Understanding the bike sharing travel demand and cycle lane network: the case of Shanghai

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Abstract

As a sustainable transportation alternative, cycling has been developed by many large cities as one essential measure for addressing the "last mile problem" in urban areas with high mobility demand. Developing a safe and friendly lane network for cycling has become an urgent task for governments, especially for many Chinese cities encountering a rapid increase in the use of "dockless" shared bikes, such as Mobike and Ofo. The emergence of such kind of app-driven dockless bike sharing systems results in a fast growth in the cycling mobility demand, and leads to a gap between the growing demand and the existing cycling infrastructure. Therefore, it is imperative to have a good understanding of the cycling travel demand and its infrastructure, and in turn to bridge the supply-demand gap. In this paper, we employ data mining techniques including graphic clustering algorithm, Louvain Method, on a large data set from one of the largest bike sharing companies in China. Then we applied the methodology in two cases in Shanghai, including a campus and an urban area. Typical cycling patterns in the spatial and temporal dimensions are identified automatically by the cluster analysis. It is also found that the construction of the cycling infrastructure is closely related to three factors: nonnegligible impact of POIs, geographical barriers, and temporal variance of the network. Managerial insights and policy measures are proposed accordingly for improving the cycle lane network.

Keywords: cycle lane network, dockless bike sharing, data mining

1. Introduction

1.1. Background

Cycling is the activity or sport of riding a bicycle, which is deemed an effective, efficient and sustainable mode of transport suitable for short or moderate distance trips. It provides numerous benefits compared to motorized traffic, such as reduced emission of pollution, relieved traffic congestion, easier parking, increased maneuverability and more physical exercise for cyclists. Cycling has been developed as one important measure for addressing the "last mile problem" in urban areas with high mobility demand.

Thus, it has been an urgent task for governments to build and improve the cycling infrastructures, i.e. the cycle lane networks, according to the cycling travel demand. Many European countries have a very good cycling culture, and developed some well-known bike cities where cycle lane networks are well established. For example, in the city of Copenhagen there are around 7000 km of dedicated cycle lanes which are segregated from motor traffic lanes (Forbund, 2011). Similarly, in Netherland, some 35000 km of bike lanes have been physically segregated from motorized traffic. On other roads and streets, bicycles and motor vehicles share the same road space, but usually with a low speed limit (Transport for London,

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2014; Fishman et al., 2014). There are also the so-called "the unravelling of modes" where dedicated bike routes are far more direct than the local car routes to common destinations, like town centers(Hembrow, 2012; Wagenbuur, 2012).

Shanghai municipal government has proposed the construction of the cycle lane network in *Shanghai Urban Transport White Paper (2002)*(Shanghai Municipal People's Government(SMPG), 2002), whose main idea was to build the cycle lane network based on the existing city roads with the objective of encouraging environmentally-friendly traveling. *Shanghai Master Plan (2017-2035)*(SMPG, 2017) also clearly proposed to increase the exclusive right of way of non-motorized vehicles by establishing the cycle lane network and gradually restoring the right of non-motorized traffic on the restricted road, to improve the accessibility, flexibility, functionality and connectivity of the cycling traffic system.

Over the years, the cycle lane network has been improving with the effort of the government while the cycling ridership has been in a declining trend due to the fast increasing of automobiles. According to the result of the fifth comprehensive traffic survey in Shanghai in 2014, the bicycle share rate has declined rapidly for years, falling from 34.4% in 1986 and 25.2% in 2004 to 7.2% in 2014 (Li and Chen, 1997; Shanghai Urban Construction Research Institute, 2015; Shanghai Comprehensive Transportation Planning Research Institute, 2005).

However, the rapid development of the dockless bike sharing systems such as Mobike and Ofo in many Chinese cities have significantly improved the cycling popularity since 2016. With the newly introduced dockless bike sharing system, short trips by automobiles has decreased by 55% while cycling ridership doubled, according to *2017 White Paper on the Bike Sharing and Urban Development*(Mobike et al., 2017).

1.2. Motivation and contribution

The emergence and rapid development of dockless bike sharing systems have introduced new challenges as well as opportunities for the government. On one hand, the dockless bike sharing systems have given rise to a fast growth in the cycling mobility demand. It is essential to understand the traveling demand pattern for the dockless bike sharing systems both in temporal and spatial dimensions. On the other hand, it is widely observed that the existing cycling infrastructure cannot meet the growing demand. For example, the cycling lanes are often not continuous, not wide enough or frequently occupied by motorized vehicles in cities. Also, parking tends to be a problem as plenty of city buildings usually are not equipped with sufficient bicycle parking spaces. Thus, it is also necessary to have a good understanding of the supply side (i.e., cycling infrastructure) and bridge the gap between supply and demand. The motivation of this study is (1) to understand the cycling travel patterns in the context of dockless bike sharing systems; and (2) to investigate the existing cycling infrastructure and identify the key bottlenecks so that can be resolved.

The major contributions of this paper are threefold: (1) We identified typical cycling travel patterns in the spatial and temporal dimensions by employing a graphic clustering algorithm on a large set of bike sharing data. Critical communities where shared bikes circulate frequently are automatically recognized. (2) We analyzed the problems of the existing cycle lane network including the lack of network connectivity and integration with urban land use. (3) We proposed a number of measures from operational management and policy development perspectives which could help improve the performance of the dockless bike sharing systems as well as the cycling network.

The remainder of this paper is organized as follows. Section 2 briefly reviews the literature on cycle lane network development and associated data mining methods. Section 3 describes the data sources and methodology used in this study. In Section 4, we present the travel patterns of the bike sharing system and critical issues of the cycle lane network via two case studies. In section 5, we propose some managerial insights and policy measures. Summary and conclusions are stated in Section 6.

2. Literature review

2.1. Cycle lane network

2.1.1. Road network design and operation

The road network design problem, which involves the optimization on the expansion of a road system in response to a growing travel demand, has long been recognized as one of the hardest and most challenging problems in the transport research area. There have been many solutions for the problem, which cope with the selection of either link improvements and expansion (i.e. the continuous form) or link additions to an existing road network (i.e. the discrete form), with given demand from each pair of origin and destination(OD). The objective is to make an optimum investment decision in order to achieve a certain target, such as maximizing system service level and minimizing the travel cost in the network (Yang and H. Bell, 1998). Many scholars have put forward models and algorithms for the road network design problem. Asakura and Sasaki (1989) proposed a bi-level framework, including a performance function describing the level of service of the transportation system, defined by the transport demand, the system capacity and the traffic management scheme. Considering the influence of bike sharing, Bao et al. (2017) proposed a data driven approach to develop cycle lane construction plans based on a large-scale bike trajectory dataset, introducing a flexible objective function to tune the benefit between coverage of the number of users and the length of their trajectories. Since Shanghai municipal government has been proposing the construction of cycle lane network, it is essential to improve the road network to satisfy the increasing cycling travel demand.

As for the operations of the bike lane system, one of the main challenge is to rebalance the shared bikes in the bike sharing network due to its imbalance between supply and demand. Rebalancing of bikes aims to relocate bikes across the network to realize a reasonable distribution (Fishman, 2014). The need for rebalancing is raised when the flow of cycling trips moves in a city. For docking bike sharing system, this leads to some docking stations becoming completely full while others are empty, which can cause inconvenience for the users (Transport for London, 2014) and significant manual costs imposed on operators (Fishman et al., 2014). Tang et al. (2011) focused on the Chinese bike sharing systems and suggested offering rewards for those who ride docking shared bikes from surplus to deficit locations and help relocate bikes to docking stations with few bikes. This is a strategy employed by many bike sharing programs, including Capital Bike Share in Washington, D.C., although its effectiveness is limited, although its effectiveness is limited (Tech, 2012; Share, 2011). Parkes et al. (2013) suggested that altering the price may be increasingly employed to resolve fleet distribution issues. However, most of these strategies tend to depend on the labor or capital investment of the government rather than the intrinsic force of the demand and supply in the system or a community to form a virtuous circle and reach an operational equilibrium.

2.1.2. Safety concerns

Another significant theme related to bike sharing and bike lane network is safety. Safety concerns are a huge barrier to cycling (Wiersma, 2010; Fishman et al., 2012).Limited cycling infrastructure and risk of collision with motorized vehicles are a major concern for all users (Fishman et al., 2012). Wiersma (2010) concluded that owing to the lack of a bike-friendly environment and the subsequent safety concerns, the bike sharing projects would suffer from low participation rates. Buck and Buehler (2012) support the significance of a safe riding environment. Using multiple regression analysis, they found a statistically prominent relationship between bike sharing activity and the presence of bike lanes. In fact, most studies agree that cyclists prefer roads with fewer travel lanes, lower volumes of motorized traffic, slower speeds and without car parking (Akar and Clifton, 2009; Caulfield, 2014; Chataway et al., 2014; Dill et al., 2014). In a word, safety is among the priorities for the design and operation of a cycle lane network.

2.1.3. Cycle lane network in Shanghai

Shanghai municipal government has well recognized the importance of developing the cycle lane network in the city and has proposed the construction of it since 2002 (Shanghai Municipal People's Government(SMPG), 2002). *Shanghai Master Plan (2017-2035)* also mentions the necessity of establishing an exclusive cycle lane network system in the downtown area (SMPG, 2017). However, considering Shanghai is a mega-city with limited resource, the travel share rate of cars is only 19.2% in 2014 while cars accounting for approximately 50% of the road resources, and the travel share rate of cycling is merely 7.2% (Shanghai Urban Construction Research Institute, 2015). The unreasonable distribution of the road resources calls for a sound cycle lane network which ensures the right of way of cycling. The goals of Shanghai municipal government are to strengthen the segregation between the motorized and non-motorized vehicles, increase bicycle ridership, improve the connectivity of facilities and safety of the traffic, alleviate the "last mile problem" and provide leisure places to improve the quality of people's life. In this paper, we consider the future expectation and existing problems to offer decision makers policy suggestions of improving the existing cycle lane network.

2.2. Clustering data mining

Clustering data mining is one of the most efficient and widely used methods in discovering the mobility patterns using spatial-temporal data, while there are normally two approaches to processing these data.

On one hand, spatial-temporal data in clustering can be handled with individual information of each item in the dataset preserved. Wang et al. (2018) applied hierarchical clustering on taxi GPS trajectory data, and proposed methods to detect anomalous trajectories and analyze anomalous behavior patterns considering distance length and time span of trajectory data. Zhou et al. (2017) applied modified density-based spatial clustering of applications with noise (DBSCAN) method on taxi data with features of 6 dimensions to evaluate city administrative regions, where coordinates of origin and destination and the rest for time and the flow are specifically exploited. Although the idea proposed by Zhou et al. (2017) is innovative, Suthar et al. (2013) mentioned that finding the proper parameters of the DBSCAN algorithm is a laborious task, which might be unfriendly to our data processing.

On the other hand, spatial-temporal data in clustering can also be transformed into attributes of the areas, including the traffic volume and origin-destination flow. In order to solve the taxi dispatching problem, Wan et al. (2013) rasterized areas of interest based on their functions and the taxi O-D flow, then applied improved DBSCAN method using statistical assumption to help merge the rasterized areas. Fanhas and Saptawati (2016) followed the idea of topology of O-D network, and applied Louvain Method on their graphic models to predict areas with frequent origin-destination flow in Bandung city. Dong et al. (2015) used K-Means clustering method on call detail record data to find the traffic zone division. They focused on the real-time user volume, inflow, outflow and increment flow as features to segment the potential functions of city. However, their data was based on aggregated data of several signal stations, which is not applicable to disaggregated bike sharing data.

Considering the topology and connection of cycle lane network, we choose to rasterize areas and weight each grid and edge with the number and flux of shared bikes and apply clustering algorithms. Different from the effort of Fanhas and Saptawati (2016), we have not only discovered the connections of frequent origin-destination areas, but also mined the insight of cycle lane network and urban planning behind the connections, enlightened by *The 2017 White Paper on the Bike Sharing and Urban Development* (Mobike et al., 2017).

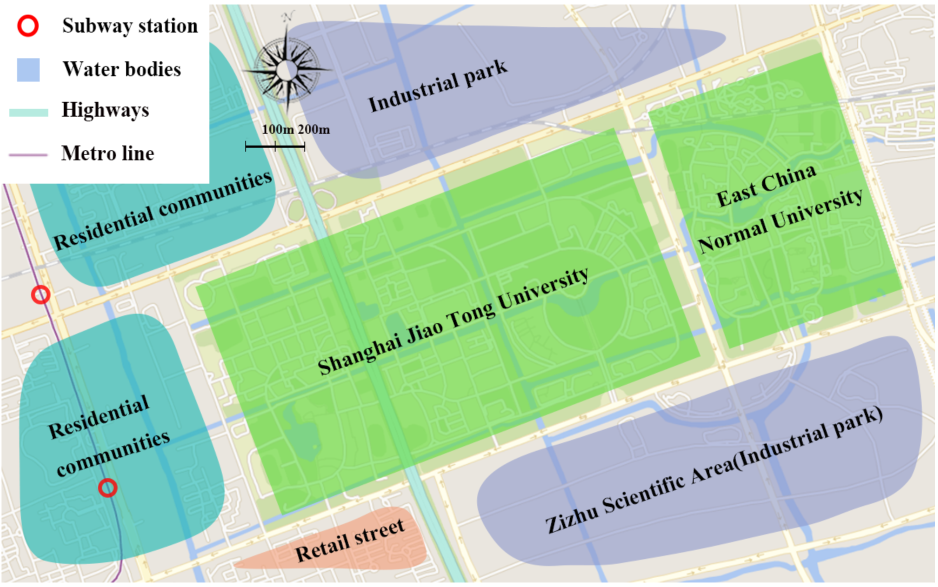
3. Data and methodology

3.1. Study area and data sources

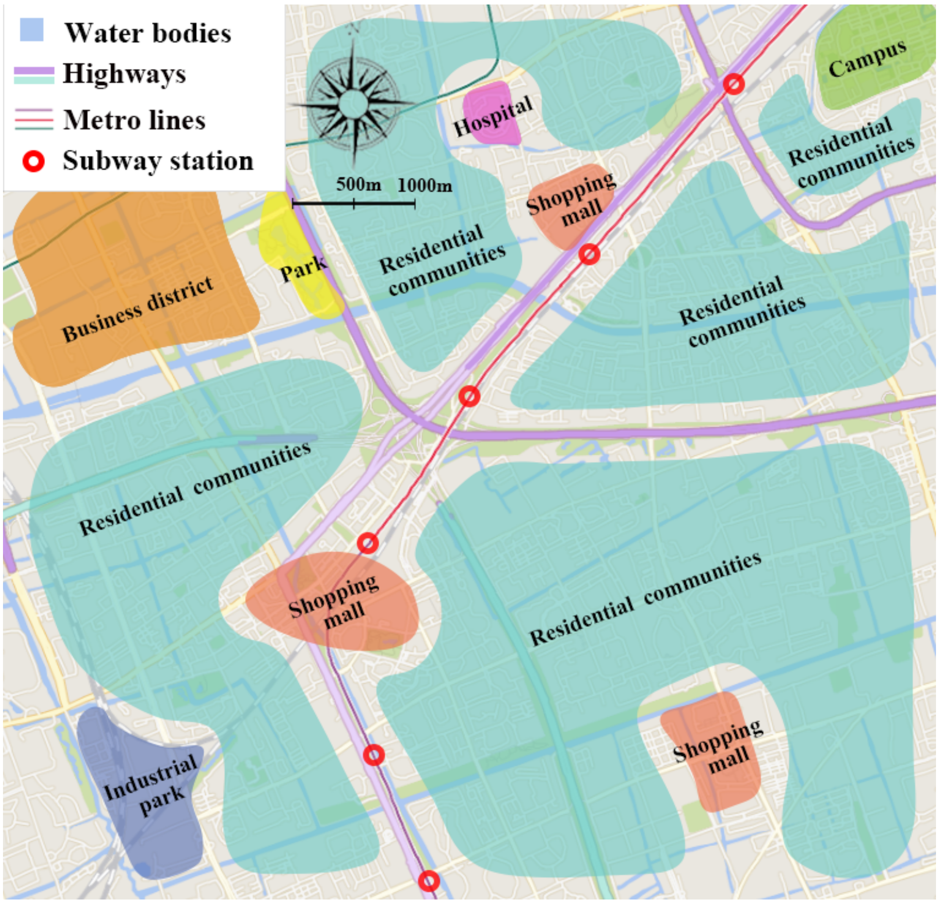
3.1.1. Study area

Our goal is to investigate the cycling travel demand pattern both in the spatial and temporal dimensions, and subsequently to understand the gap between urban infrastructure planning and cycling demand. We conduct the data mining and analysis on two selected areas in Shanghai: (1) a suburban low-density area (5 km by 2.7 km) covering the campus of Shanghai Jiao Tong University and its surrounding area; and (2) an urban high-density area (7 km by 6 km) covering commercial centers and well-developed transportation infrastructures including metro lines and expressways. The land use of these two study areas can be roughly divided as Figure 1 have presented.

In order to exploit the mobility pattern, we divide the study areas into zones. A simple zoning method is employed, which is to simply rasterize the area into rectangle grids. After rasterization, each single grid is considered as an analysis zone serving as the origin and destination of bike flows over the network. The number of grids should be carefully selected so that the travel demand origin-destination flow exhibits in a clear pattern. In our study, the two study areas are rasterized into 100x100 and 80x80 grids, respectively.



i First study area, centering the campus of Shanghai Jiao Tong University



ii Second study area, centering Xinzhuang Subway Station

Figure 1: Land use division of study areas

We choose these two study areas to compare the properties of a well-circulated cycle lane network to an unknown one. The first study area is a cycling friendly area with a safe cycle lane network. Therefore, we choose this area as an ideal reference. The second study area contains huge potential of using shared bikes, however, the quality of the cycle lane network in it remains unclear.

3.1.2. Bike sharing data

The study is mainly based on a data set from one of the largest dockless bike sharing companies. Each data entry records the bike id, type and geographical locations of the available bikes (not in use) in the study area, as is shown in Table 1. The data was collected in an hourly basis. The data set for study area 1 was collected from July 6 to September 22 in 2017, 6000 records each day on average, and the data set for study area 2 covers the period from September 30 to November 11 in 2017, 35000 records each day on average. Considering of the cycling travel variation over the whole day, we focus on three typical time periods for analysis: Morning (6:00-13:00), Afternoon (14:00-18:00) and Night (19:00-23:00).

Table 1: Examples of bike sharing data

BikeIds	Longitude	Latitude	Biketype	Time	Timezone
0200011625#	121.4501332	31.0360122	1	7:00:00	Morning
0210084016#	121.3830957	31.1244704	999	15:00:00	Afternoon
0210086190#	121.3987916	31.1220635	2	20:00:00	Night

* This bike sharing company has produced two types of shared bikes and there are called as ”red-packet bikes”, whose biketype is 999, offering bonuses for customers if they help circulate shared bikes.

3.1.3. Points of Interest from Baidu Map

POIs can provide us with useful information of study areas, especially land use pattern, which is essential in understanding the traits of grids and their interconnections in cycle lane network. We use the data collected from Baidu Map API, one of the largest geographic data providers in China. We extract different patterns of POIs, in the research area to explore the land-use patterns, including transportation infrastructures, government agencies, residential areas, restaurants, medical and educational institutions. Fields like POI name, address, longitude and latitude are contained in the POI data and the examples are given in Table 2.

Table 2: Examples of POI data

POI_Name	POI_Address	Longitude	Latitude	Label
Gui Jiang Road Bridge	Xuhui District,Shanghai	121.417804	31.151726	Traffic
Shu Xiang Court	Xuhui District,Shanghai	121.434544	31.144554	Estate
Xinguang Police Station	Primus Road No.505	121.393421	31.129078	Government

3.2. Louvain Method

Louvain Method is a fast, efficient and unsupervised approach for identifying elements with strong interactions which together form a community (i.e. cluster) in large networks (Blondel et al., 2008; Fanhas and Saptawati, 2016). A community can be an indication of frequent communication and circulation in a transport network. In the context of a bike sharing system, a community (or cluster) refers to a self-sustained zone where cycling activities are performed from one location to another within the zone. Those bikes inside a community have small possibility to ”escape” from the community (Fanhas and Saptawati, 2016), which is considered as a critical judgement for interconnections between grids in our research.

The method allows to discover the hierarchical structure of communities (Blondel, 2011). Similar to other clustering methods, such as optimizing Euclidean distance in K-Means clustering (Tan et al., 2006), communities can be automatically identified by maximizing the modularity value, which measures the density of links inside communities compared to connections between communities. The modularity value Q for a weighted graph is defined mathematically as follows (Blondel et al., 2008):

$$Q = \frac{1}{2m} \sum_{ij} \left[A_{ij} - \frac{k_i k_j}{2m} \right] \delta(c_i, c_j)$$

Where

- A_{ij} is the edge weight between node i and j
- k_i and k_j are the sum of weight of edge
- m is the sum of all the weight of edges in the graph
- c_i and c_j are the communities of the node
- δ stands for a Kronecker delta function

In order to optimize the modularity value efficiently, Louvain Method has two steps that are repeated iteratively.

The first step is the assignment of nodes to their neighbor communities according to modularity changes until no further modularity increment. In initialization stage, each node is considered a community. Then for each node i, modularity changes are calculated by removing node i from its original community into all the neighbor communities, which can be computed by (Blondel et al., 2008; Fanhas and Saptawati, 2016):

$$\Delta Q = \left[\frac{\sum in + k_{i,in}}{2m} - \left(\frac{\sum tot + k_i}{2m} \right)^2 \right] - \left[\frac{\sum in}{2m} - (\frac{\sum tot}{2m})^2 - \left(\frac{k_i}{2m} \right)^2 \right]$$

Where $\sum in$ is the sum of all the weights of the edges moving into the community i. $\sum tot$ is the sum of all weights of edges inside the community. k_i is the weighted degree of node i. $k_{i,in}$ is the sum of the weights between node i and other nodes in the community and m is the sum of the weights of all edges in the network. Then node i will be assigned to the community with greatest modularity increment and will remain in the origin community if no increment is guaranteed. This step is executed repeatedly and sequentially to all nodes until no modularity increment occurs. The first step ends once this local maximum of modularity has been attained.

The second step is grouping the nodes in the same community found in the first step and constructing a new network where previous communities are now regarded as the nodes. Links between nodes of the same previous community are now considered the self loops of the new node and edges between nodes from different previous communities are now represented by edges between nodes. The second step ends after creating the new network and the first step is reapplied.

These two steps are repeated until there are no more changes. A directed weighted network is acceptable in Louvain Method with modified modularity (Malliaros and Vazirgiannis, 2013). But we consider the prototype of the method, which is based on undirected graph, since the directions of connections between zones are neglectable.

4. Results and findings

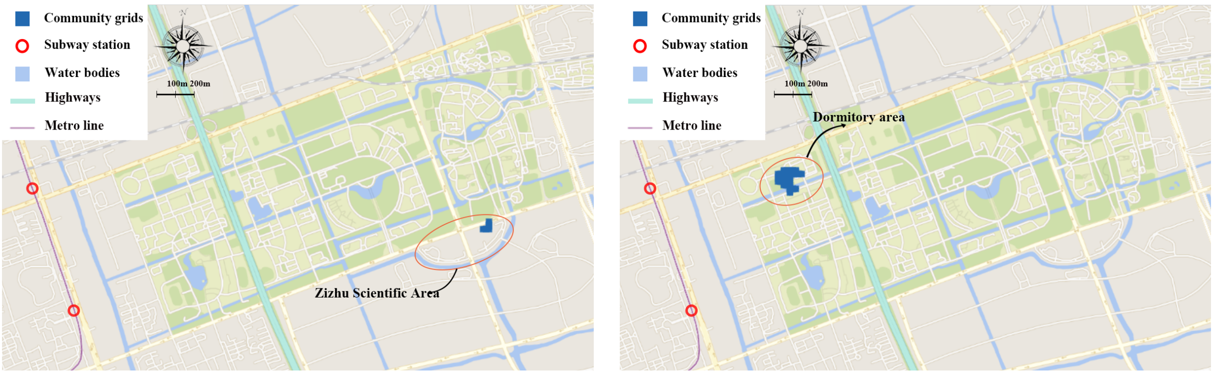
In this section, we conduct case studies for the two selected area in the city of Shanghai, in order to examine the cycling mobility pattern of the newly introduced dockless bike sharing systems and to understand the performance of the cycling network infrastructure.

4.1. Significant cycling mobility patterns

Using the data described above, we applied Louvain Method (Jeub et al., 2016) on the first study area to find typical cycling mobility patterns in a well-connected cycle lane network. 561 communities in total are generated, each of which represents one typical mobility pattern. We have identified the following four significant community configurations.

4.1.1. Adjacent-grid communities

One typical community configuration is that grids with strong interactions tend to be located geographically close to each other and thus form a community cluster. Figure 2 shows two examples of the adjacent-grid community. This is the most popular cycling mobility pattern identified, reflecting the bicycle movement within a small area. The community shown in Figure 2i is a common type of adjacent-grid communities, consisting of three or four grids in size. We attribute such dots-like trips to the bike rebalancing activities by system operators, as is regulated by the Shanghai transport agency (Ministry of Transport of the People's Republic of China, 2017). Such kind of small communities cannot reflect real cycling mobility demand. However, adjacent-grid communities with more grids typically reflect the inherent cycling demand of short-distance trips in these areas, such as the example shown in Figure 2ii. In this example, the community consists of the dormitory area and dining halls, and it is formed due to the significant internal short-distance cycling demand.



i Zizhu Scientific Area　　ii Dormitory area in the campus

Figure 2: Examples of adjacent-grid communities

i Research center　　ii Industrial park

Figure 3: Examples of radial-pattern communities

4.1.2. Radial-pattern communities

Another type of communities not only includes a bulk of adjacent and closely located grids, but also contains a number of geographically distant grids, showing strong connections between the central bulk and remote grids. These radial-pattern communities can be regarded as the evolutive pattern of adjacent-grid ones. Figure 3 shows two examples of the radial-pattern communities, with a research center and an industrial park serving as the central bulk, respectively. The grids in the central bulk are usually important POIs, such as subway stations, shopping malls and workplaces. The existence of the central bulks indicates the well met short-distance cycling mobility demand in the core areas. Those remote grids in the radial-pattern community demonstrate the long-distance cycling mobility demand. Thus, radial-pattern communities show the importance of POIs in forming communities.

4.1.3. Grouped communities

A grouped community consists of multiple adjacent-grid and radial-pattern sub-communities, reflecting a higher-level community structure. As shown in Figure 4, each bulk represents an adjacent-grid community or the center of a radial-pattern community, while the grouped communities unveil the connections among these community clusters. Each community cluster shows strong inherent connectivity, and the whole grouped community reflects a higher coherence of the whole area.

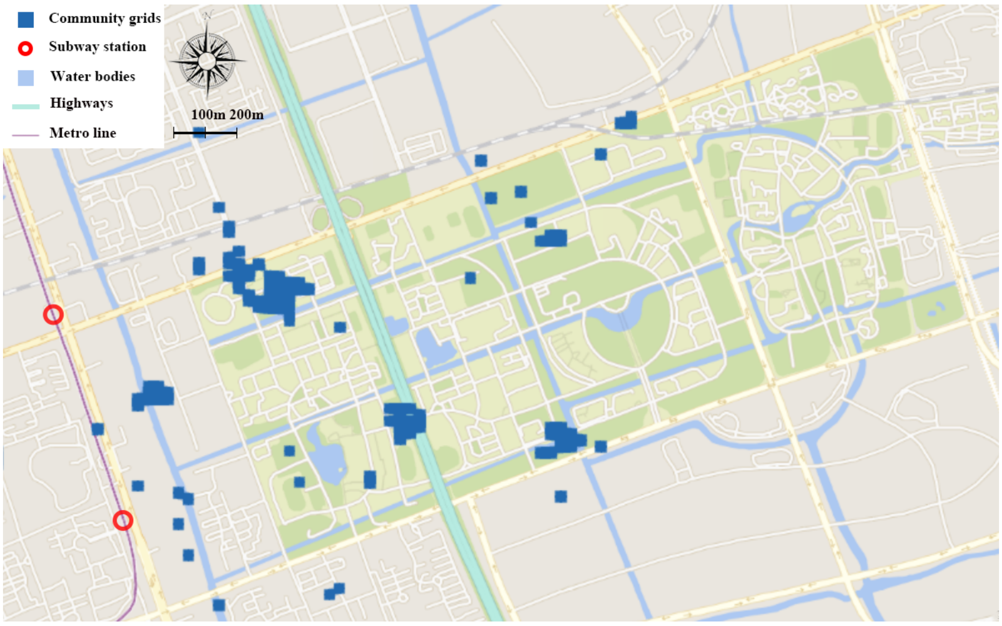


Figure 4: Example of grouped communities in the first study area

4.1.4. Unseparated communities

Another significant community pattern is an entire cluster formed by a large set of grids within a certain area, which can be considered as the highest-level community structure, like the one shown in Figure 5. The unseparated community pattern shows that the connections between all the grids in the community are at the same level and cannot be further grouped. It indicates that all grids are fully connected. In a well-connected cycle lane network, those fully connected grids form a big unseparated community and cover the cycle lane network to a large extent. From a macro perspective, the existence of this community pattern can reflect the influence that the surrounding environment has on the formation of the communities. Therefore, this community pattern can serve as an important indicator for integration between cycle lane network and the city land use.

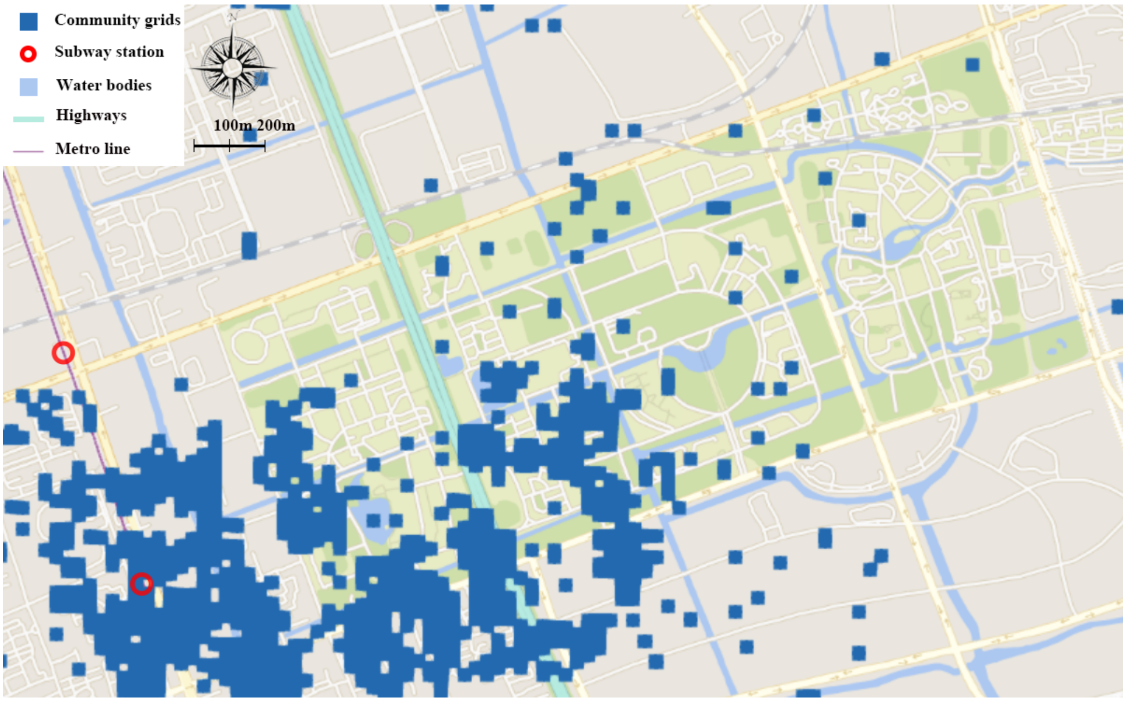


Figure 5: Example of unseparated communities in the first study area

In summary, the above four significant cycling mobility patterns show progressive states of communities, from a single cluster to a network-wide community.

4.2. Cycling mobility demand factors

We further employ the Louvain method on the second study area and examine the effect of land use on the cycling mobility demand.

4.2.1. Importance of POIs

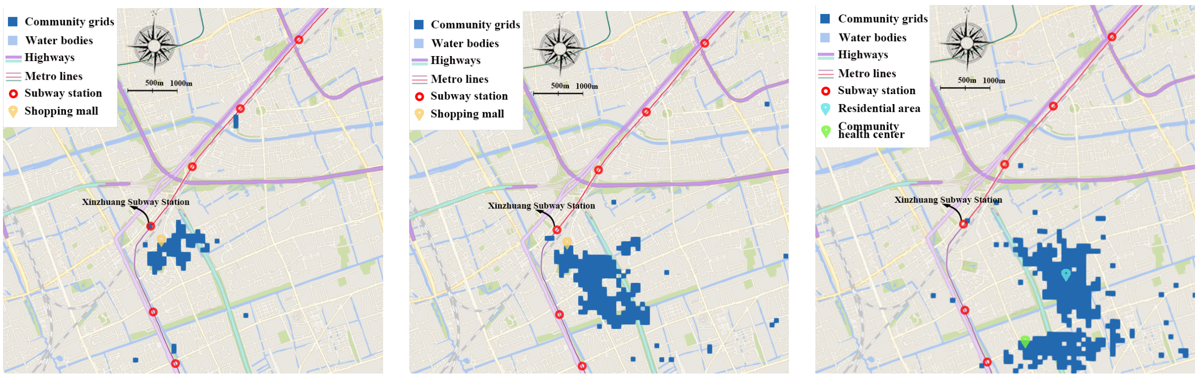
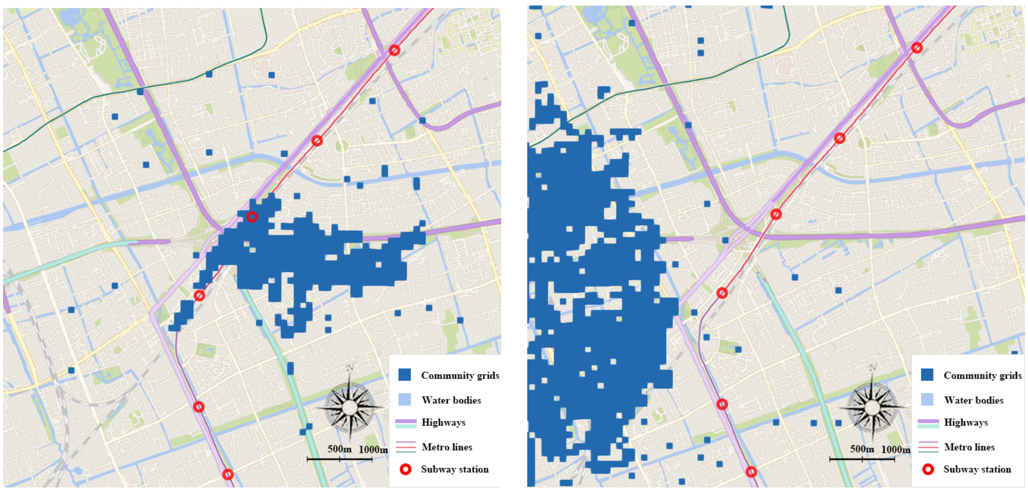


Figure 6: Community connection between subway station and nearby POIs

POIs play an important role on cycling mobility demand, even though they are of small size in the entire community. Figure 6 shows that one major POI, Xinzhuang subway station, appears in multiple communities due to its strong connection with its nearby residential buildings, community centers and shopping centers, while it is located away from the central bulk of the community. Thus, the development of cycle lane network should take into account not only those cycling demands within or between large bulks in communities, but also those important POIs (e.g., transport hub, shopping center) especially if they are located away from the large bulks of the communities. As such, the cycling mobility demand between the POIs and other areas can be well met.

4.2.2. Geographical barriers

By investigating the unseparated communities in the second study area, we find that some closely located cycling demand communities are isolated with each other due to some geographical barriers, such as express ways, metro lines, rivers and so on. Those geographical barriers prevent cyclists to move from one side to the other, making the cycle lane network not well connected. It could be attributed to the independent planning of transportation systems and inconsistency between cycle lane network and land use. Figure 7 shows two examples of the geographical barriers. As can be seen, communities are segmented by highways, metro lines and rivers. A well-connected cycle lane network is supposed to contain a large community covering the study area to a large extent like the Figure 5 instead of many isolated communities. Therefore, in order to build a well-connected cycling network, it is important to improve the integration of the cycling infrastructure with the urban land use and other transportation systems.



i Blocked by highways and subways

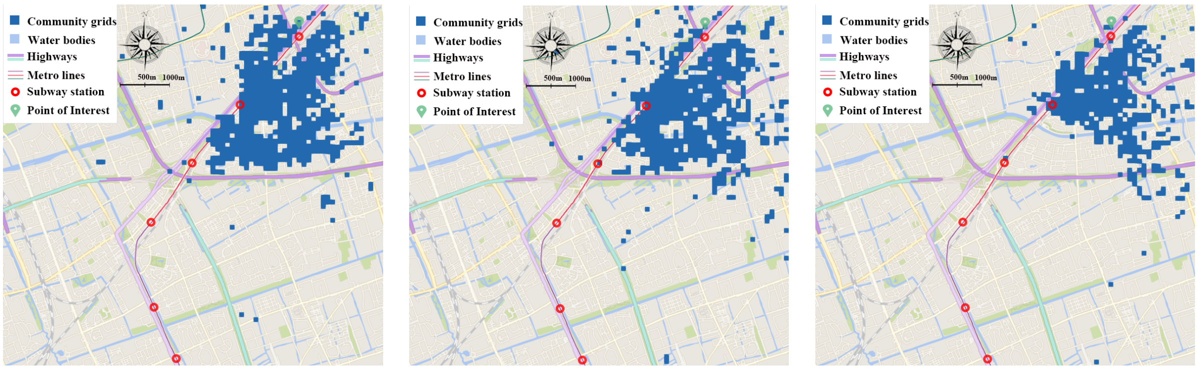
ii Blocked by highways and rivers

Figure 7: Examples of geographic barriers by urban land use

4.2.3. Temporal analysis of communities

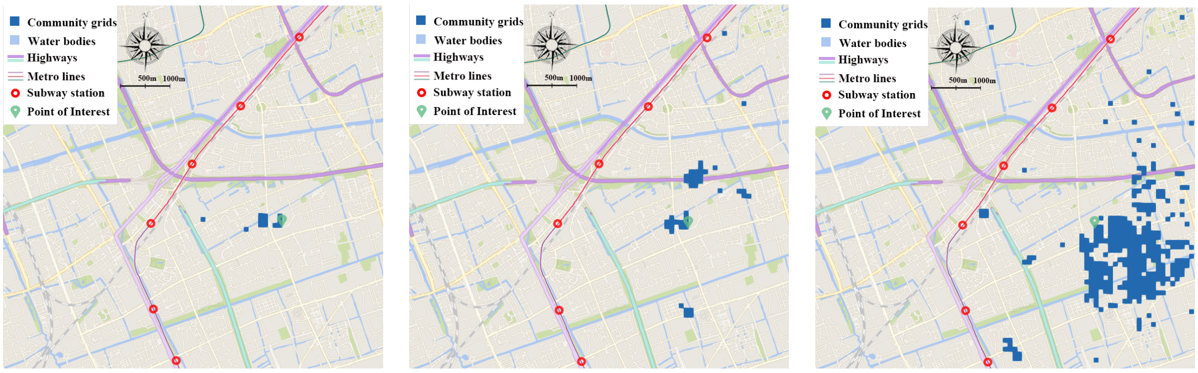
The patterns of the communities change over time and exhibit dynamic nature, which helps us to understand the cycling mobility demand during different time period of a day. We identify communities during the three time period (Morning, Afternoon and Night) associated with the same POIs, in order to find the temporal variance of communities. We find that most POIs have similar community patterns in terms of size and shape among three time periods, as shown in Figure 8, which can be defined as "time-invariant" communities.

However, "time-variant" communities with changing orientation and distribution patterns are also identified. In such cases, the associated POIs are usually not at the center of radial-pattern or grouped communities. It indicates significant change of cycling mobility demand over time of day in the area. For example, in Figure 9, communities the POI belongs to change remarkably among three different time zones (Morning, Afternoon and Night) of a day. This can explicitly indicate the cycling mobility demand of the area changes sharply during the day. Understanding the time-varying nature of the cycling mobility demand are helpful for system operations, such as bike rebalancing in the time-variant community areas. We discuss the policy implications and recommendations in the following section.



i Time period: Morning   ii Time period: Afternoon   iii Time period: Night

Figure 8: POI with time-invariant communities



i Time period: Morning   ii Time period: Afternoon   iii Time period: Night

Figure 9: POI with time-variant communities

5. Policy implications and recommendations

By investigating the cycling mobility demand patterns via data mining techniques, we identify the critical issues of Shanghai's cycle lane network:

(1) Cycle lanes are not well connected in the form of a network structure; and
(2) The existing cycle lane network turns out to be an isolated system without sound integration with urban land use and public transportation system.

The booming of the dockless bike sharing systems calls for the improvement of cycle lane infrastructure as well as corresponding management policies (Mobike et al., 2017). In reviewing the findings of this study with respect to bike sharing travel demand and cycle lane network performance, we suggest the following measures both in operational management and policy development perspectives.

5.1. *Introduction of electronic bike parking fences*

The electronic bike parking fence is a new concept for centrally managing dockless shared bikes, which takes GPS or other locating techniques to stipulate that shared bikes must be parked at typical positions instead of being thrown around. They help transport agencies to administrate dockless shared bikes collectively, standardize their parking and better control the distribution and rebalancing of shared bikes. The locations of the electronic bike parking fences ought to be well determined in view of the demand distribution in the spatial and temporal dimensions. Those essential locations in cycle lane network can be considered, such as metro stations, shopping malls. As mentioned above, centers of radial-pattern communities and bulks in grouped communities can actually play the role. Therefore, to centrally manage the shared bikes as well as optimize the cycle lane network, electronic bike parking fences can be set up in well-selected locations with consideration of the actual land use and infrastructure construction.

5.2. *Integrated planning of urban land use and transport systems*

It is important to ensure that the cycle lane network should be developed and expanded in consistency with the urban land use and other transport systems. In view of the discontinuity between cycle lanes and other transport infrastructures, those separated cycling areas call for improvements in order to form up an integrated cycle lane network. We suggest that transport agencies connect the separated communities by building up some overpasses or tunnels, like the "Bikesnake" established in Copenhagen, a cycle bridge connecting two areas over a block of commercial area (Visitcopenhagen). Also, some dispensable geographical barriers could even be removed if necessary. Meanwhile, transport agencies should also consider the coverage of important POIs to better enhance the integration between land use and cycle lane network. Due to its importance in forming communities, POIs should be well considered in the cycle lane network design along with electronic bike parking fences and geographical barriers.

5.3. *Setting up restricted areas for shared bikes*

To better manage the bike sharing system, there is still the need to set up restricted areas for shared bikes as a complement to cycle lane network for the purpose of improving the safety, efficiency and the appearance of the city. Shanghai municipal government has published *Guidance on Encouraging and Standardizing the Development of the Internet Renting Bicycles* (Ministry of Transport of the People's Republic of China, 2017) and imposed regulations on cycling behaviors, including nonstandard cycling and arbitrary parking. In addition, there are a number of crowded, historical but narrow roads in the downtown area of Shanghai, such as East Nanjing Road, Middle Huaihai Road, where a walking and cycling-friendly environment is indispensable. This measure can be useful for protecting the preserved historical areas and reducing accidents for areas with high safety risks. Hence a well-designed cycling network should consist of not only well-connected cycling lanes but also some areas with restricted or even forbidden cycling activities.

5.4. *Traffic monitoring of important POIs*

Traffic monitoring is needed for important POIs, especially those associated with time-variant communities. Shanghai municipal government has strict surveillance of automobiles but lacks monitoring of bicycle. Meanwhile, as introduced above, there exist some critical POIs that may belong to several communities in different directions at different time periods, implicating the variation of bicycle flow. Therefore, these important POIs are typical spots which need monitoring by effective measures in order to prevent accidents.

5.5. *Construction of a cycling mobility control system*

Considering that the future urban governance will definitely turn digital, we propose to establish a cycling mobility control system by government and bike sharing companies to further assist in optimizing cycling lane network. As a data-driven bike-sharing management platform, the cycling mobility control system consists of a Geographic Information System (GIS) and data platforms from bike sharing companies to provide basic data of supply and demand sides respectively. The supply data in GIS include cycle lane data, electronic bike parking fences data and restricted areas data, while the demand data in companies' bike sharing data platforms includes bike-sharing usage data and bike distribution data. Upon this cycling mobility control system, functions including bicycle rebalancing, bicycle network planning, safety risk assessment and traffic monitoring can be supported. The specific structure of this control system is presented in Figure 10. Therefore, combined with the above research findings and policy recommendations, the construction of such management platform can be beneficial on further cycling lane network optimization.

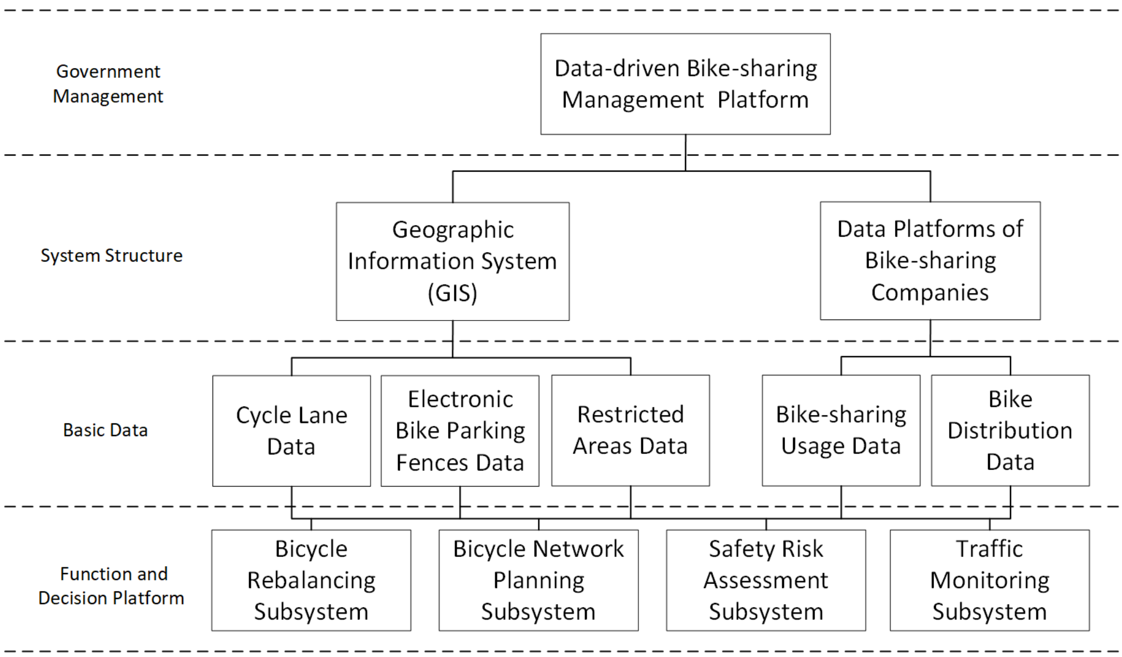


Figure 10: Structure of cycling mobility control system

6. Conclusion

This paper has obtained an in-depth understanding of the cycling infrastructure in the city and proposed to bridge the supply-demand gap between the existing cycle lane network and the booming cycling mobility demand. The emergence and fast development of dockless shared bikes has raised the challenge to improve current cycle lane network to meet their traveling demand. We managed to fetch bike sharing and POI data and choose two study areas to represent suburban and urban cases. A graphic clustering algorithm, Louvain Method was then applied to recognize communities where cycles circulate frequently. Besides four typical cycling mobility patterns, we have discovered that Shanghai's existing cycle lane network has some flaws including lack of network integrity and connectivity with urban land use. Therefore, we propose five pieces of suggestion to ameliorate current cycle lane network with concerns about safety, efficiency and management of shared bikes, including electronic bike parking fences, integrated planning of urban land use and transport systems, setting up restricted areas for shared bikes, traffic monitoring and cycling mobility control system construction.

In our future research, we would like to design a model to describe the topology of future cycle lane network with electronic bike parking fences and integrated cycle lane system. Then to optimize the structure of such network using operation research methods to help the government better improve current cycle lane network.

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