SPATIAL LOCATION-ALLOCATION MODELING OF BIKE SHARING SYSTEMS: A LITERATURE SEARCH

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ABSTRACT

Bike sharing systems have been appearing in more and more cities around the world. This programme provides the general public with free or affordable access to public bicycles, and promotes the integration of public transport systems and bike sharing systems to improve mobility, traffic and environment related problems. As to this programme, the location-allocation of the bike rental stations is the key determinant that influences the performance of the bike sharing system, and determines whether bike sharing system has a good connectivity with other external systems (i.e. public bus system, public facilities…) in urban area, and whether the spatial interaction between bike rental stations is effective. Therefore, a rational and effective location-allocation of bike rental stations decides whether bike sharing programmes can develop smoothly and successfully. This paper aims at providing a literature survey on the implementation and of bike sharing systems, scientific studies on bike sharing system, and location-allocation model. And based on the literature survey, this paper proposes four key-points relating to the location-allocation of bike rental stations.

Keywords: bike sharing system, location-allocation model, literature survey

1. INTRODUCTION

With the rapid development of motorization and urbanization, urban mobility and accessibility are declining in the whole world, especially in the growing cities of Asia countries (Gakenheimer, 1999; Sudhakara Reddy et al., 2012). This causes various transport issues relating to urban mobility, such as traffic congestion, insufficient transport facilities, mode shift from public to private transport and etc. (da Silva et al., 2008; de Vasconcellos, 2005; Gakenheimer, 1999; Sudhakara Reddy et al., 2012). Moreover, the increasing use of private transport brings about negative externalities, including traffic accidents, traffic congestion and air pollution (de Vasconcellos, 2005; EuropeanCommission, 2007).

Against this context, the concept of sustainable transport started to attract wide attention. Sustainable transport refers to any types of transports with fuel-efficient, space-saving and healthy lifestyle, and calls for a balance between the transportation and resource needed by present and future generations(Han, 2010; Richardson, 2005). Particularly, non-motorized transport modes are concerned as vital determinants of sustainable transport (Rietveld et al., 2004), especially the bicycle being named as the individual non-motorized transport mode that is associated with the benefits in terms of environment, society and economy(Jensen et al., 2010; Pucher et al., 2010; Vandenbulcke et al., 2011; Wardman et al., 2007).

The combined use of bike and public transports for one trip, which has been regarded as part of the search for more sustainable transport solution, has grown over the past decades (Keijer et al., 2000; K. Martens, 2007). As a feeder mode, bicycle is faster than walk, and more flexible than other public transports; moreover, the use of bicycle as access/egress trip can substantially reduce the door-to-door travel time and improve the weak accessibility of public transport trips (Grotenhuis et al., 2007; Keijer et al., 2000; K. Martens, 2007). Hine et al. (2000) also indicated that the integrated use of bicycle and public transports can make the transfer and public transports become more attractive to passengers. However, given the growing consensus on the benefits of cycling, the important question for researchers is how to increase cycling (Pucher et al., 2010).

Recently, bike sharing systems have been launched as a kind of sustainable transport modes to address the issues relating to urban environment, society and transport, which provide public and easy access to bicycles, and offer an alternative to increase bicycle use by integrating public bicycle with other transport modes, and cover bicycle purchase and maintenance cost as well as storage and parking responsibilities (DeMaio, 2009; Shaheen et al., 2010). All these benefits make bike sharing systems more convenient and attractive to the users (DeMaio, 2009; Shaheen et al., 2010). However, in reality, there are common issues shown in the implementation of bike sharing systems, including the irrational distribution of bike stations, and imbalanced distribution of public bikes (Kaltenbrunner et al., 2010; Liu et al., 2012; Vogel et al., 2011).

Nowadays, Europe has experienced a real boom of bike sharing programs, which make the public bicycles accessible as a part of other public transports (Bührmann et al., 2008; Karel Martens, 2004). Moreover, there is an increase in cities around the world that have already implemented or planned to build bike sharing systems. Although bike sharing systems just started for short periods in Asia, China has shown great interests, and more than 10 Chinese cities have built bike sharing systems by now. In particular, the bike sharing system in the city of Hangzhou has become the largest system in the world (MIDGLEY, 2009).

2. OVERVIEW OF BIKE SHARING SYSTEM

2.1. Description of bike sharing systems

Bike sharing systems mean a number of public bicycles that can be picked up and dropped off at numerous fixed bike stations across an urban area, and mainly contains public bicycles, bicycle network, and bike rental stations with bicycle racks and service terminal (e.g. system access and user registration, information systems etc.), which are used to prevent the bicycles from theft and vandalism, and to record/track the rental information of public bikes (Figure 2-1) (CSD, 2011; TransportCanada, 2009). So far, there are basically two types of bike sharing systems, which are considered as "manual system" and "automated system"; the former one is supervised by staff when users renting/returning bicycles at bike stations; and the latter one is equipped with a self-service machine for providing users with renting/returning bikes(TransportCanada, 2009).

(a) Bike station (b) Service terminal (c) Bike racks

Figure 2-1 Bike sharing system in Nice, France.

Bike sharing is an innovative program that provides rental of free bicycles in inner urban areas, this is different from traditional, mostly leisure-oriented bicycle rental service as it provides fast and easy access and can be used for daily mobility (Bührmann, 2008). The public bicycles are available for shared use to the general public for free or against a small fee, which can serve as a feeder mode of public transportations (public bus, metro, etc.) or motorized vehicles to reduce traffic congestion, noise and air pollution (Figure 2-2) (MIDGLEY, 2009).

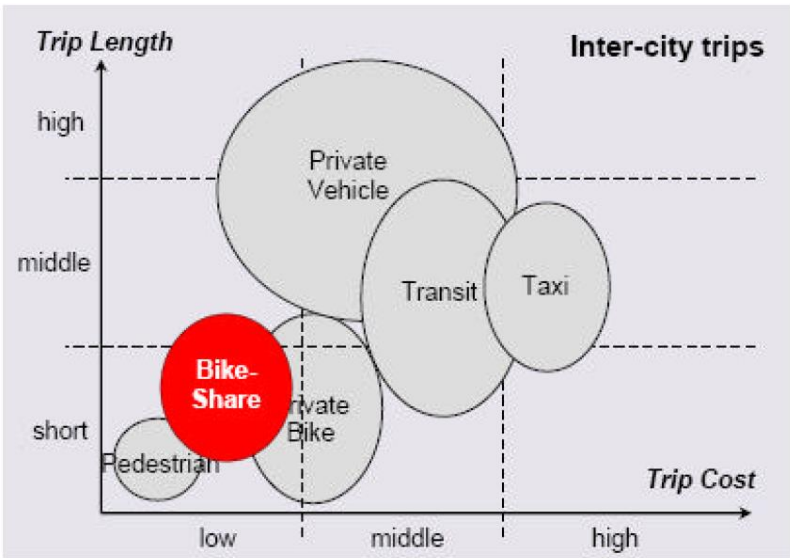


Figure 2-2 The role of public bicycles
(source:(CSD, 2011))

The basic premise of bike sharing programs is sustainable transport (MIDGLEY, 2009). It aims to increase bicycle usage, extend the accessibility of public transports to final destination, and lessen impacts of our current transport activities on environment and urban mobility (DeMaio, 2009; Kaltenbrunner et al., 2010; Lin et al., 2011). According to Bührmann (2008), bike sharing programs have a high added value in the long run if properly implemented, which can change people’s travel behavior and help to reach a real bicycle culture.

2.2. History of bike sharing systems

In retrospect to the evolution of bike sharing systems, it can be categorized into four generations: white bikes, coin-deposit systems, information technology based systems, and demand-responsive and multimodal systems. Bike sharing systems primarily originated in Europe, but now it has been spread around Americas and Asia (DeMaio, 2009; Shaheen et al., 2010).

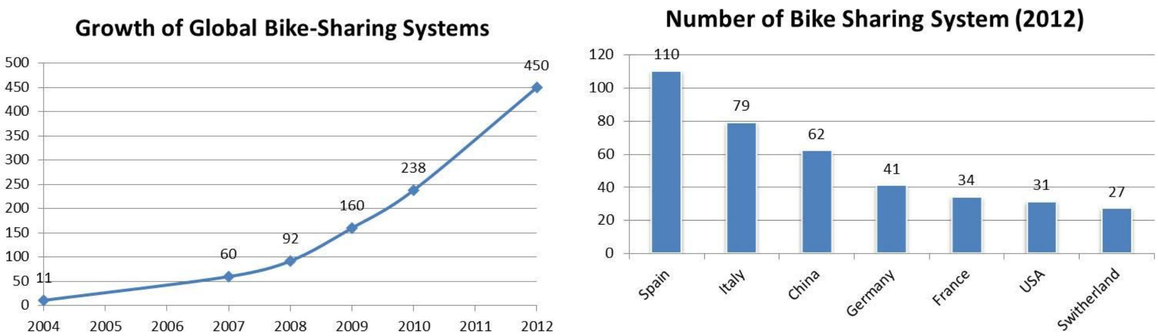
The 1st generation began in 1964 in Amsterdam called White Bike Plan which was seen as the solution to traffic problem. The operators gathered a handful of bicycles, which were painted white, left permanently unlocked and distributed across the inner city of Amsterdam for freely use to the general public. However, this program didn‘t go as planned since the bikes were stolen or damaged, so that this system collapsed within days (DeMaio, 2009; Shaheen et al., 2010).

Nearly 30 years later, in 1995, a new bike sharing system called Bycyklen was operated in Copenhagen, which represented the 2nd generation of bike sharing system, with many improvements in contrast to the 1st generation. This bike sharing system were specially designed, users could pick up and return bikes at specific bike stations throughout the central urban area with a coin deposit. Despite 2nd generation -- with stations and organization to operate the program -- is more formalized than the 1st generation, it still experienced the theft and damage of bicycles due to the anonymous use of customers (DeMaio, 2009; Shaheen et al., 2010).

By contrast with the first two generations, the 3rd generation is smartened with a variety of technological improvements, including electronically locking racks or bike locks, telecommunication systems, smartcards, mobile phone access and on-board computers. Nowadays, the bike sharing systems have evolved to a fourth generation, called demand-responsive and multimodal systems, which builds on the third generation (DeMaio, 2009; Shaheen et al., 2010).

Bike sharing programs have grown in popularity throughout the world, availability studies show that these programs are well used, and that cycling has increased in cities which have implemented bike sharing programs (Pucher et al., 2010). According to the unscientific count of bike sharing world map (Figure 2-3), a growing list of cities have built bike sharing systems, and around 450 systems were built in the world (Figure 2-4 (a)) and most systems were launched in Spain, Italy, France, Germany, China, etc. (Figure 2-4 (b)) (BSB, 2009). By now, Europe remains the leadership for the growth, development and success of bike sharing systems (BSB, 2009; Shaheen et al., 2010). Moreover, China and USA also show their interests in the implementation of bike sharing systems. In addition, among the existing bike sharing systems in the whole world, Vélib system (France) and Hangzhou system (China) can be the largest and successful bike sharing system (ITDP-China, 2010).

Figure 2-3 Bike Sharing World Map
(Source: (BSB, 2009)& Google)



(a) (b)

Figure 2-4 Growth of Global Bike-Sharing Systems (a) and Number of Bike Sharing System (2012) (b)

3. SURVEY OF STUDIES ON BIKE SHARING SYSTEMS AND LOCATION MODELS

3.1. State-of-the-art researches on bike sharing systems

Bike sharing systems have rapidly emerged around the world in recent years. In order to fully understand bike sharing systems, studies on such systems across multiple fields and are motivated by different issues (Borgnat et al., 2011; Lathia et al., 2012). Besides the guidelines introduced by governments and organizations which are operating bike sharing systems, studies on bike sharing systems mainly focus on three aspects.

Firstly, some studies paid attention to understanding the current situations or the operation of existing bike sharing system in a city. MIDGLEY (2009) reviewed the objectives and implementation bike sharing system, and introduced bike sharing systems that are operated in Paris, Barcelona and Italy. Jensen et al. (2010) discoursed that shared bicycles can compete with cars in terms of speed by analysing the data gathered relating to bicycle trips in Lyon. Fuller et al. (2011) found that the majority of public bike users are young people in Montreal, and the users regard cycling as the main mode of transportation to work and prefer to reach bike stations within 250 m of home. Lathia et al. (2012) found that quicker access to bike sharing system promotes the greater weekend usage and reinforces weekday commuting trend by analysing the passive sensor data of London’s shared bike programme. Fuller et al. (2012) found that greatly constrain the primary motorized mode of transportation may lead to short-term increase in cycling by investigating the immediate and sustained effects of two London Underground strikes on the use of shared bike programme. Liu et al. (2012) summarized the reasons that result in the failure of Beijing’s bike sharing system, for example, the irrational distribution of bike stations, users’ safety concerns, public bike equipment getting worse, and so on.

Secondly, some studies focused on applying a set of data mining techniques to explore spatial-temporal trends of bike sharing system in a city.Froehlich et al. (2008, 2009) operated spatial-temporal analysis on the usage data of Barcelona’s bike sharing system, to understand the human behaviour and city dynamics, and to reveal the relationship between activity, location of bike stations and time of the day. Kaltenbrunner et al. (2010) inferred the cycling activity of Barcelona’s population and their spatial-temporal distribution by using spatial-temporal data. AndBorgnat et al. (2011) modelled the time evolution of the dynamics of movement and disentangled the spatial patterns to understand and visualize the flow of bicycles in the city by relying on non-stationary statistical modelling and data mining. Vogel et al. (2011) provided Data Mining techniques to gain insight into activity patterns, and found that reasons for certain pickup and return activities at bike stations are complex and diverse.

Furthermore, little scientific studies proposed approaches on locational models of bike sharing system. Lin et al. (2011) adopted a hub and spoke distribution model to determine the locations of bike stations and bike lanes, which only considered direct links between stations to avoid all complications associated with assigning riding traffic on the built bike lanes of the existing street network. dell'Olio et al. (2011) proposed a stated preference survey for estimating potential users, and a model to determine the optimal area for locating bike rental stations by calculating the distance to public facilities, OD, and bike lanes. And García-Palomares et al. (2012) proposed a GIS-based method to calculate the spatial distribution of potential demand for public bicycle trips, and to determine the potential area for locating bike stations on workdays by using traditional location-allocation models (P-Median and Maximize Coverage). Additionally, Larsen et al. (2011) proposed a GIS-based grid cell method for bicycle facility prioritization and location, and suggested that this method can be used for bike sharing system, however, this method is only useful for identifying opportunity zones but not appropriate for detailed analysis.

In sum, the majority of the scientific researches mainly focused on understanding the existing bike sharing systems, and exploring spatial-temporal trends of bike sharing system in a city by using data mining techniques (Borgnat et al., 2011; Froehlich et al., 2008, 2009;

Kaltenbrunner et al., 2010; Vogel et al., 2011). Little scientific knowledge regards to determining the location and capacity of bike rental stations and the creation of underlying bicycle network (dell'Olio et al., 2011; García-Palomares et al., 2012; Lin et al., 2011). However, the allocation of bike rental stations and bicycle network determines the successful of bike sharing system (Lin et al., 2011; Vogel et al., 2011). Therefore, it is necessary to develop suitable methods for spatial location-allocation of bike sharing systems, including location and capacity of bike rental stations, and bicycle network.

3.2. Location-allocation models

Location-allocation models were introduced as a way of simultaneously addressing both location and allocation decisions in the planning process, which means that determining the locations of facilities and determining who is served by which facility (Richard L. Church et al., 2008). Based on the literature survey, classical location models mainly contain p-median problem (PMP), the location set covering problem (LSCP), and the maximal covering location problem (MCLP) (Melkote et al., 2001). Moreover, the distance-constrained p-median problem (DCPMP), and spatial interaction location-allocation model (SILA) were also introduced to deal with location-allocation problems (Farhan et al., 2006). As an example, the traditional spider plot of a p-median problem solution is illustrated in Figure 3-1. For the features of these well-known models, the summary is shown in Table 3-1.

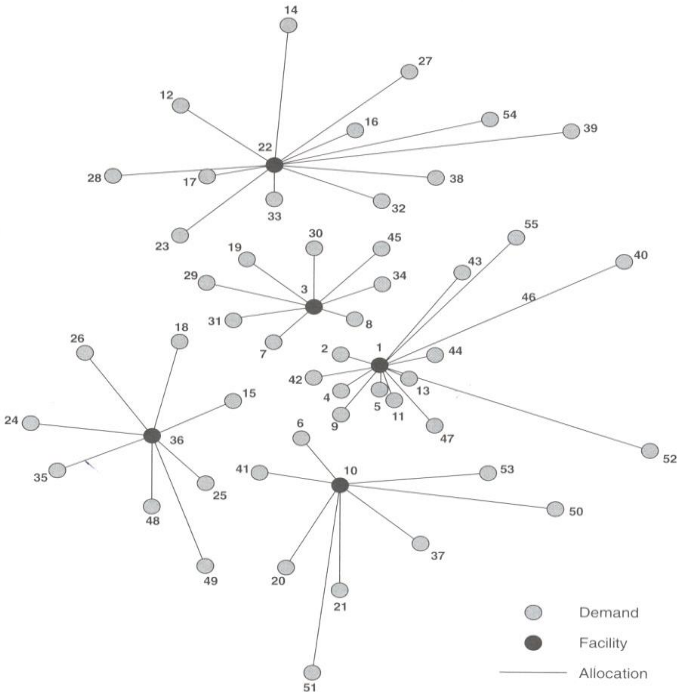


Figure 3-1 spider plot of location and allocation decisions (p-median problem)
(source: (Richard L. Church et al., 2008))

Table 3-1 Introduction of classical location models

Models	Objectives	Issues considered in models		
		Partial regional service	Coverage range	Distance decay
LSCP (Toregas et al. 1971)	To find the minimum number and location of facilities needed to cover all demands.	No	Yes	No
PMP (Hakimi 1964, ReVelle and Swan 1970)	To find the location of p facilities so that the total demand-weighted travel distance between facility and service area is minimized.	No	No	Maybe
DCPMP (Toregas et al. 1971)	To address the coverage range of facilities based on PMP model.	No	Yes	Maybe
MCLP (Church and ReVelle 1974)	To maximize the demand suitably covered by a set number of facilities.	Yes	Yes	No
SILA (Fotheringhan and O'Kelly 1989)	To locate facilities by simultaneously addressing distance decay, coverage range, and the attraction of facility.	No	Yes	Maybe

New methods have also been developed to improve these classical location models in recent years. For example, Farhan et al. (2006) developed spatial location models that could simultaneously address the issues on distance decay, coverage range and partial regional service for both desirable and undesirable facilities sites decisions. Murray et al. (2007) proposed an approach (Extended Planar Maximal Covering Location Problem-Euclidean) to extend the PMC (Planar Maximal Covering Location Problem) which follows MCLP for coverage optimization in continuous space facility siting, and the proposed approach considered more general representations (point, polygons, or lines) of demand than PMC that only accounted for a point-based abstraction of demand in continuous space. R. L. Church et al. (2008)also gave an in-depth introduction to location-allocation, and especially illustrated the heuristic solution for solving the p-median problem in location-allocation models. Alexandris et al. (2010) presented a new model for maximal coverage location problem, based on partial coverage of demand area and the capabilities of GIS, which is quite robust and less susceptible to the values of parameters than conventional location models. Furthermore,

With respect to bicycle facility model, Rybarczyk et al. (2010) indicated that the methods used for bicycle facility planning can be divided into two categories: supply-based and demand-based models, and he also proposed a multi-criteria evaluation analysis to integrate both supply-based and demand-based criteria to plan bicycle facility. And Larsen et al. (2011) presented a GIS-based, grid-cell model for prioritizing and locating cycling facilities, and proposed that the grid-cell model can also be used in locating other cycling facilities such as bike parking or public bike station.

4. INTRODUCTION TO BIKE SHARING SYSTEM IN WUHAN, CHINA

- **Description of bike sharing system**

Wuhan launched a bike sharing system in April, 2009, which is the first system that free of charge and aims to satisfy people who demand for access to “the last mile” to destination easily. This bike sharing system is operated by Xinfeida Bicycle Company in cooperation with Wuhan municipal government, so called "Wuhan Mode"—— government-led which invest no or a little money, and bicycle company implements market-oriented operation. According to the statistics investigated by ITDP-China (2010), the numbers of public bikes and bike rental stations have been up to 9500 and 1,118 respectively in August 2011.

- **Implementation of bike sharing system**

The sites-selection of bike rental stations was implemented by urban municipal management bureau in cooperation with other institutes. In order to satisfy the different demands of public bike users and strengthen the connection between bike rental stations and other facilities in urban area, bike rental stations are built around bus stops, residential communities, business area, recreational area, colleges and metro stations. At the initial phase of this project, Bicycle Company is responsible for building the bike sharing system. And in the following years, government will provide allowance with buying bicycles and building bike rental stations. The final objective of this bike sharing system is to build 2000 bike stations to cover the centre area of Wuhan, and the average spacing distance of bike stations is 300 meters.

- **Operation of bike sharing system**

This bike sharing system is a "manual and self-service" system, which aims to achieve 24h service in the city. Currently, users need a "public bike point-card" which they can get by paying certain deposit (Table 4-1) with ID card or other valid document, and the deposit will be refunded when people cancel the card. As to the bike rental stations with self-service system, an intelligent box that installed in the station can be used for returning and picking up bike keys by themselves. And regard to the stations with manual system, worker are employed to manage the pick-up and return of public bikes. Public bikes can be rent and returned at any bike rental stations during 7am-9pm.

Table 4-1 Deposit Introduction of Bike Sharing System in Wuhan (2012)

Group	Deposit (CNY)
Student	200
Local people	300
Non-Local people	400
Families receiving minimum social welfare support	—

- **Pricing of bike sharing system**

The pricing mechanism of Wuhan's bike sharing program has experienced some changes since 2009 (Table 4-2), in order to deal with the problems existing in the process of operation. At this stage, Wuhan bike sharing program adapt automatic charging system by using "public bike point-card", and people can use the public bikes free of charge in 2 hours. But users who rent public bikes exceed 2h will be fined 1CNY/h which is still lower than the fees of other public transport, and users who cannot return public bikes in 2h for three times or in 24h, their card will be frozen.

Table 4-2Pricing Changes of Bike Sharing System (2009-2012)

	Date	Pricing
1	2009.04	Totally Free
2	2011.07	• "Public Bike Card" applied with deposit. • Users who rent public bikes exceed 2h will be fined with 1yuan/h. But users who cannot return public bikes in 2h for three times or in 24h, their "public bike card" will be frozen.
3	2012.06	• "Public Bike Card" applied with deposit, but families receiving minimum social welfare support are free. • A complete rent and return bike can save one point, and the upper limit is 4 points/day. Users can check their points on the website of bike sharing system. • Users who rent public bikes exceed 2h will be fined with 1yuan/h. But users who cannot return public bikes in 2h for three times or in 24h, their "public bike card" will be frozen.

- **Feedback since operation and Future plan**

Since the first day of launching, the bike sharing program has been welcomed by the citizens. According to the results of on-site questionnaire survey that has been done on bike rental stations in Wuchang area of Wuhan city in 2011, it is obvious to find that the major purpose of public bike uses is commuting, and 42% of duration of using public bikes is between 10 and 30 minutes. And 70.5% of respondents do not satisfy the bike sharing system, and respond that there is a lot of space to improve the bike sharing system of Wuhan.

Moreover, 91.5% of public bike users responded the bike sharing system with the problems on the location-allocation of bike stations, including insufficient public bikes and bike stations, and irrational locations of bike stations. 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'.

In order to promote the use of public bikes, new policies are implemented in June 2012. Firstly, "public bike point-card" is introduced, by which users can save points. These points can be used for paying for the fine and exchanging a gift at the end of year. Secondly, families that receiving minimum social welfare support can get the card with free of charge.

5. DISCUSSION AND CONCLUSIONS

Although bike sharing systems attract worldwide attentions, and past studies have acknowledged the supporting role of bike sharing systems in urban transport system, it is still under the way of exploring and development. Moreover, it is evident that little researches paid attention to determining the locations and capacity of bike rental stations, and designing bicycle network from a transport geographical point of view, and simultaneously took account of the role of stakeholders played in the bike sharing systems. Therefore, this paper proposes four points relating to the location-allocation of bike sharing systems:

Firstly, factors that determine the acceptance and level-of-service (LOS) of bike sharing systems should be identified. Little studies paid attention to exploring how to enhance the use of public bikes compared to the increasing use of private motorized transport. However, bike sharing systems are emerged as an option of public transport systems, and as a solution to alleviate the current transport issues and achieve the goal of sustainable transport, so that the factors which determine the acceptance and LOS of public bikes become extremely important and cannot be ignored. Moreover, facing the various modes of urban transport, it is necessary to identify the unique characteristics and advantages of public bikes compared to other transport modes, and in what situation the usage of public bikes can be enhanced. Therefore, in order to make bike sharing systems operate smoothly and successfully, the factors that determine the acceptance and LOS of public bikes should be identified.

Secondly, location-allocation of bike sharing systems should be based on spatial characteristics of urban environment. Spatial characteristics of urban environment are interacted with the implementation of bike sharing system. Firstly, spatial characteristics of urban environment (e.g. urban infrastructure, urban form, and land use distribution…) determine the scale and type of bike sharing systems. Secondly, spatial characteristics of urban environment have effect on the location-allocation of bike rental stations and bicycle network, when consider improving the mobility and accessibility of travel. Furthermore, the combination of spatial characteristics of urban environment and location-allocation of bike rental stations can contribute to sustainable urban transport systems and sustainable urban development. Therefore, it is necessary and essential to involve spatial characteristics of urban environment in the location-allocation of bike rental stations.

Then, geo-spatial assessment techniques should be used for location-allocation of bike sharing systems. Although the allocation of bike rental stations and bicycle network determine the success of bike sharing system (Lin et al., 2011; Vogel et al., 2011), little scientific researches propose methods for determining the location and capacity of bike rental stations and designing bicycle network by using geo-spatial assessment approaches . However, geo-spatial assessment techniques can be regarded as primary approaches that are used to gain better insight into the spatial relationships between different facilities. Therefore, in order to analyse and investigate the spatial relation and interaction between bike sharing systems and other urban transport systems or elements of urban environment, it is inevitable and necessary to take account of geo-spatial assessment techniques for location-allocation of bike sharing systems.

Furthermore, location-allocation of bike sharing systems should be implemented in more collaborative decision support environment. Bike sharing systems are supported and operated by stakeholders who have great influences on the functionality and development of bike sharing systems, so that the opinions of stakeholders are very important for the location-allocation of bike sharing systems. In order to achieve rational and practical location-allocation of bike sharing system, the opinions of stakeholders should be included in the criteria and factors that are used for location-allocation of bike sharing systems. So as to make bike sharing system can operate and perform well, it is essential to involve stakeholders in the process of location-allocation of bike sharing systems, which means the location-allocation of bike sharing systems should be operated in more collaborative decision support environment.

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