangzhou, Wuhan and so on (Figure 2); moreover, the bike sharing system in some of these cities are working well, and the most successful one is the bike sharing system in Hangzhou. In addition, Wuhan is the first city that launches a free public bike sharing system in China since 2009.

Figure 2 Bike Sharing System in Chinese cities
(Source: http://www.chinabikesharing.org/)

This paper focuses on evaluating the performance of bicycle sharing system in Wuchang area, one of the three major urban areas of Wuhan. In this study, the "performance" evaluation is operated in two dimensions: operational efficiency and spatial effectiveness. The "operational efficiency" 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. Besides, the "spatial effectiveness" 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.

2 CHARACTERISTICS OF BIKE SHARING SYSTEM IN WUHAN

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 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 Wuhan Bike Sharing System
(Source: http://www.chinabikesharing.org/)

- ***Implementation of Wuhan's Bike Sharing System***

Since 2010, the sites selection of 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.

- ***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.

- ***Operations of Wuhan's Bike Sharing System***

This bicycle sharing system is a "manual + self-service" system *t*o achieve 24 hours service (Figure 4); 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 4 Manual & Self-service system of Wuhan's bike sharing system

- ***Feedback Since Operation 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.

However, 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.

- ***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.

3 PERFORMANCE SURVEY

In order to do analysis on evaluating the performance of bike sharing system, the available data——road network data (polyline), land use pattern data(polygon), data on population distribution (raster), existing bike stations (point), bus stop locations (point), metro stations (point)——were collected.

In addition, with the purpose of understanding the characteristics of bike users, a 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, bus stops. Due to several reasons (e.g. limited time…), only 200 samples of questionnaires were distributed at 24 bike stations, including weekdays and weekend. In order to investigate 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. At last, the results were concluded and are shown in the following figures (Figure 5,Figure 6,Figure 7,Figure 8,Figure 9). And most of the bike users responded that they wanted to find a bike station in 5 minutes but not further than 10 minutes by walking from their home or work place.

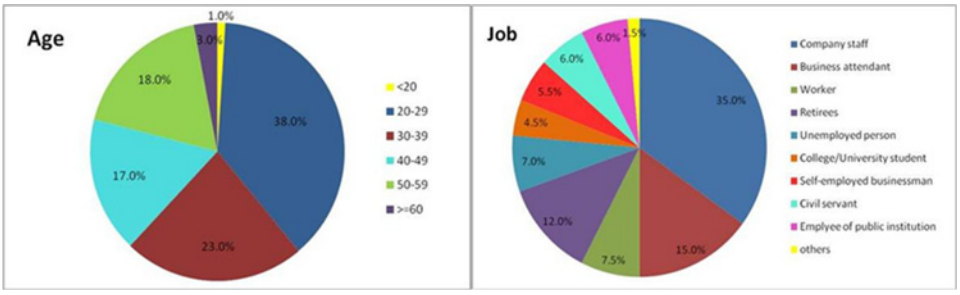


Figure 5 Bike Users' age (left) and Bike Users' job (right)

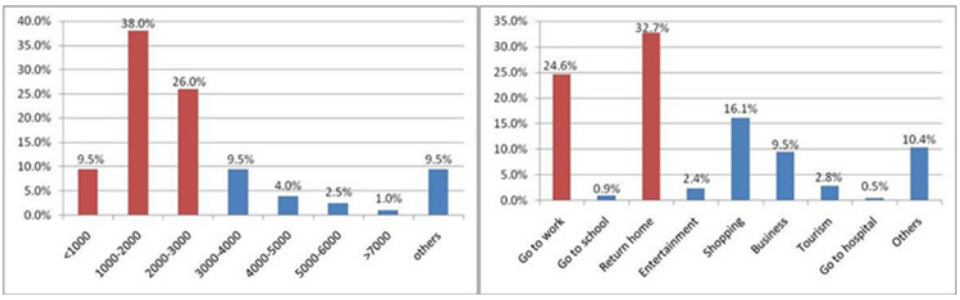


Figure 6 Bike Users' income (left) and Travel Purpose (right)

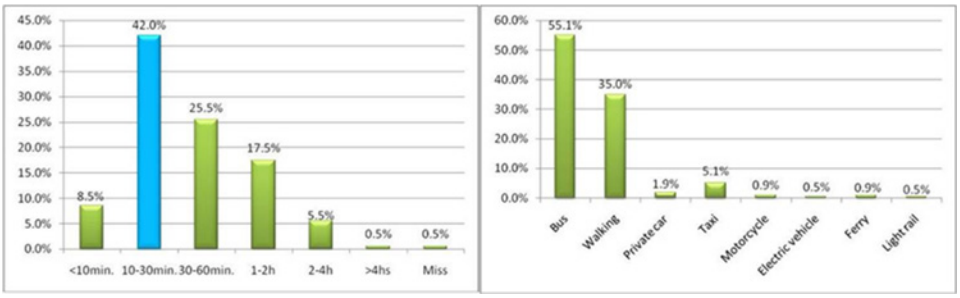
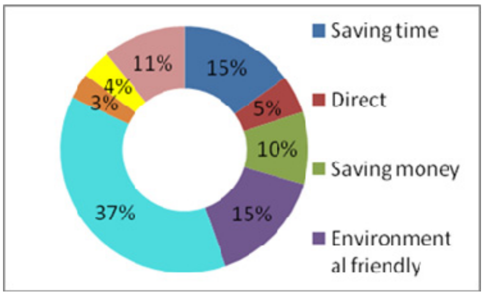


Figure 7 Rental Time (left) and Integrated Travel Mode (right)



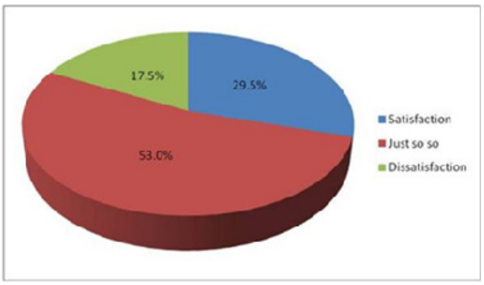


Figure 8 Reasons for Renting Bikes *Figure 9 Bike users' view to bike sharing system*

4 PERFORMANCE EVALUATION OF BICYCLE LANE

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 the 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 identifies 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 (Figure 10).

Figure 10 Bike Lane Network

In light of the results, the bike lane network is not completed and connectivity. The discontinuous bike lanes are shown in blue box (Figure 10), 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 bike lane***

The analysis on the 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 solution only emphasized the right of way on motor vehicles. But the right of way on bicycles has been lost gradually (Figure 11).

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.

Figure 11 Bike lane in Wuchang area

5 SPATIAL ANALYSIS ON BIKE STATIONS

5.1 Characteristics of Bike Stations

- ***Catchment population 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, 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.

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 (Figure 12(left)). Because the population data has been collected, the catchment population is used to calculate the potential population served by each bike station, and the results are shown in Figure 12(right).

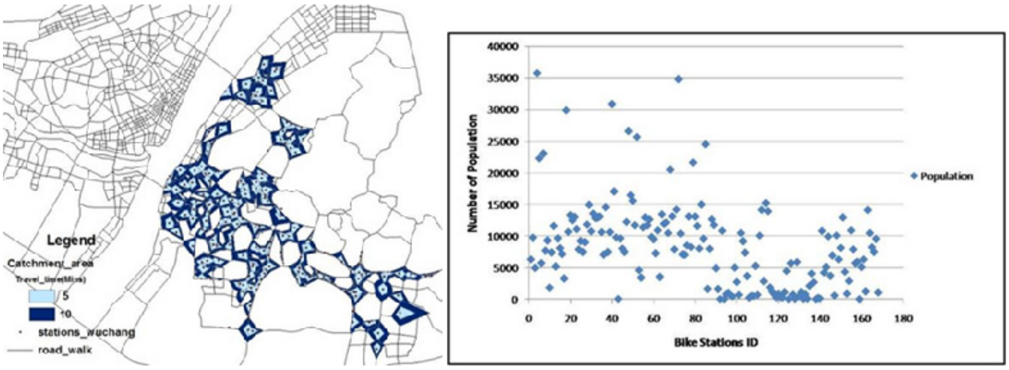


Figure 12 Catchment area (left) and catchment population (right) of bike stations in Wuchang area

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

Given that the survey in Wuchang area, 62% of respondents use bikes to transfer to public transportation, and 36% of respondents use bikes as an only mode of transportation. 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 was performed by using Network Analyst in ArcGIS. After the automatic running of analysis, the results of travel time between bike stations are derived: 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.

5.2 Accessibility Analysis

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.

- ***Accessibility between bus stops and bike stations***

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; 10minutes is identified based on performance survey in this study (see chapter3). Moreover, the theory on MSAP (maximal service area problem) is considered to deal with service area of facilities. The analysis was operated by using Network Analyst in ArcGIS, and the results were performed in ArcGIS (see Figure 13, Figure 14).

Figure 13 Number of bike stations covered by per bus stop in 10 minutes

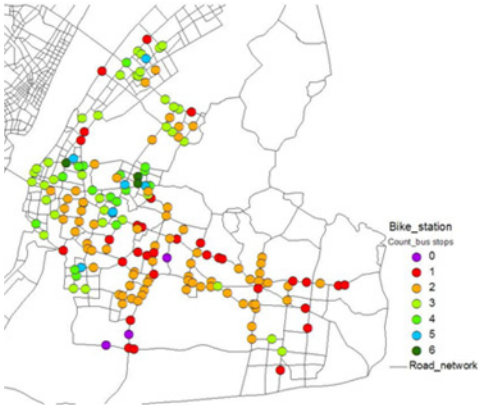


Figure 14 Number of bus stops covered by per bike station in 10 minutes

In the results, during 10 minutes, 55% of bus stops are covered by bike stations, but 45% of bus stops are not covered by bike stations (Figure 13). Moreover, some of the bike stations only serve 1 bus stop, but some serve 2 to 6 bus stops (Figure 14), so the spacing between bus stops and bike stations should be improved.

- ***Accessibility between bike stations and communities or specific facilities***

According to the principle of planning and building bike stations— bike stations are built around specific facilities (i.e. business, college, entertainment), and 57.3% of respondents in investigation who use bikes for commuting trips (see Figure 5), it is necessary to analyze the accessibility between bike station and specific facilities 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. And the data of population distribution is used as the location of residential communities (Figure 15(left)). The accessibility analysis was operated by using Network Analyst in ArcGIS, the area with no adequate are shown in red box (see Figure 15)

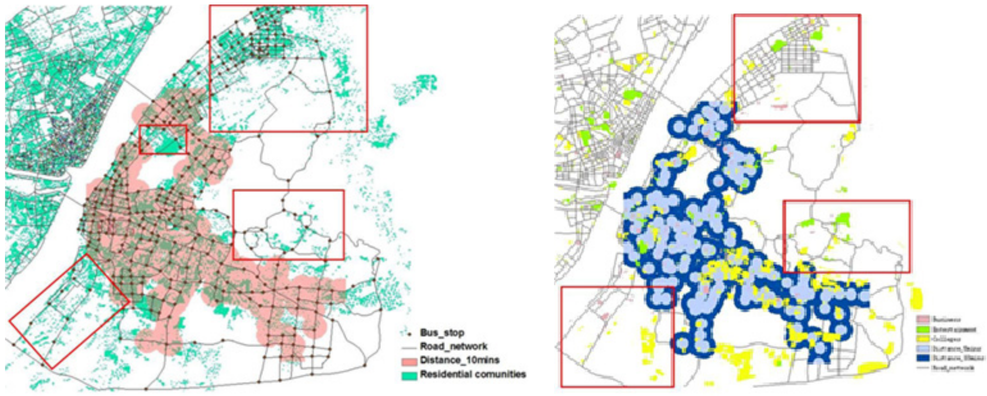


Figure 15 Distance of allocating communities (left) and specific facilities (right) to bike stations in 10 minutes (in Wuchang)

According to the results of accessibility analysis between bike stations and communities or specific facilities, the areas with insufficient bike stations are almost the same part in Wuchang area (see red box in Figure 15), in which the bus stops are not covered by bike station.

5.3 Optimization of Station Distribution

In this study, the method of optimizing bike stations is a straightforward method based on spatial analysis, which focuses on access and accessibility analysis. And the bike stations are seen as terminal stations and transfer stations in this research. The optimization is performed in two phases (coverage method and reduction method), and both two phases are performed based on population distribution, maximal service area, and station spacing. The process of optimization was operated in ArcGIS.

- The first phase (coverage method) is to optimize the locations of some existing bike stations, and to locate new bike stations in areas where there are insufficient bike stations.
- The second phase (reduction method) is to reduce redundant new bike stations which were located in the first phase. In addition, the reduction method was operated in accordance with the following two criterions: first is to remove the bike stations which are along express way; second is to remove bike stations which around bus stops, if there is no population distributed in the maximal service area of bus stop.

Finally, after the optimization, the number of new additional bike stations is 174, and the total optimal bike stations is 342 (original bike stations is 168). Figure 16(left) shows optimal bike stations including new bike stations and existing bike stations. Figure 16(right) shows the distribution of bus stops and optimal bike stations.

Figure 16 Optimal bike stations (left) & Bus stops and Optimal bike stations (right)

6 CONCLUSIONS

The bike sharing system in Wuhan is in general working well. Distribution of bike stations has been planned, and bike stations have been deployed in major urban areas of the city. From on-site survey, the usage rate is quite high. However, some problems need to be tacked. Firstly, there is serious shortage on the right-of-way bike lanes. Secondly, the spatial distribution of bike stations needs further improvement, especially in terms of the relation with bus and subway stops. Thirdly, the whole urban area of the city has not yet been fully covered.

Due to the limitation of research time and unavailable data, there are some of deficiencies in this research. Firstly, the quantitative traffic flow data is needed to analyze the demand of bike station. In this case, it will be more practical for improving the balanced supply and demand of bike stations. Secondly, it is necessary to implement an optimization model to improve the spatial effectiveness of bike stations. Methods applied in this research can be further improved. For example, a spatial analysis method combined with simulation software can be used to optimize the spatial location of bike stations.

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