Study on the Site Selection of Stations in Bike-sharing System

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Abstract

Bicycle sharing systems (BSS) have increased in number rapidly in recent years because of their potential benefits of mainly sustainability, health and the connection with urban rail transit. In practice, the unreasonable selection of station sites compromises system success. Most studies just focused on the user demand or travel costs while considering station site. However, the bike demand actually is influenced by multiple factors including built environment of street and the spatial accessibility to stations. A new method of locating bike-sharing system based on the space syntax is presented in this paper and the goal are predicting the potential bike demand and building an optimization model for station sites considering spatial accessibility to stations. Finally, a case study is performed over the the campus of Nanjing Normal University to verify the availability.

Keywords

Bike-Sharing Systems, Site Selection of Stations, Spatial Accessibility, Optimization Model.

1. Introduction

In recent years, the bike sharing system has become more and more popular in the world from just a handful in the late 1990s to over 800 currently [1], because of its safety, cost saving, increased health benefits etc. Bike sharing systems set docking stations from every 1-2km, and each docking station is equipped with 20 to 50 unified bicycles. Users can borrow a bike at one rental station and finally return to the other rental stations or the same rental station after a short journey. Unreasonable layout design of stations in bike-sharing system will make the service ability poor, at the same time, causing the waste of resources [2].

Chen [3] used a mathematical model to pick out the geographic position of public bike stations with the goals of minimizing users' total travel time and public investment. The model can make sure that the demands for renting and returning bikes in each station are satisfied to a certain extent.

Li [4]applied the bi-level programming models including the traditional discrete model and stochastic user equilibrium model. The models minimize the overall costs for the upper-level programming and minimize the travel costs for the lower level programming from the perspective of decision makers and users respectively. But there were some difficulties solving the model.

Martinez et al.[5] Came up with a public bicycle network to maximize the economic effect of public bicycle system operation considering the costs of purchase of bikes, construction of stations and re-posting bike. The main purpose of the method is to maximize revenue.

The paper [6] proposed an optimization method by using the information about the station capacity, unmet demand and the required number of bicycles at any given time and location. The model can minimize unmet demand, operating costs and the costs of scheduling bikes between the stations which was in low service.

A maximal covering location approach described by Ines Frade [7] determined the optimal location, the optimal capacity of each station, considering an initial investment, the annual supplementary budget from the system provider, and the income from the user subscriptions as the constraints. The main purpose of the method was to maximize the demand coverage.

All these works missed the impact of station spatial accessibility to each bike station in the street networks. Indeed, the bike demand is influenced by surrounding built environment and the transportation street networks [8, 9]. Our work is based on space syntax theory, which primarily applied to the fields of architecture and urban design to explore the structural relationship of urban components [10-12].The work first develops a prediction model for predicting the potential bike demand. Then, a math-optimization model considering both station spatial configuration and built environment attributes is presented such that the station covered demand and accessibility are maximized. Finally, the performance of our prediction model and optimization strategy are comprehensively evaluated on campus of Nanjing Normal University and the experimental results demonstrate the effectiveness of our method. The method in this paper helps bike-sharing providers more accurate in location planning.

2. Problem Description

The problem of site selection of stations is to ultimately choose a set of optimized stations from a large number of candidates [11]. Bike-sharing stations within dense urban environment are the transport mode that provides the most level of bike demand coverage and get the closest to everywhere in a city. This is crucial to ensure accessibility of almost door-to door travels for almost users. Station candidates are usually set at the primary and secondary street segments which typically generate ridership flows (see figure1). The bike-sharing stations set on more-integrated street segments which are more accessible from other streets, are likely to attract more potential cyclists, while the bike-sharing stations set on the less-integrated street segments, cannot be reached easily (traversing many turns) and may attract less cyclists [13].

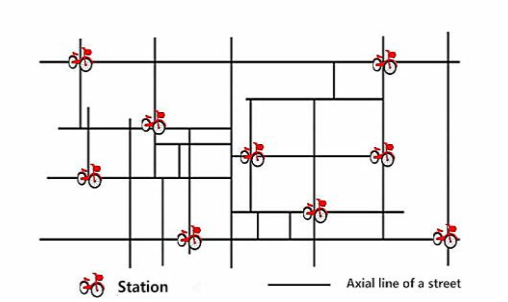

Fig. 1 The street network for bike stations

The integration derived from the space syntax measures how the streets are connected to each other within a bike-sharing station network and what some segments are more accessible than other streets. The main measure of "depth" from the space syntax is the sum of the links (road segments) which have to be passed if users want to move from that street to all other streets. The value of integration and control of a street acquired from space syntax reflects the degree of gathering or discrete from it to all other roads in the network. The value of integration can be calculated as follows:

$$RA_i = \frac{2(MD_i - 1)}{n-2} \tag{1}$$

$$MD_i = \frac{\sum_{j=1} d_{ij}}{n-1} \tag{2}$$

Where MD_i represents average depth value of road segment i in the street network. n is the total number of street segments in the connected graph which is came into being from space syntax. d_{ij} means the total "depth" from street i to j. The i represents the street where the station site along.

The control value of station i can be calculated as follows:

$$ctrl_i = \sum_{j=1}^{k} c_j \tag{3}$$

Where c_j represents the number of roads directly connected to street j where the station i site along.

The bigger the integration value is, the more convenient the street segment will be accessed to, the more attractive the users gathered. At the same time, the bigger the control value is, the greater the flows of ridership are assigned. There are multiple roads directly crossed by bike sharing stations and these roads are also contacted by other distributor street segments making up of road network around the stations, see Fig.1. Bike demand would be generated from this street network and flow to bike stations.

3. The Analysis of the Bike Demand

This paper considers two kinds of factors, which the first derived from standard public transport planning and the second derived from space syntax configuration approaches. The standard transport planning considers primary variables: employment density, population density, land use, and buffer distance from stations[14].the paper combines the spatial structure variables from the space syntax and the built environment variables about roads to establish the multiple linger regression model with actual demand data acquired from various practical investigate as the dependent variable. The factors influencing road bike demand are presented in table1.

Table 1. Factors influencing road bike demand

Factors	Environment	Spatial relation
Variables	Population at 500m Building density Bus stop density Road comfort Risk factor Intersection density	Average depth Connectivity Control value Relative asymmetry

In addition, in order to filter out the most influential variables on demand, we should make some analysis of correlation for the two kinds of variables.A math regression model is shown as follows:

$$Q_k = \alpha * X_1 + \beta * X_2 + \chi * X_3 + \delta * X_4 + \eta * X_5 + \omega * X_6 + \varepsilon \tag{4}$$

$\alpha, \beta, \varphi, \delta, \eta$ are regression coefficients and $X1$-$X6$ represent the space and environmental variables.

According to the turnover rate of per sharing bike [4], bike capacities of one station can be expressed as follows:

$$N_{bike} = \frac{p * \sum_{k}^{n} Q_k}{\lambda} \tag{5}$$

Where λ represents turnover rate. n represents the number of roads crossed by the stations. P is the probability of using a bike to travel.

4. The Decision of Location of Stations Based on the Space Syntax

In China, the public bicycle project is severed as welfare which is mainly dominated by the government and its purpose is to attract more people to use bicycles but not vehicles for short trips. Therefore, the decision of station location needs to consider whether the location would attract more people easily access to it. If the users reach the rental points more convenient and pass less turns, and the points would attract more potential customers, and the planning efficiency is higher.

On the other hand, to avoid unnecessary infrastructure construction, the overlapping rate a_{ij} is also introduced into the model. a_{ij} is the overlapping area dividing by the total coverage area, and the expression is showed as Eq.(6).

$$a_{ij} = \frac{1}{\lambda}\left(\arccos\frac{d_{ij}}{2r} - \frac{d_{ij}}{2r}\sqrt{1-\left(\frac{d_{ij}}{2r}\right)^2}\right) \tag{6}$$

Where d_{ij} represents the distance between candidate bicycle-sharing point i and j, and r for the rental station coverage radius.

The local integration value measures the ability and the convenience of one passing to the destination. Integration degree can be represented as IN here and calculated by Eq.(1), Eq.(2). Based on the above ideas, the optimization model based on space syntax can be expressed as follows:

$$MAX \sum_{i=1}^{n}\sum_{k=1}^{m}(IN_{ik} + Q_{ik}) * Y_i; \tag{7}$$

$$a_{ij} <= \sigma \quad \forall \text{i,j}, \tag{8}$$

$$l_{ij} <= l_{\max} \quad \forall \text{i,j}, \tag{9}$$

$$l_{ij} >= l_{\min} \quad \forall \text{i,j}, \tag{10}$$

$$\sum_{i}(Y_i * c) <= b \quad \forall \text{i}, \tag{11}$$

$$Y_i = \{0,1\} \quad \forall \text{i}, \tag{12}$$

Symbols of the model in the following details as follows:

N : the set of candidate stations;

IN_{ik} : the integration value of road k which directly connected to station i;

Q_{ik} : the bike demand of road k which directly connected to station i;

l_{ij} : the distance from bicycle candidate station i to j;

a_{ij} : the overlapping area between candidate bicycle-sharing candidate i and j;

c : the fixed construction cost per station;

b : the fixed economic construction investment;

Y_i : is1if the station i is opened ,and 0 otherwise.

The primary optimization objective is to maximize the total Integration and demand covered by the bicycle sharing network shown as Eq.(7); constraints Eq.(8) ensures overlapping rate between any points within reasonable scope; Eq.(9),(10) represent distance constraints between the two stations because users cannot use bike when the distance length is longer from the origin to the destination. Eq.(11) is the budget constraints. Eq.(12) ensures that the decision variable is 0 or 1.

5. The Application Study

The design of public bike system needs to determine the location of stations and the number of required bikes. The methodology was applied to the campus of Nanjing normal university. Space syntax axes diagram of Xian-ling campus of Nanjing Normal University acquired through space syntax software.We assume that there are 15 candidate points set on the campus, the fixed construction cost per station is 1500 RMB, fixed investment cost is 10000 RMB and each candidate point has coverage of 200 meters, and the distance between two points is not more than 2000 meters and not less than 200 meters.

According to the space syntax axes diagram, we calculate the value of control and local integration of the road segments which directly crossed by the stations. The road environmental data including building density with population, road width and bus stops is acquired by the actual survey. At the same time, for the bike demand of peak hours of the typical road segments as the dependent variable, using the linear regression to obtain road bicycle demand-forecast model during peak period as follows:

$$Q = 169.21 * X_1 + 114.09 * X_2 + 52.11 * X_3 + 432.65 * X_4 + 67.51 * X_5 - 133.07 * X_6 + 19.52.$$

Where Q is the bike demand on one road, Xi denote respectively the value of integration, the control value, building density, bus stop density, road comfort(if there is a gradient or not) connected with stations. According to the Eq.5, we can acquire the bike capacity of the each station.

The resulting value of Y_i =1 through the Eq.(7)-(12) calculated by optimization software is converted into practical significance and the result of application case is presented as the table 2.

Table 2. The Result of Application Case

NO	Location	Integration	Demand	Capacity
1	West gate	0.13	342	35
2	South gate	0.15	372	38
3	Huacheng Building	0.48	475	48
4	East dining room	0.37	345	35
5	West dining room	0.31	395	40
6	North building	0.26	437	44

In practice, the station of Huacheng building is in the center of the campus, which has four arterial roads passed it, and it links to the west dining room. At the same time, one school bus stop poses nearby. It does gather higher traffic flow, so the station of Huacheng building should be opened as a real station. On the other hand, the candidate point of south dormitory is surrounded by graduate student dormitories which may generate heavy traffic demand, but it is in the most southern direction in Xian-ling campus on space. There is no transited and connected road between the body district of school and south dormitory area. So the model has filtered off the site. The results of the example application show the model performs well.

6. Conclusion

In this paper, we developed a comprehensive bike station network optimization approach by selecting bike-station location with high demand and spatial accessibility. To the best of our knowledge, this paper is the first attempt to integrate concept of space syntax and surrounding social factors for planning the location of public bike station. Case analysis is applied to verify the applicability of the model. We believe that the methodology can provide urban managers with good insight into where bike-sharing stations should be located in their towns, and therefore it contributes significantly to the future planning of bike-sharing systems. Actually, this paper predicted the demand incorporation of environmental features and spatial factors without considering the influence of social-demographic variables such as gender, educational attainment, household income, and car ownership of users, so the future work can work on developing quantitative models for adequate combination of the environmental attributes, the spatial characteristics and the social-demographic features.

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