Bike-share System Development and the Inter-Relationship between Bike-share System and Mass Transit based on Data-driven Methodology

Tianqi GU

BEng (Transport Engineering), MEng (Transportation Planning and Management)

A thesis submitted for the degree of Doctor of Philosophy at

Monash University in 2020

Institute of Transport Studies

Department of Civil Engineering

COPYRIGHT NOTICE

ABSTRACT

Bike-share system (BS) has existed for 50 years and experienced rapid development in recent years. Known as an ideal first-mile interchange mode with mass transit, BS is considered as a sustainable, healthy and "transit-friendly" transport mode. Among all the countries, China owns the largest BS market in the last decade and was the born-place of the dockless bike-share system (DBS), which largely change the way people live. During this period, like many other developing communities, more and more cars have been swarming into cities. Infrastructure design has been transferring to car-oriented and conflicts between cars and bicycles intensified. On the other hand, in order to face the challenge of increasing mobilization by cars, this country has been conducting continuous mass transit constructions. Therefore, it is meaningful to investigate how two-wheel transport mode, especially BS and DBS develop in China, and how BS, DBS and mass transit systems interact.

In this research, an empirical review of the development of two-wheeled transport in China is firstly proposed. This component of research aims at investigating the development of two-wheeled transport, comprising human-powered bicycles, E-bikes, and motorbikes in China from 1985 to 2019. During this period, government policy changed from "encouraged", "discouraged", "converted and re-recognized" to "encouraged again" due to sophisticated socio-economic change. It is found that the mode share of human-powered bicycles decreased steadily until 2016, the year dockless bikeshare (DBS) emerged. E-bikes and motorbikes witnessed an independent growth trend and policies from that of human-powered bicycles. After reviewing abundant macro factors at a national level, it is concluded that the future of the human-powered bicycle transport mode in China is promising, due to favorable government policies and the growing demand. E-bikes have an uncertain future since local policies differ and safety issues are yet to be addressed while the future of motorbike is growing marginal.

As for DBS, its development has experienced "free growth", "regulated" and "limited" phases in a short time. While the central government initially held a "neutral-positive" policy towards this new transport mode, the rapid expansion of dockless fleets soon exceeded cities' limits and resulted in local government policies changing from "neutral-positive" to "neutral-negative" until forceful limiting regulations have been implemented recently. It is found the sudden rise of DBS systems is due to three factors: (1) the growing user demands (the main factor), (2) the (partial) support from the government, and (3) the operators' strategy to over-supply. Still, financial sustainability is the main challenge that requires investigation. By reviewing how two-wheel transport mode and DBS develop, public transport is found to be a conditional influential factor. Therefore, a question remains as to measure this impact and find out the influential factors.

For the inter-relationship between BS and mass transit systems, a ''before-and-after'' study with a "difference-in-difference" methodology is initiated to measure changes of an existing BS during a period when a new metro system opened. The result indicates that most BS ridership and users within the new metro's catchment (the treatment group) have largely increased, except for BS stations located near metros' hubs. As for BS trip-pattern, after the new metro opened, a general trip-pattern change from balanced (similar returning and renting in morning and evening) to imbalanced (high returning in the morning and high renting in the evening) is observed. This further indicates that BS services along with metros, tend to serve "first-mile" interchange (origins to metros) rather than "last-mile" interchange (metros to destinations) in the morning and vice versa in the evening regardless of the land use type. Novel factors that impacting the combination of public transport and BS are investigated, expected to inspire other developing communities that share the same developing circumstance.

Inspired by the research outcome of two-wheel transport development in China, the author thought the transferring infrastructure and traffic condition might be new factors influencing the "marriage-quality" between mass transit systems and BS. These factors could be unique in developing communities with cycling tradition. A survey is designed to reveal how participants altered their BS usage frequency after

the new metro opened, followed by a probit model to estimate significant influential factors. The model indicates that as more columns of road separations exist, the cyclists are less likely to use BS towards metros. The higher congestion level promotes more cycling towards metros as well as the parking fee level. The combination of BS and metros could attract former motor vehicle users in bad traffic conditions, which could be instructive for urban planners and road designers.

In general, the main contribution of this thesis is three-fold. Firstly, it demonstrates how two-wheel transport mode, especially, for the first time, how BS and DBS develop in China with up-to-date information. Secondly, based on BS data collected during a time window a new metro opened, a difference-in-difference model is used to directly measure the immediate impact from a new metro to an existing BS, where a new and general index is developed to indicate BS/DBS trip-pattern. This is the first time that a before-and-after-change study is conducted in this research topic. Thirdly, novel factors in a developing community-context, are found to influence the combination of BS and metros by using a data-driven methodology.

LIST OF PUBLICATION

The following publications have arisen from the research reported in this thesis:

Journal Papers (Published)

1. Gu, Tianqi*, Kim, I. *, & Currie, G. (2019). To be or not to be dockless: Empirical analysis of dockless bikeshare development in China. Transportation Research Part A: Policy and Practice, 119, 122-147. (SCI, IF: 3.693). (2019 best PhD Thesis Award, Department of Civil Engineering)*

2. Gu, Tianqi*, Kim, I. *, & Currie, G. (2019). Measuring immediate impacts of a new mass transit system on an existing bike-share system in China. Transportation Research Part A: Policy and Practice, 124, 20-39. (SCI, IF: 3.693)*

5. Gu, Tianqi*, Kim, I. *, & Currie, G. The Two-wheel Renaissance in China - an Empirical Review of Bicycle, E-bike and Motorbike Development. International Journal of Sustainable Transportation. Under Review*

Conference Papers (Published)

3. Xiao D., ***Gu T Q****, Bao Y, & Kim, I.(2019) Inferring The Optimal Number Of Dockless Shared Bike In A New Area By Applying The Gradient Boosting Decision Tree Model. The 96th TRB Annual Meeting, Washington, D.C., USA, 2020.*

4. Song C Q, Bao Y, Gu T Q, et al. Perspectives on opening a gated community and its effect[C]//COTA International Conference of Transportation Professionals (CICTP) 2017. American Society of Civil Engineers, 2018: 3248-3257.

Journal Papers (Under Review)

6. ***Gu, Tianqi****, Kim, I. *, & Currie, G. More congestion plus less physical road separations promote cyclists towards metros? - Investigating Impact of factors influencing interchanging behavior between bike-share and mass transits. Transportation Research Part A: Policy and Practice. Under Review*

** Corresponding Author*

THESIS INCLUDING PUBLISHED WORKS DECLARATION

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes four original papers published/reviewed in journals. The ideas, development and writing up of all the papers in the thesis were the principal responsibility of myself, the candidate, working within the Institute of Transport Studies, Department of Civil Engineering under the supervision of Dr. Kim Inhi and Prof. Graham Currie. The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research.

In the case of chapters 3 to 6, my contribution to the work involved the following:

Thesis Chapter	Paper	Publication title	Publication status	Nature and extent (%) of the student's contribution
3	5	The Two-wheel Renaissance in China - an Empirical Review of Bicycle, E-bike, and Motorbike Development.	*Accepted*	75%
4	1	To be or not to be dockless: Empirical analysis of dockless bikeshare development in China.	*published*	75%
5	2	Measuring immediate impacts of a new mass transit system on an existing bike-share system in China.	*published*	75%
6	6	More congestion plus less physical road separations promote cyclists towards metros? - Investigating the impact of factors influencing interchanging behavior between bike-share and mass transits.	*Accepted*	75%

I have renumbered sections of submitted or published papers in order to generate a consistent presence within the thesis.

Student signature: **Date: 27/02/2019**

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the student and co-authors' contributions to this work. In instances where I am not the responsible author I have consulted with the responsible author to agree on the respective contributions of the authors

Main supervisor signature: **Date: 27/02/2019**

ACKNOWLEDGEMENTS

They say it could be a tough journey, maybe even a lonely one. Luckily, it is just half-right. Here I would like to express my sincere gratitude to those nice people who companied me in this tough journey. Firstly, I would like to express the deepest appreciation to my supervisor Dr. Inhi Kim and professor Graham Currie. Dr. Inhi Kim convincingly guided and encouraged me to be professional. Without his persistent and patient help, I would still be outside the gate of academic. Professor Graham Currie inspired me with his rich experience and optimistic attitude, which encouraged me at crucial time points. Dr. Kun An and Dr. Nan Zheng are also acknowledged for their great advices and encouragements during stages of this research. Then, I wish to acknowledge the support and great love of my friends in Monash. Kai Huang and Bo Wang, I cannot imagine how could I go so far without your guys' help. Kai, you are always helpful to others, and I am sure live will treat you the same way. Bo, no doubt you will achieve great academic accomplishment, I wish you a bright future on your seeking. Lillian, Xiao Dong, Wen Tao and Xin Yuan, thanks for your help and accompany, I will miss your laugh and hope you all good luck. I would also like to express my thanks to Min Major, and Fatin Hasan, our research managers for their support for almost all administrative matters. Thanks are extended to my CCDI colleagues Chutian Zhuang and other friends who helped me out of this journey. Finally, the greatest thanks go to my family members, My parents and my wife, for their caring support and love. Without them, I cannot make it.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Overview

This thesis proposes empirical studies of the (dockless) bike-share system (DBS) and establishes a data-driven methodology to understand the inter-relationship between the bike-share system (BS) and the mass transit system. This chapter is to introduce the research background, followed by the objectives and scope. The contributions are then discussed. The last part shows the thesis structure.

1.2 Background

As an ex-bicycle kingdom, China's two-wheeled transport modes development fluctuated in the last 35 years while traditional human-powered bicycle transport kept shrinking until DBS showed up not long ago. Apart from strong government control, other social and economic factors together (public transport, social awareness, city expansion, resident income) impact the general trend of all two-wheeled transport modes. Up-to-date information towards China's two-wheeled transport development and related policies after DBS showed up is limited but important for urban planners, policymakers and even potential stockholders of DBS in overseas countries. It could help people to understand the reason for cycling return and how to promote it properly. It could also inspire other Asian and Latin American communities that share the same transformation period of urban transport as China do.

AS for DBS in China, it had grown from 2 million in 2016 to 23 million in 2018 and made itself one of the most significant shared transport modes. This innovation now has spread to overseas countries including the US, UK, and Australia, bringing convenience along with the downside known as fleet "congestion" (casual parking of bikes blocking pedestrian access). However, little up-to-date literature could be found in terms of how DBS has been implemented, developed, and supported in China. Its development along with the governments' policy in different phases requires solid, up-to-date information from both national and city levels, which is hard to find in the existing literature. No systematic review of DBS is seen by the time 【Paper 1】 was published.

This research, for the first time, develops an empirical study of DBS development and provides up-to-date information in China-context; So that appropriate policies could be implemented, and potential negative impacts avoided. For instance, overseas cities like Melbourne are experiencing vandalism and improper parking of dockless fleet bikes (King 2018), which have already been experienced and counter-measured by many Chinese cites. Besides, the over-supply of DBS is another urban management issue.

Moreover, one of the main functions of BS (DBS) is to enhance mass transit by offering "last-mile" or "first-mile" service. Since the latter normally changes the transport environment in a city-scale and requires huge financial investment, cautious response measures (BS included) should be considered (Li et al. 2015), especially for China - the largest BS market where new mass transit systems keep growing (Bao 2018; Dong et al. 2018). Therefore, it is essential to understand mass transit impact on BS and make proper preparation in policy, management, and operation. The research outcome could be further adopted in other developing communities in Asia and Latin America that share the same transport developing period. 【Paper 4】

So far, a literature of the inter-relationship between BS and mass transit normally focus on how BS impact mass transit, e.g. how much public transport and walking are substituted by BS (Martin and Shaheen 2014). Among the limited pieces of research studying the inter-relationship between these two transport modes, most of them adopted the SP survey and built an estimation model. On the contrary, a more direct and accurate way is to observe how real BS/DBS trip changes after a new metro is introduced. However, the opportunity to snapshot the time window (covering the period a new metro is open while BS data is collected) is quite rare. However, in this thesis, a before-and-after change study is firstly developed in this BS and mass transit inter-relationship research topic. It indicates the new metro impact on BS directly – by measuring the change of trip-demand (the number of renting and returning bikes in BS stations) and trip-pattern (the difference between renting and returning at different times in BS stations). Insight on this impact could enhance the understanding of BS's role as an interchanging mode of mass transit. Normally, BS are considered useful in "first and last mile" to interchange mass transit systems, in which "first-mile" indicates trips from origins (for instance, home in morning peak) to the metro stations while the "last-mile" indicates trips from metro stations to destinations (for instance, working place in morning peak). Although these two trips are always discussed in the same context, limited research focuses on identifying the difference between these two. However, due to the difference in land use, cycling facilities' demand and supply, and difficult to find the available bikes and docks, the "first-mile" and "last-mile" might occur independently and require different management. By identifying the renting and returning numbers in one BS station near a metro station in continuous time (namely, the temporal trip-pattern in station-level), "first-mile" or "last-mile" could be distinguished. For instance, when returning bikes largely outnumber renting ones in the morning, it could be interpreted that more users are cycling shared bikes towards metro stations rather than away from them. In other words, BS serves as "first-mile" in this case rather than "last-mile". By studying the inner mechanism, BS functions could be identified more precise to motivate cycling and promote interchange between BS and mass transit. 【Paper 2】

Once one figures out how the BS trip-pattern and trip-count changed after a new metro was open, a natural question followed is what influential factors caused these changes. The author holds the hypothesis that as a developing community with cycling tradition and cycling-oriented network, novel influential factors that impacting the marriage between BS and mass transit could be found. The built environment, land use, and infrastructure conditions are widely accepted as influential factors of this inter-relationship (Zhang et al. 2017; Campbell et al. 2016), while these factors are normally observed and analysed from developed communities cases. The network, travellers' awareness and infrastructure designs are mostly car-oriented while the traffic condition is normally stable. On the other hand, in developing communities like cities in China, the idea of infrastructure design is rapidly changing towards car-oriented, confronting the long cycling tradition. The traffic condition is rapidly changing since more cars are swarming into cities. Then, a data-driven methodology is then used to investigate potential novel influential factors. The research outcome could be inspiring for other new economies that facing the same transforming period. Our finding indicates that more road separation brings inconvenience for cyclists. This result is inconsistent with the former idea that independent bicycle lanes are beneficial to promote cycling, which might be constructive to an urban planner to plan and design a better road to promote cycling from a different point of view. 【Paper 5】

1.3 Research aim, objectives and scopes

The main aim of this research is to improve the research scope of the bike-share system, by conducting a series of empirical studies towards the two-wheel transport, especially BS (DBS) development and building up a robust framework to optimize the existing BS and mass transit inter-relationship research methodology. The detailed objectives of this research are shown in the following:

- To better understand the development of two-wheel transport modes, especially BS and DBS in developing communities as China.
- To build up an advanced data-driven methodology to measure the inter-relationship between BS and mass transit.
- To identify influential factors in this inter-relationship that is novel in a developing community context.

Table 1 represents the research scope. It covers sub-goals and related methodologies with related publications attached. By combining those elements together, four sub-topics are explored in this thesis.

Table 1-1 Research scopes

Topic	Subtopic	Methodology	Publication
1	An empirical study of two-wheel transport modes development in China	➢ Systematic Review	Published in IJST. Gu et al. (2020)
2	An empirical study of the development of BS, DBS	➢ Systematic Review	Published in TR Part A. Gu et al. (2019a)

			Accepted in TRB 2020. Dong and Gu et al. (2019a)
3	A study of the impact of new mass transit on an existing bike-share system	➢ Before-and-after change study with difference-in-difference model ➢ k-means clustering	Published in TR Part A. Gu et al. (2019b)
4	A study of factors influencing BS and mass transit integration	➢ Ordered Probit model ➢ SP survey ➢ Spatial data analysis	1st round under review in TR Part A. Gu et al. (2019)

1.4 Contributions

This thesis offers up-to-date information on two-wheel transport modes, especially BS (DBS) development. Besides, a novel data-driven mathematical methodology, as well as novel research outcome are drawn which could be inspiring for all parts that involved in the bike-share market. The detailed contributions are shown in the following.

Sub-topic 1:

- The empirical study of two-wheel transport modes development in China is proposed. Policy backgrounds are firstly organized, and influential factors in a nation-level are firstly identified over a long-time span.

Sub-topic 2:

- The empirical study on the development of BS and DBS is proposed, with up-to-date information.
- DBS users' characteristics are exerted from massive data and firstly investigated.
- Influential factors and feasibilities of DBS are firstly given.

Sub-topic 3:

- A novel data-driven methodology to study the impact of new mass transit on an existing BS is proposed, based on research outcome from sub-topic 1 and 2.
- The difference-in-difference model is firstly adopted in this topic to acquire a before-and-after study result.
- A new index is proposed to initiate a k-means clustering, which could be further used in other shared mobility research.

Sub-topic 4:

- A data-driven methodology to study factors influencing BS and mass transit integration is proposed, based on research outcome from sub-topic 1, 2 and 3.
- Ordered Probit model based on an SP survey data is adopted. The model and survey are designed in a developing community-context, where rapid mobilization, changing the idea of infrastructure design and cycling tradition co-exist at the same time.

1.5 Thesis Structure

Figure 1-1 shows the structure of the thesis. It is divided into three parts, and the total seven chapters are made up.

- Part I: (Chapter 1 - Chapter 2): Introduction and Literature review are provided.
- Part II: (Chapter 3 - Chapter 6): Four sub-topics mentioned above are presented.
- Part III: (Chapter 7): Conclusion of this thesis.

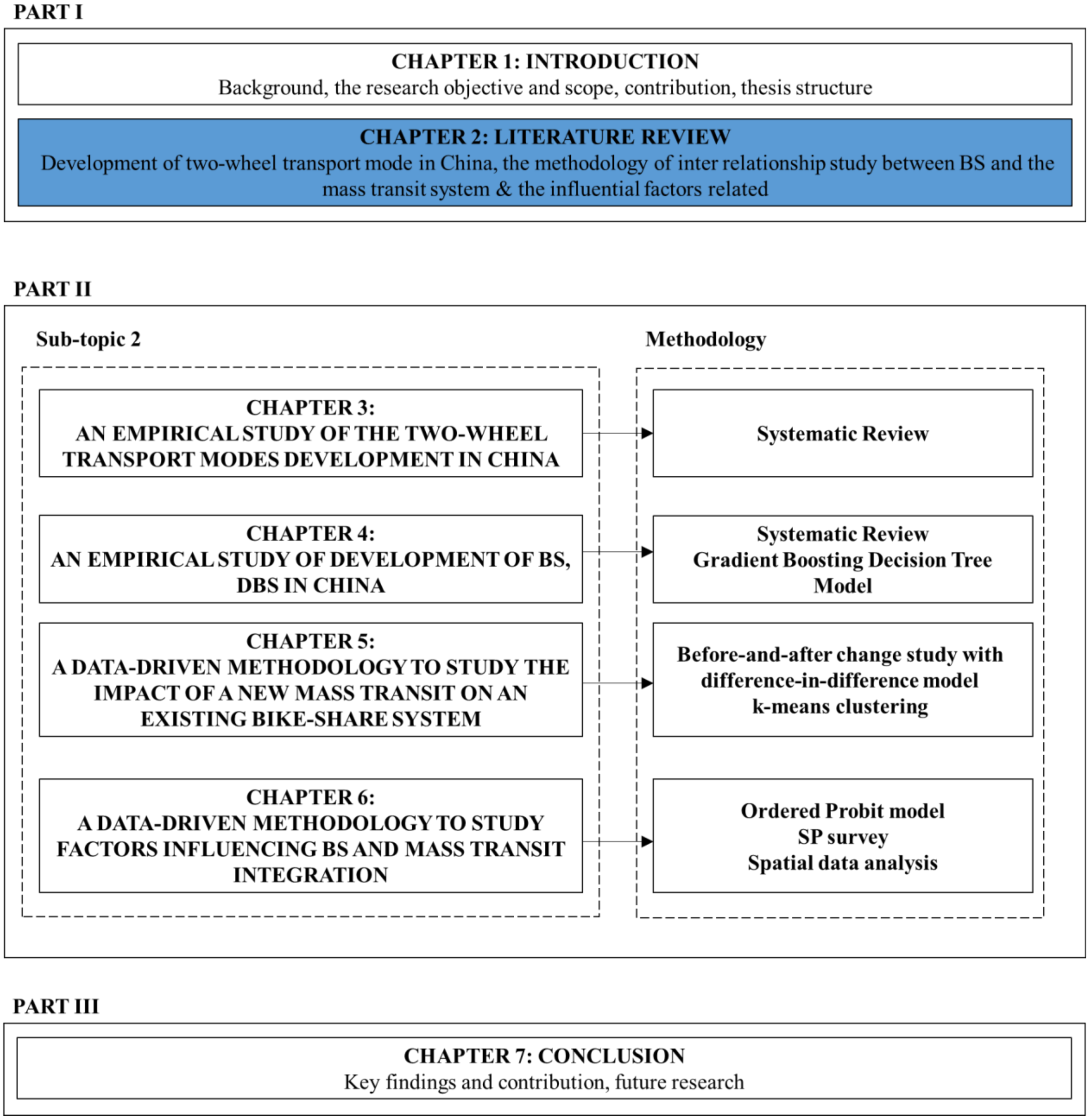
Part I of this thesis is made up of two chapters. In Chapter 1, the background of the BS, DBS and their relation with the mass transit is firstly introduced, followed by the research aim, objectives and scope. The contributions and thesis structure are then explained. In Chapter 2, it mainly reviews the related studies in three aspects: the development of two-wheel transport mode in China, the methodology of inter-relationship study between BS and the mass transit system as well as the influential factors related. Research gaps are identified, and solution methods are proposed.

Part II of this thesis focuses on the empirical studies and implementation of models in four chapters. Chapter 3 (sub-topic 1) is a systematic review of the two-wheel transport modes in China. Chapter 4 (sub-topic 2) is an empirical study of BS and DBS development in China. Chapter 5 (sub-topic 3) measures the immediate impact of a new mass transit system on an existing BS. It includes a before-and-after change study with a difference-in-difference model, a k-means clustering, and a case study. Chapter (sub-topic 4) proposed a data-driven methodology to investigate the factors including the integration between BS and the mass transit system. It includes an Ordered Probit model based on the survey and the same case study as in sub-topic 3.

Part III of this thesis includes one chapter. Chapter 7 involves the key findings and contributions to this research. Also, it shows the recommendations for future work.

Figure 1-1 Thesis structure

CHAPTER 2: LITERATURE REVIEW



2.1 Overview

The aim of this chapter is to review the existing studies on BS development in China and its role in terms of mass transit systems. The related literature is organized in three categories:

- Challenges in the up-to-date studies of two-wheeled transport and BS/DBS development in China (Section 2.2).
- Challenges in the before-and-after change methodology studying inter-relationship between BS and mass transit (Section 2.3).
- Challenges in data-driven methodology to investigate influential factors of BS and mass transit integration, considering developing communities' fast transforming background (Section 2.4).

Finally, it concludes with a summary of research gaps through this literature review. Solution methods to address those gaps are then presented in the following chapters.

2.2 Challenges in the study of two-wheeled transport mode and BS/DBS development in China

As an ex-bicycle kingdom and the birthplace of the innovative DBS together with active government control, a better understanding of China's two-wheeled transport and BS/DBS development would be inspiring information for urban planners, policymakers and even potential stockholders of DBS in overseas countries. The two-wheeled transport modes could be divided into human-powered bicycles and motor-bikes/E-bikes. So far, limited systematic review work has been done in organizing how these two-wheeled transport modes developed, while it was crucial to understanding how DBS rose and how to revive cycling. More importantly, as a developing community with a long cycling tradition, not only network, infrastructure design, but also social awareness in China are quite different from developed communities. Since abundant cycling-related studies are conducted based on developed communities' cases (in which normally bicycles are subjected to a private car), the investigation towards history, policy and social attitude of two-wheeled transport in China could bring a whole new perspective in bicycle transport research area. The outcome could be general and valuable for other developing communities. 【paper 4】

2.2.1 Problems in the two-wheeled transport mode development in China

2.2.1.1 The development of human-powered bicycles in China and government policies

Limited studies are related in this field, most of which are out-of-date. Zhang, Shaheen, and Chen (2014) conducted a review of human-powered bicycle transport in China, which covered a limited period. They concluded there were four phases of bike development in China between 1900 and 2012 (4 years before DBS showed), namely the Initial Entry and Slow Growth Phase (1900 to 1978), the Rapid Growth Phase (1978 to 1995), the Bicycle Use Reduction Phase (1995 to 2002) and the Attitudes and Policies Diversification Phase (2002 to 2012). Limited pieces of research covered fragments of bicycle development in China. Frame, Ardila-Gomez, and Chen (2017) presented a comparative analysis of data from Wuhan and Amsterdam to explore why "China was no longer the Kingdom of Bicycle". They concluded that earlier government attitudes towards transport policy and infrastructure construction were the main reasons for the decline of human-powered bicycle use in China. Similarly, Yang et al. (2015) reviewed the government's human-powered bicycle transport strategies, the quality of the two-wheeled cycling infrastructure, and the prevalent ideas for cycling planning in an early stage. They concluded that these three issues were not friendly to cycling for a decade and should be reversed if China wanted to revive cycling. Zhao et al. (2018); Frame, Ardila-Gomez, and Chen (2017) compared two-wheeled transport policy and infrastructure between Wuhan and Amsterdam, and Beijing and Copenhagen, respectively, and suggested ways of promoting local cycling in these two Chinese cities. 【paper 4】

2.2.1.2 The development of motorbikes and E-bikes in China and government policies

Research of E-bike draws more attention than a traditional bicycle. Users' behaviour, safety issues are widely discussed (Ling et al. 2015; Zhang, Shaheen, and Chen 2014). However, investigation of regional differences of policies and challenges of future development is limited. Unlike human-powered bicycles, policies towards motorbikes and gasoline mopeds have both regional and temporal variations. According to Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017)'s report about the E-bike industry, the first batch of E-bikes appeared in Shanghai in 1983. By the end of 2000, E-bike production had begun in China, and then in 2004, a large-scale enterprise was formed. The boom of rapid development for E-bikes in China occurred in 2007 when their production exceeded 20 million per annum in that year, annual production, and sales of E-bikes reached 30 million in 2010, which now accounts for more than 90% of the international export market. China has become the largest producer, consumer, and exporter of E-bikes (Ruan, Hang, and Wang 2014; Ling et al. 2015). Industrial reports have argued that E-bikes have had stable production and sales, but as the market has become saturated, it might be at a turning point (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017). 【paper 4】

2.2.2 Problems in the study of two-wheeled transport mode and BS/DBS development in China

It is widely accepted that the development of BS could be divided into 4 generations: 1) White Bikes (or Free Bike Systems) that firstly appeared in Amsterdam in 1965; 2) Coin-Deposit Systems that firstly appeared in Copenhagen in 1995; 3) IT-based Systems; and 4) Demand-Responsive, Multi-Modal Systems (Bachand-Marleau, Lee, and El-Geneidy 2012; Shaheen, Guzman, and Zhang 2010a). Most current BS in China are third generation products where bikes are normally returned and rented by smart cards or credit cards while the terminal centres record the time, location as well as the users' personal information (Ricci 2015). According to the Bikesharingmap (2017), cities and places deployed BS increased from 101 to 1,286 at an annual rate of 152.8% from 2010 to 2017. By the end of 2016, China had already become the largest BS market until now. By that time, 1.9 million bikes and 430 cities and places deployed BS while the total number of shared bikes worldwide was 2.29 million. Fourth generation BS (also known as a dockless bike-share system, namely DBS) is a highly flexible dockless system comprising GPS and personal smart phone, easier to be installed (Shaheen, Guzman, and Zhang 2010b; Parkes et al. 2013). 【paper 1】

Although China holds the largest BS and DBS market by far compared to other countries, research on development and policy of BS in the Chinese context is not as glaring as its position in the world BS market (Fishman 2016), let alone the research on DBS. Zhang et al. (2015) presented an empirical study and analysed bike-sharing systems in five Chinese cities. They concluded that well-planned configurations of transport, system design, and choice of a business model are key to a sustainable and successful city bikeshare system. Tang, Pan, and Fei (2017) and Karki and Tao (2016) studied BS in Shanghai and Suzhou during the development and policy introduction of BS in the early 2010s. Reviews of BS development in China-context are limited. As Fishman (2016) stated in his review paper "no country has the bikeshare scale of China, yet research activity does not reflect this". 【paper 1】

Thus, no paper so far had discussed the development and the policy background of BS and DBS in the Chinese context. Therefore, one of the biggest research gaps is that although China holds the largest BS and DBS market by far compared to other countries, little is known and understood about how BS and DBS have been implemented, developed, and supported. BS and DBS development and the governments' policy in different phases of its development require solid, up-to-date information based on both national and city levels, which is hard to find in the existing literature.

2.3 Challenges in the relationship between BS and mass transit

2.3.1 Problems in the study of the interrelationship between BS and mass transit

A direct way to investigate how BS and mass transit integrate is to initiate a before-and-after study. It could bring a relatively accurate outcome in studying how ridership and users' behaviour change. However, this methodology-based study is few since the opportunity to take the snapshot is rare. Not to mention those studies in a developing community context. Overall, research related to BS-mass transit integration tended to focus on BS's impact on transport mode substitution areas, based on the SP survey conducted in developed or car-oriented communities (e.g., how much public transport and walking are substituted by BS) (Fishman 2016). For instance, a number of studies have indicated that BS had a conditional positive impact on increasing public transit trips. Recently, in a survey taken near metro stations in Nanjing, Ji et al. (2017) found commuting BS users were more likely to interchange to the metro. A study conducted by Nair et al. (2013) on usage patterns of Paris' Velib' stations near transit stops revealed that the coupling of BS and transit stops can lead to higher public bicycle use. By comparing BIXI (a BS in Montreal, Canada) cyclists with private bike users, Bachand-Marleau, Larsen, and El-Geneidy (2011) found that regular BIXI users were more inclined to integrate cycling with public transport. Noland, Smart, and Guo (2016) found that proximity to transit, especially subway stations that are well utilized, generates bikeshare trips, so did Faghih-Imani et al. (2014) revealed in the case in Montreal. While the majority of the studies tended to support a positive effect of BS on public transport, Martin and Shaheen (2014) compared the two American cities of Washington DC and Minneapolis. He found introducing a BS may cause diverse results since BS might cause a shift away from public transit in core urban environments with high population density. On the other hand, studies of how mass transit systems influence BS are very rare while it is important, especially in the largest BS market China where new mass transit systems keep growing (Bao 2018; Dong et al. 2018). 【paper 2】

2.3.2 Problems in the study of the influential factors

In general, most of the studies are conducted based on cases in developed or car-oriented communities. Cycling habits and cycling-friendly network in these cases are different from developing communities as Vietnam, Indonesia, and China. In the latter places, new infrastructures are constructed to feed more cars while rich people just left bicycles no so long ago. In the meantime, alleys that fitting cycling are still marked in historical urban patterns, which make cycling favourable. To meet the challenges as congestion, the government throws money on mass transit and BS. Therefore, novel factors that influence the integration between BS and mass transit, could be different from former developed community-based studies.

2.3.2.1 Weather

As for the factors that might influence the BS and mass transits' integration, abundant researches have been done. A large number of studies have indicated that weather and temperature have a significant influence on cycling. Miranda-Moreno and Nosal (2011) found temperature, rainfall and humidity had an immediate and large impact on cyclists. Ding (2016) studied the impact of the built environment and weather on Seattle's BS-Proto and found annual members and non-members behaved differently in different weather conditions. By studying Brisbane's 'CityCycle', Corcoran et al. (2014) found strong winds and rainfall could significantly reduce BS trips. Although some studies focused on air pollution and cycling (MacNaughton et al. 2014; Jarjour et al. 2013; Hatzopoulou et al. 2013), most of them focused on health impacts while no previous research considered air pollution's impact on BS usage. 【paper 2】

2.3.2.2 Calendar event

As for calendar events, Kim (2018) found that heat and non-working days differently affect the demand for public bikes. Corcoran et al. (2014) concluded that calendar events (as public holidays) did exert some subtle variations in the spatial distribution of trips. Borgnat et al. (2009) predicted the number of bicycles hired per hour in Lyon's community bicycle program by introducing explanatory factors such as the number of subscribed users, the time of the week, the occurrence of holidays or strikes, and weather parameters. 【paper 2】

2.3.2.3 Spatial factors

A lot of research have already focused on how land use, POI or built environment influence BS ridership or demand; many of which indicated that proximity to metro stations promote BS demand (Wang, Tsai, and Lin 2016; Faghih-Imani et al. 2014; Wang and Zhou 2017; Jäppinen, Toivonen, and Salonen 2013). A high level of walking connectivity and walking-friendly built environments near transit station areas are vital to bicycle-transit passengers (Bernardi, La Paix-Puello, and Geurs 2018). By studying the bicycle-metro integration in Beijing, Zhao and Li (2017) concluded that the presence of bicycle-sharing programs, mixed land use, and green parks in metro station areas were associated with higher rates of cycling transfer. El-Assi, Mahmoud, and Habib (2017) used a case in Toronto to reveal that proximity to universities promote BS ridership. However, whether proximity to a metros' hub (metro lines' intersection) plays a positive role as influential factors remains a research gap. 【paper 2】

An exclusive bicycle lane is normally considered to be beneficial for cycling and BS in western countries or car-oriented areas. A very recent study conducted in Mashad, Iran found that road separations are closely associated with high BS usage, and users prefer exclusive bicycle lances out of safety concern (Abolhassani, Afghari, and Borzadaran 2019). Similarly, Noland, Smart, and Guo (2016) introduced a trip generation models for bikeshare in New York City and found that more bicycle lanes (especially on-street bicycle lane) within BS service area are associated with increased weekend and holiday trips, which was consistent with what Wang, Tsai, and Lin (2016). Jenhung Wang et al. (2016) found in Taipei's Youbike system and Xize Wang et al. (2015) demonstrated in the Minneapolis bike share system. A recent study conducted in Zhongshan, China by Zhang et al. (2017), also presented that BS trip demands were positively influenced by the length of bike lanes and branch roads. However, some domestic research from China argued that wide roads and too many road separations make cyclists and metro users inconvenient (Yin, Wu, and Hao 2017). 【paper 2】

2.3.2.4 Traffic condition

Most studies of BS mentioned that BS are environment-friendly and could mitigate urban congestion, and many of them mentioned BS had a conditional substituting function of private traffic mode (Wang and Zhou 2017; Fishman 2016; Zhang et al. 2017; Tran, Ovtracht, and d'Arcier 2015). Hamilton and Wichman (2018) found that BS can reduce congestion at the neighbourhood scale in Washington, D.C. By using a DID model to study on a larger scale, Wang and Zhou (2017) found that the introduction of BS shows a conditional but significant mixed impact on traffic congestion in general. Additionally, policies designed to discourage car use, such as congestion charging and road pricing, could benefit the promotion of BS. (Buehler et al. 2017).

On the other way around, the level of traffic congestion and parking fee are seldom considered to influence the usage of cars, while they are listed as significant reasons why people turn to BS and metros in a survey conducted in Suzhou, China (will discuss in section 3). Another challenge is that although BS is considered to mitigate traffic congestion, no research so far investigates whether novel factors (traffic congestion, road separations, parking fee) have any effect on users' preference to use BS to interchange metros. 【paper 3】

2.4 Challenges in data-driven methodology to analyse BS and mass transit integration

2.4.1 Problems in choosing the impact study methodology

2.4.1.1 Before-and-after study

One of the essences of establishing a successful interchanging system between bike-share and transits is to understand how they affect each other. A direct way to study this effect is so-called ''before-and-after'' studies, or ''quasi-experiments,'' which are not seldom used in the domain of transport research (Lathia, Ahmed, and Capra 2012). It is useful and accurate when studying a large-scale transport environment's change, by observing and comparing two complete datasets created by splitting one observation into the pre- and post-invention period.

In an early study of London, UK's underground's strike's impact on its BS (the 'Boris bikes') usage, Fuller et al. (2012) concluded that limiting transportation options (even it is unintended) may have a potential to increase population levels of physical activity by promoting the use of cycling. Based on the survey and the modelling, Martin and Shaheen (2014) studied how public transit in Washington DC and Minneapolis reacted after new BS systems were introduced by asking whether the survey participants used more public transit after new BS was introduced. Wang and Zhou (2017) examined whether the launch of BS can reduce citywide congestion. In this before-and-after change study, the authors employed a difference-in-differences model with two-way fixed-effects panel regression and concluded that the introduction of BSSs shows a significant mixed impact on congestion in general. This difference-in-difference method is frequently used in evaluating transport policy problems (Li, Graham, and Majumdar 2012; Hurst and West 2014; Billings 2011). The idea of building treatment and control groups at different times inspired this research. 【paper 2】

The challenge in this research is that a continuous time window with "before-" BS data and "after-" BS data is needed. Moreover, the control group and treatment group of BS should be divided according to a spatial connection with mass transits.

2.4.1.2 Index to indicate BS usage and cluster

Overall, clustering is widely used in impact analysis, especially in indicating significant BS usage patterns. When comparing the BS usage pattern (as the station-based temporal distribution of trips), clustering is widely used. In very recent research conducted in Shenzhen, China Wu, Wang, and Li (2018) applied time series analysis in two districts' comparison study (similar to a before-and-after change study) and used NAB (Normalization Available Bicycles) as an index to cluster BS stations in different districts. Similarly, the same clustering methods (as k-means and hierarchical cluster respectively), are used by Wang, Tsai, and Lin (2016) in their study in Taipei's BS system, Kim (2018) in his study in Daejeon, Korea. Lathia, Ahmed, and Capra (2012) used a data-centric approach combined with GIS-based analysis to cluster 66 London bike-share stations. They recorded NAB and detected how BS stations changed before and after a system-scale bike-sharing policy was released. 【paper 2】

However, challenges exist that NAB data cannot tell the difference between rebalance and actual usage, which makes it less accurate. Most of the shared bike research relied on the survey or using real-time number of the available bike (NAB) since the BS NAB dataset is normally easy to access. However, by NAB, it is hard to reflect the changing of both renting and returning bikes over a continuous time since NAB is collected in a discrete duration. In addition, NAB could mask the effects of rebalancing since it cannot tell the number-change is caused by operators or users. Faghih-Imani et al. (2014) studied BIXI in Montreal to investigate how bicycle infrastructure and land use impacted BS flow, in which NAB in station-level was used directly to transfer to the value of renting and returning. In this process, the author commented that "by using available bikes, it is not possible to directly distinguish whether or not the addition (removal) of bikes is due to customers or operators". Besides, the methodology based on NAB cannot be used in dockless bike-share (DBS) since there are no stations or docks of DBS while renting or returning data of DBS are usually accessible and accurate. Therefore, continuous real-time renting and returning trip data with rebalancing excluded is much more needed not only for accurate research of regular BS but also for DBS. 【paper 2】

2.4.1.3 Survey and probit modelling

Traditionally, sampling surveys and expert interviews have been widely adopted in BS research especially in issues as transport mode shift and measuring BS's impact on other transport modes. When investigating how public transport demand changed after a BS program opened in two US cities, Martin and Shaheen (2014) asked survey participants how they changed their bus/metro usage frequency after the new BS program operated. To make the survey simple and easy to understand, they gave scales in the option (as "increased a lot", "increased a little", "decreased a little" and so on). Accordingly, the ordinal regression model (to fit the multiple levels of options) was used to find out significant factors. In a very recent study, Nikiforiadis and Basbas (2019) also used an ordinal regression model that utilizing questionnaire survey data and field measurements. As a standard methodology to study the level-choice problem ordered (ordinal) regression model is widely used in transport mode choice areas (Ma et al. 2018; Daisy, Millward, and Liu 2018). 【paper 3】

2.4.2 Problems in processing spatial analysis

In organising big data of BS usage or preparing spatial analysis process, acquiring spatial data as congestion/travel time is a cardinal step to initiate a comparison between the control group and treatment group. In a very recent study conducted in Madrid, García-Albertos et al. (2018) calculated travel times between transport zones using the Google Maps API and constructed origin and destination (OD) travel matrices. Ji et al. (2017) acquired an estimated walking time by local Map provider Bai's API. These studies inspired us to turn to local Navigation Maps API to acquire the spatial index (as congestion, accessibility). 【paper 3】

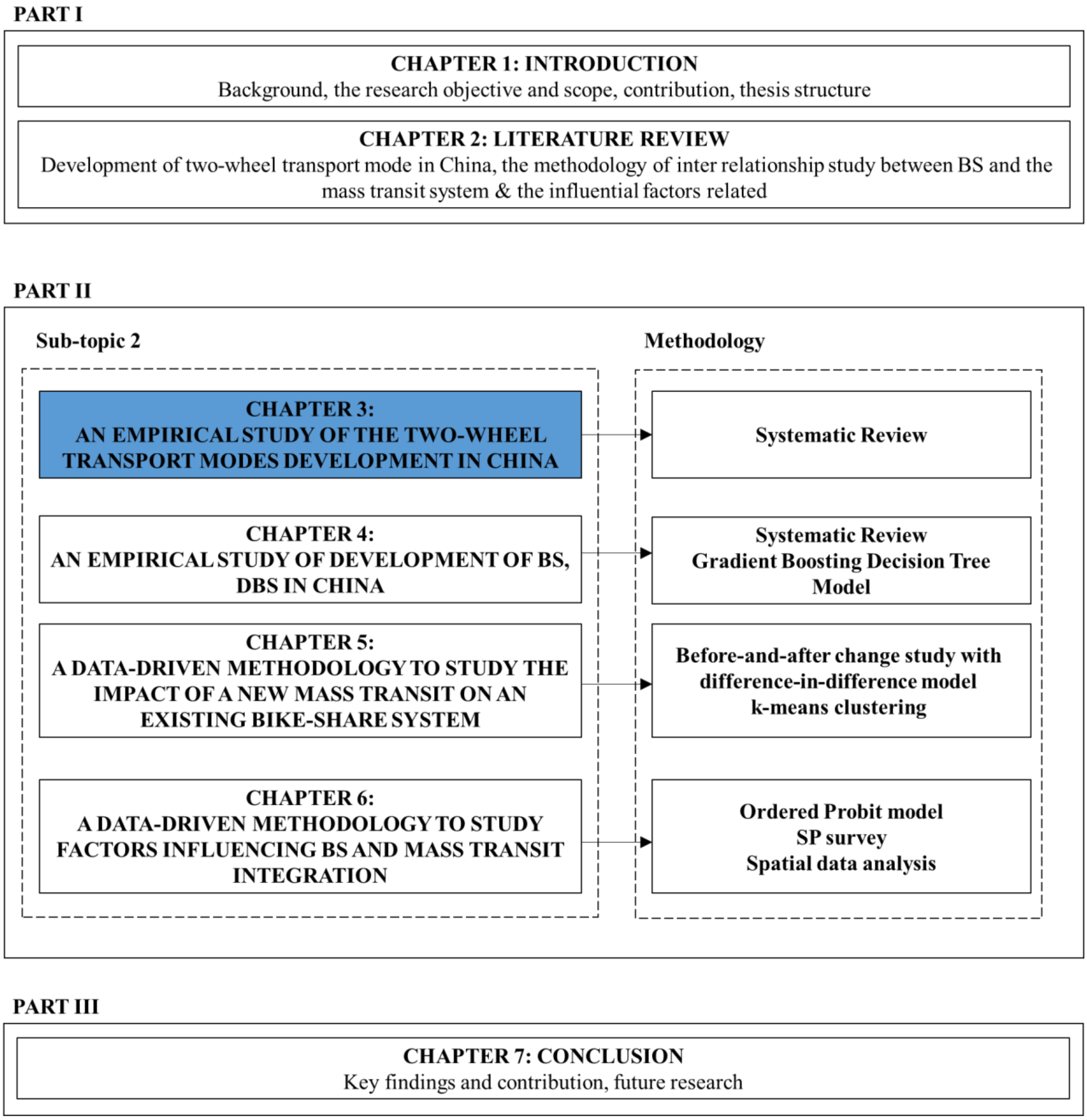
2.5 Research gaps

Based on the review of existing studies, five main research gaps in the knowledge are identified.

- The limited up-to-date studies of two-wheeled transport mode's development and policies related in the developed community as China
- No up-to-date research so far about BS/DBS development and policies related in the developed community as China
- No study conducting a before-and-after change caused by the impact of a new metro on BS, in a developed community as China (the biggest shared bike market and one of the biggest mass transit market)
- No research so far considering the new BS index that distinguishing renting and returning and study the difference between first-mile and last-mile
- The limited studies of the potentially influential factors as traffic condition and road design, considering developing communities' fast transforming background

The following four chapters will attempt to fill the above research gaps.

CHAPTER 3: AN EMPIRICAL STUDY OF THE TWO-WHEEL TRANSPORT MODES DEVELOPMENT IN CHINA



3.1 Overview

In the last decade, China has built the world's leading traditional bikeshare (BS) market. According to Gu, Kim, and Currie (2019b), the rapid growth of the BS market and the recent dockless bikeshare (DBS) market has resulted in 23 million DBS fleets deployed in over 200 cities in China by January 2018 and converted the long decreasing trend of human-powered bicycles across the nation. Motorbike transport development also has lagged while electric bike (E-bike) usage has boomed. An E-bike is classified as non-motorized for registration purposes in China. As an ex-bicycle kingdom and the birthplace of the innovative DBS together with active government control, a better understanding of China's two-wheeled transport development and related policies would be useful and inspiring information for urban planners, policymakers and even potential stockholders of DBS in overseas countries.

In general, up-to-date and systematic studies of two-wheeled transport development in China have been limited. Zhang, Shaheen, and Chen (2014) studied the human-powered bicycle transport evolution in China from the 1900s to 2011. Very recently, Gu, Kim, and Currie (2019b) performed an empirical analysis, focusing on DBS development in China and the reasons behind the DBS boom. Yang et al. (2015) proposed three major reasons why cycling had declined in China. Since the research was conducted before DBS emerged, the new cycling revival was not discussed. Zhao et al. (2018) and Frame, Ardila-Gomez, and Chen (2017) compared two-wheeled transport policy and infrastructure between Wuhan and Amsterdam, and Beijing and Copenhagen, respectively, and suggested ways of promoting local cycling in these two Chinese cities.

However, much of the existing literature covers the time before 2015, which means the resistance of two-wheeled transport caused by BS and DBS is neglected. Moreover, the existing literature focuses on a particular aspect of the big picture of two-wheeled transport development in China. The formation of government policy in different phases, as well as influential factors related to the development of two-wheeled transport, requires reliable, up-to-date information based on both national and city-level data, which is hard to find in the existing literature.

In this component of research, an empirical analysis of the development of two-wheeled transport is conducted, based on up-to-date literature and reports acquired from domestic and international sources. This chapter is further extended in Chapter 4 when it comes to the latest development of DBS. The research gap and objective are described in Table 3-1.

Table 3-1 Research gap and objective of Chapter 3

Research topic	Research gaps	Research objective
An empirical study of the two-wheel transport modes development in China	➢ Existing literature is limited. ➢ The resistance of two-wheeled transport caused by BS and DBS is not covered. ➢ User preference, infrastructure, social awareness of cycling in a developing community-context are seldom investigated.	➢ To organize the development of two-wheel transports modes (human-powered bicycles, motorbikes and E-bikes) in China. ➢ To investigate influential factors behind the development, especially the policies.

3.2 The development of the human-powered bicycle in China

Zhang, Shaheen, and Chen (2014) concluded there were four historical phases of bike development in China between 1900 and 2012, namely the Initial Entry and Slow Growth Phase (1900 to 1978), the Rapid Growth Phase (1978 to 1995), the Bicycle Use Reduction Phase (1995 to 2002) and the Attitudes and Policies Diversification Phase (2002 to 2012). During this latter phase, E-bikes and BS development began in China (until 2010). Frame, Ardila-Gomez, and Chen (2017) presented a comparative analysis of data from Wuhan and Amsterdam to explore why "China was no longer the Kingdom of Bicycle". They concluded that earlier government attitudes towards transport policy and infrastructure construction were the main reasons for the decline of human-powered bicycle use in China. However, Yang et al. (2015) reviewed the government's human-powered bicycle transport strategies, the quality of the two-wheeled cycling infrastructure, and the prevalent ideas for cycling planning. They concluded that these three issues had not been friendly to cycling for a decade and should be reversed if China wanted to revive cycling. Overall, studies of BS evolution and development in China are rare but with practical importance, since DBS is changing the way people travel and the public are paying more attention to healthy, green modes of transport, that is, cycling.

3.2.1 The growth of human-powered bicycle ownership from 1985 to 2019

Human-powered bicycles were introduced to China in the early 20th century, and again after the Economic Reform in 1978, when they became the most important mode of transport until the early 2000s. Human-powered bicycle ownership reached its peak in the 1990s. There were 197 bikes per 100 households in urban China in 1993, and 147 bikes per 100 households in rural China in 1995 (National Bureau of Statistics of China 2018). In other words, each urban family owned almost two bikes while every rural family-owned 1.5 bikes at this time. Figure 3-1 shows the ownership peaks that occurred in the 1990s and the steady decrease in ownership after 2000, especially in urban areas. In 2006, human-powered bicycle ownership in urban China was 117.57 bikes per 100 households, accounting for 59.6% of its peak value in 1993. A similar trend occurred in rural China. Although the National Statistical Yearbook (National Bureau of Statistics of China 2018) ceased to record public human-powered bicycle ownership after 2006, the China Academy of Transportation Sciences released nationwide human-powered bicycle ownership reports in 1995, 2001, 2003, 2012 and 2013 (Yin, Wu, and Hao 2017). They show that human-powered bicycle ownership reached its peak of 670 million in 1995, then fell to 290 million by the end of 2014. The steep decrease occurred between 1995 and 2001 when one-third of bicycle ownership vanished.

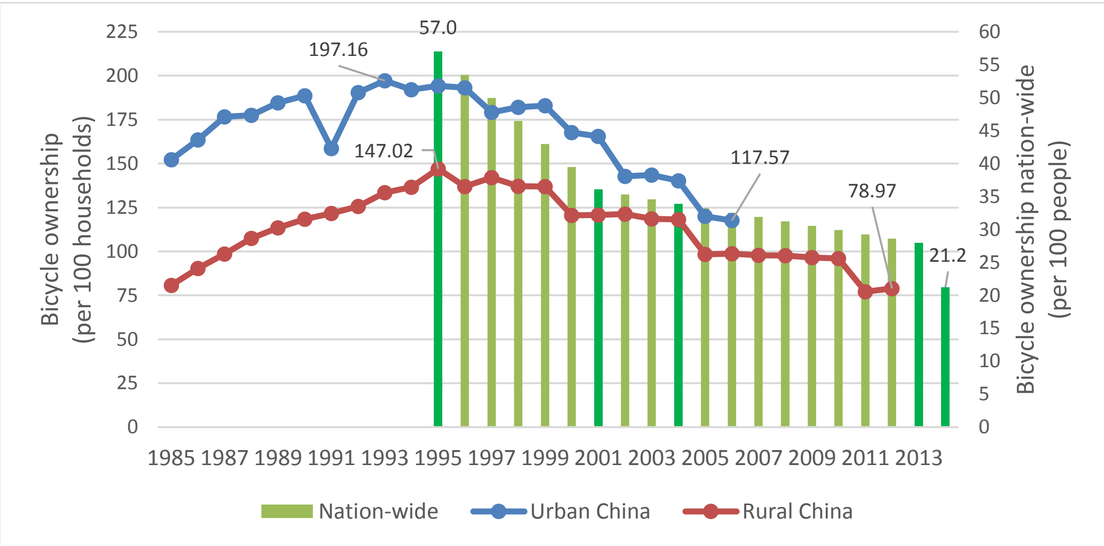


Figure 3-1. Human-powered bicycle ownership between 1995 and 2012

Note: For human-powered bicycle ownership nationwide, only data from 1995, 2001, 2004, 2013, and 2014 (green bars) are provided, thus the authors have used linear interpolation to add the missing year data. Source: Yin, Wu, and Hao (2017); National Bureau of Statistics of China (2018).

The annual production of human-powered bicycles could be used to understand the change in human-powered bicycle ownership nationwide. A slight decrease was seen from 2006 to 2016 as shown in Figure 2. The bars represent the production of bicycles and E-bikes from domestic manufacturers. In that decade, the production of regular two-wheeled human-powered bicycles decreased at the rate of 21.2% while E-bike production increased markedly from 2006 to 2013. However, in 2017, human-powered bicycle production increased from 53.03 million to 58.99 million at a rate of 11.2% in one year. According to the Secretariat of China Bicycle Association (2017), this recovery of the human-powered bicycle industry was closely related to DBS, which began in 2016 and blossomed in 2017. Considering that overseas consumption had always been relatively stable, the increasing production was apportioned to the domestic market, which was caused mainly by DBS consumption. BS and DBS development will be discussed in the following sections.

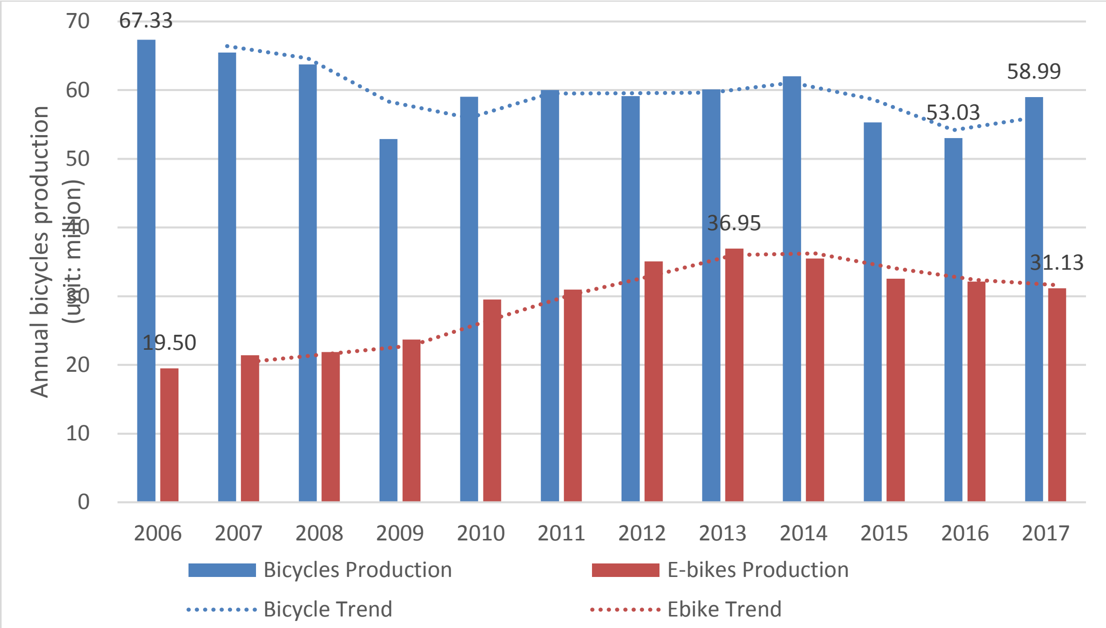


Figure 3-2. Human-powered bicycle production and E-bike production in China from 2006 to 2016

Source: Secretariat of China Bicycle Association (2017) and the National Bureau of Statistics of China (2018).

Zhang, Shaheen, and Chen (2014) systematically studied the human-powered bicycle transport evolution in China from the 1900s to 2011 and concluded that income was closely associated with human-powered bicycle and motorbike ownership. By comparing human-powered bicycle ownership in different income groups, they found that higher income groups welcomed human-powered bicycles in the 1970s until the 1990s, which led to a higher rate of possession in higher income groups. However, after the 1990s, these higher income groups became wealthy enough to purchase motorbikes, E-bikes or even private cars. Accordingly, their ownership of human-powered bicycles declined and was exceeded by lower income groups.

This also explained why rural China's private-car ownership shared a similar yet slower trend with urban China because the average income in rural China has always been lower than in urban China (see Figure 3-3). Besides, almost the same trend was found in the growth rate of private car ownership and GDP, which both continually increased from 2000 on (see Figure 3-4) (National Bureau of Statistics of China 2018). Table 3-2 shows the correlation analysis between GDP growth and private car ownership growth. As p = 0.003<0.05, lgGDP's coefficient of 0.066 is significant. A clear positive relationship is seen.

Table 3-2. Correlation analysis between GDP growth and private car ownership growth

Private_car_ownership	Coefficient	St. Error	t-value	p-value	[95% Conf Interval]
lgGDP	0.066	0.021	3.19	0.003	0.024***
Constant	0.361	0.042	8.49	0.000	0.274***

Mean dependent var	0.229	SD dependent var	0.062
R-squared	0.259	Number of obs	31.000
F-test	10.152	Prob > F	0.003

Akaike information criterion (AIC)	-90.740	Bayesian information criterion (BIC)	-87.872
*** $p<0.01$			

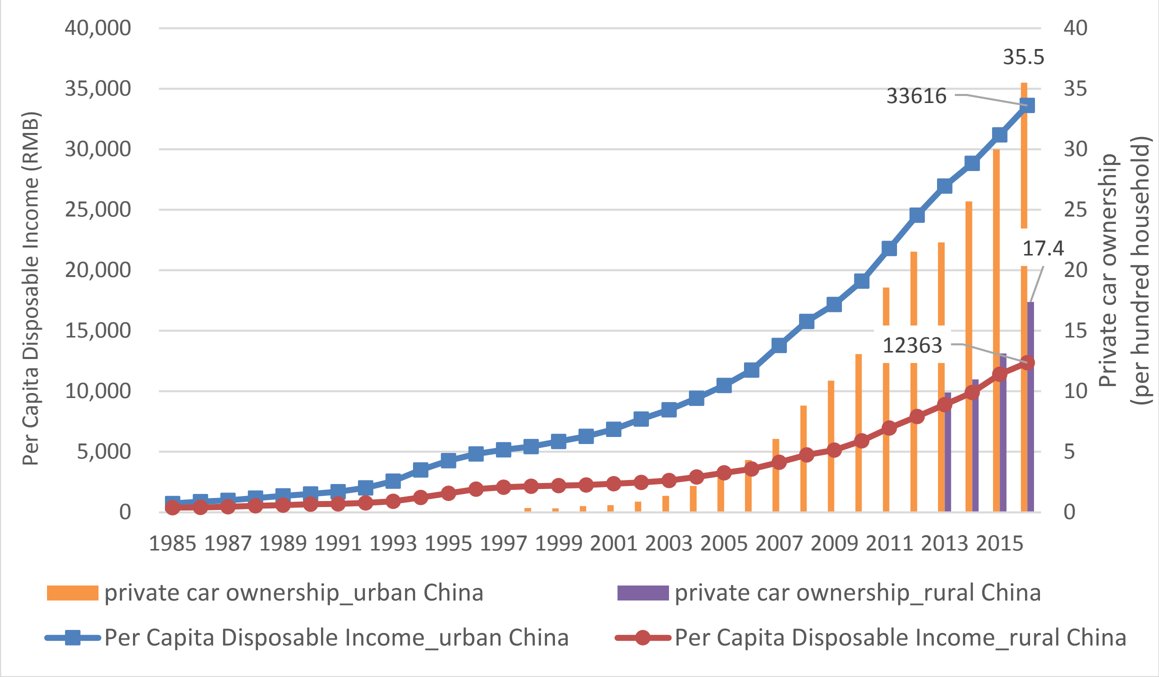


Figure 3-3. Urban and rural per capita disposable income growth vs. private car ownership growth

Note. No urban private car ownership data are available before 1998; no rural private car ownership data are available before 2013. Source: National Bureau of Statistics of China (2018).

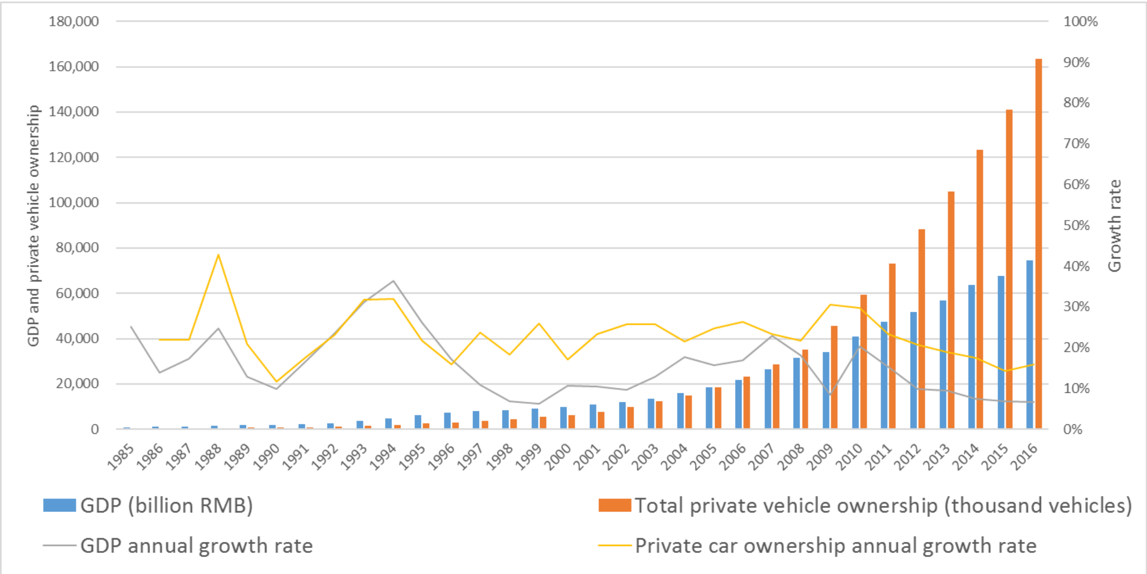


Figure 3-4. GDP and overall ownership of cars in China from 1965 to 2016.

Source: National Bureau of Statistics of China (2018).

Even though many human-powered bicycles are still registered and included in the statistics, most of them are no longer used and lie forgotten in bicycle garages; they are called "the sleeping bicycles". According to Liu's survey conducted in Hangzhou, China, among 2.76 million registered private human-powered bicycles, more than 90% were sleeping bicycles (Liu and Yang 2016). Therefore, the ownership is not representative of human-powered cycling's role in urban transport. To better understand how human-powered bicycles exist in China, the split between the various modes of transport is studied as follows.

3.2.2 Mode share of human-powered bicycles from 1985 to 2019

Overall, the mode share of human-powered cycling has changed dramatically over the past three decades. Generally, human-powered bicycle transport was dominant in most cities before 2000. For instance, the cycling mode of transport (the number of cycling trips over the total number of trips made) in Beijing was as high as 67% in 1986 (Gu, Kim, and Currie 2019b). However, from the late 1990s to 2015, there was an apparent decline in both ownership and bicycle transport nationwide. Table 3-3 lists some of the major cities with a tradition of human-powered cycling and shows that cycling has fallen dramatically in the past 30 years. Mode share is the percentage of people using a particular mode of transport. This transport comprises the following: human-powered bicycles, E-bikes, motorbikes and cars that are individually owned; and human-powered BS bikes and DBS bikes and E-bikes, mopeds and the like, which are owned by various companies and are hired out to individuals. By the end of 2017, Beijing and Shanghai had populations of over 20 million, and other major cities had populations of over 10 million, except for Nanjing, which had a population of 8 million. Generally, there was a sharp fall of human-powered cycling in all cities between 1986 and 2016: In Beijing, the cycling mode share fell from 67% to 13.5% while in Guangzhou and Suzhou it fell more dramatically. In contrast, the use of private cars in these cities increased or remained at a relatively high level, for instance, Suzhou's private car mode share has increased from 20.43% to 30.75% in the last 10 years (Suzhou Planning Bureau, 2018).

Interestingly, recently (2016 and 2017), cities with available data, such as Beijing and Shenzhen, reported a slight increase in the human-powered cycling mode share, which coincides with the year (2016) DBS began in China. Based on ownership and the mode share between human-powered bicycles, DBS and BS, Table 3-3 shows that when DBS emerged in 2016, it began the revival of human-powered cycling in China. In Shenzhen, from 2015 to 2017, the human-powered bicycle mode share rose from 8% to 10.7%, while 9.8% of cyclists (over 1% of the total travelers) were once private automobile drivers (Yin, Wu, and Hao 2017). Beijing had the same trend, as shown in Table 3-3, where the human-powered bicycle mode share increased slightly from 12.6% in 2015 to 13.5% in 2016.

Table 3-3. Human-powered bicycle mode share in Chinese cities over three decades

Beijing		**Shanghai**		**Guangzhou**		**Wuhan**		**Nanjing**		**Suzhou**		**Shenzhen**	
Year	Bicycle mode %	Year	Bicycle mode %	Year	Bicycle mode %	Year	Bicycle mode %	Year	Bicycle mode %	Year	Bicycle mode %	Year	Bicycle mode %
1986	67.0	1981	30.5	1984	34.1	1987	35.3	1986	44.1	N/A	N/A	1985	44
1995	41.18	1995	41.2	1998	21.5	1998	29	1999	41.0	1996	63.7	1995	21.8
2005	30.3	2005	30.3	2006	14.0	2003	19.2	2007	40.1	2009	11.1	2001	14.3
2015	12.6	2015	12.6	2015	8	2016	18	2015	28.8	2015	4.5	2015	8.0
2016	13.5	2017	N/A	2016	N/A	2017	N/A	2015	N/A	2017	2.6	2017	10.7

Note. The bicycle mode share in Nanjing contains both human-powered bicycles and E-bikes. Cities with available 2017 data, Beijing and Shenzhen, have dockless bikeshare while Suzhou has no dockless bikeshare.
Source: Gu, Kim, and Currie (2019b)

More importantly, an index of a fleet's penetration is widely used in many DBS assessment reports. Table 3-4 shows the penetration of BS and DBS in selected cities in China and overseas (DBS has more penetration). The overall DBS and BS penetration in Chinese cities is higher than in overseas cities. Most of the data from Chinese cities were acquired from local government annual transport reports and respective city statistical yearbooks. The overseas city data were collected and collated from the Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017b) as well as from DeMaio and Meddin (2017). Since human-powered bicycle mode share increased at the same time as

DBS emerged and while DBS has a substantial penetration and a significant number of bicycle fleets, it is safe to say that DBS has promoted an overall revival of human-powered cycling. An industry report, the white paper released by Mobike Global & Beijing Tsinghua Tongheng Planning and Design Institute (2017)–one of the largest DBS operators–showed that cities that had DBS witnessed an increase in human-powered cycling from 4.8% to 11.6% between 2016 (when Mobike, a leading DBS company emerged) and 2017.

Table 3-4. Critical index of cities with the highest BS and DBS volume

	Urban Population (million)	BS (10k)	DBS (10k)	Start time of DBS	Penetration of DBS (fleets/pop)	Penetration of BS (fleets/pop)
Beijing	21.7	8.6	235	9, 2016	10.83%	0.40%
Shanghai	24.2	3.03	170	4, 2016	7.02%	0.13%
Hangzhou	9.5	8.96	84	2, 2017	8.84%	0.94%
Shenzhen	12.5	2.2	89	1, 2016	7.12%	0.18%
Guangzhou	14.5	1	80	9, 2016	5.52%	0.07%
Nanjing	8.3	4.15	45	1, 2017	5.42%	0.50%
Wuhan	10.9	8	70	1, 2017	6.42%	0.73%
Chengdu	16	0.18	145	1, 2016	9.06%	0.01%
Suzhou	11.5	7.8	No DBS exists			0.67%
Washington D.C.	0.68	3.7	*	7, 2017	*	0.5%
Montreal	1.7	6.3	-	-	-	0.4%
Berlin	3.7	8.5	-	-	-	0.2%
Paris	10.6	18.2	-	-	-	0.2%

Source: National Bureau of Statistics of China (2018); Gu, Kim, and Currie (2019b) Note: Washington D.C., Montreal, Berlin, and Paris are cities with the highest BS penetration. Data from overseas cities were collected in August 2017. *Note that Mobike began in Washington D.C. in September 2017, but no figures about its market penetration are available.

3.2.3 Influential factors behind the decline and then revival of human-powered bicycles in the last three decades

There were many reasons for the long-term decline in human-powered bicycle usage. Apart from household income discussed previously, scholars have already shown that it was related to factors such as city topography, urban expansion, appropriate infrastructure, changes in public transport and government policy and even weather conditions (Fishman 2016; Shaheen, Guzman, and Zhang 2010; Martin and Shaheen 2014; Ahmed, Rose, and Jacob 2010; Böcker, Dijst, and Prillwitz 2013). It is understandable that cities with a flat terrain are more favourable to cycling than hilly cities. This explains why most cities with a bicycle-tradition are located in east China, which has vast flat plains while central and west China have hilly topography. Zhao and Li (2017) commented that a continually increasing city size and urban expansion presented considerable challenges to human-powered bicycles. Krizek et al. (2007) found that when the cycling distance was over 2.5 km, the probability of cycling decreased dramatically. By studying urban transport trends and policies in China and India, Pucher et al. (2007) found as city size increased, trip length increased, and human-powered bicycle use decreased sharply. According to Zhang, Shaheen, and Chen (2014), the popularity of human-powered cycling in China in the 1980s and 1990s was highly attributable to relatively low household incomes, compact urban construction, and short trip distances, which is consistent with what Pucher and Buehler (2008) revealed when investigating the success of cycling in the Netherlands, Denmark, and Germany.

Moreover, some studies have indicated that human-powered cycling, especially BS cycling, had a conditional positive impact on increasing public transport, especially mass transit like the metro. Gu, Kim, and Currie (2019a) investigated BS usage before and after a new metro line opened and observed a sharp increase in BS trip counts along the new line. In a survey taken near metro stations in Nanjing, China, Ji et al. (2017) found that commuting BS users were most likely to interchange at the metro. There are many earlier studies which drew similar conclusions (Nair et al. 2013; Bachand-Marleau, Larsen, and El-Geneidy 2011).

Figure 3-5 shows the results of a national survey conducted by the China Academy of Transport in 2013, (Yin, Wu, and Hao 2017) to discover the reasons that travellers no longer chose human-powered bicycles as a mode of transport. The main reasons were long commuting distance, shrinking cycling space, unfavourable infrastructure in which to cycle, insufficient places to park, the concern of bicycle theft, and air and noise pollution. This was confirmed by Suzhou Planning Bureau & Jiangsu Institute of Urban Planning and Design (2019) who conducted a non-motorized traffic planning survey in 2019 (Suzhou Planning Bureau & Jiangsu Institute of Urban Planning and Design 2019). 800 participants were asked to choose the three most important reasons why they would not use personal bicycles to commute (see Figure 3-6). Long commuting distance, narrow and/or bicycle lanes occupied by motor vehicles, and the availability of E-bikes were the main reasons as well as the availability of convenient public transport, and noise and air pollution from cars on the road. In this case study, as public transport became more convenient, participants became reluctant to use their bicycles.

Since the literature about influential factors of bicycle development across China is either out-of-date or fragmentary and inconsistent, this research re-builds the situation at a macro level. To better understand these factors, a preliminary analysis was made using national-level indexes.

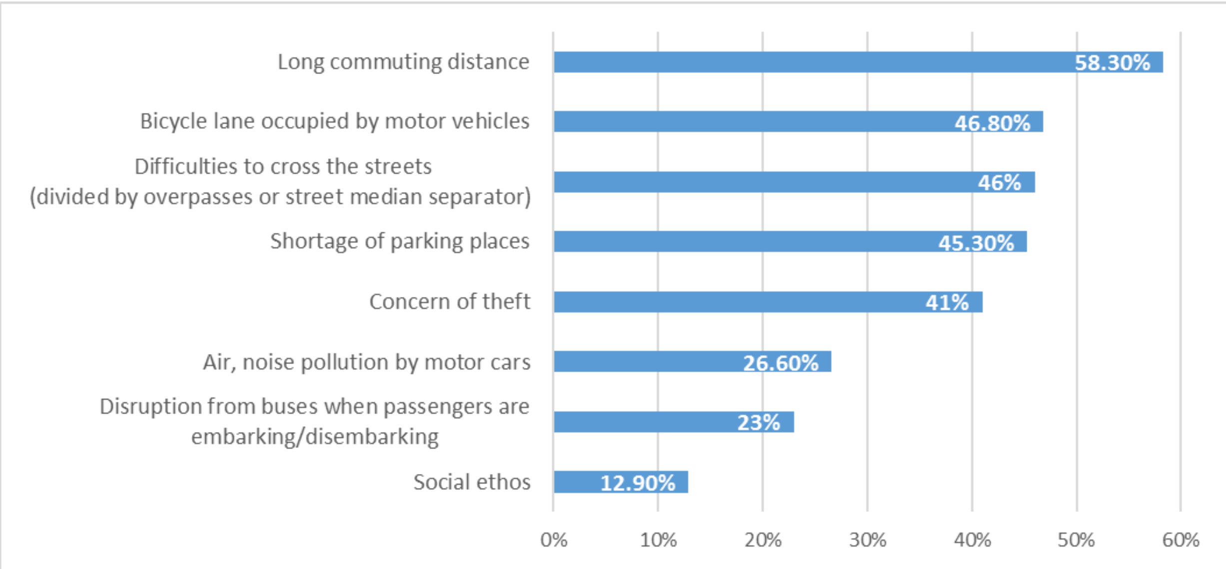


Figure 3-5. A national survey showing the main reasons why travellers no longer choose human-powered bicycles

Source. Yin, Wu, and Hao (2017).

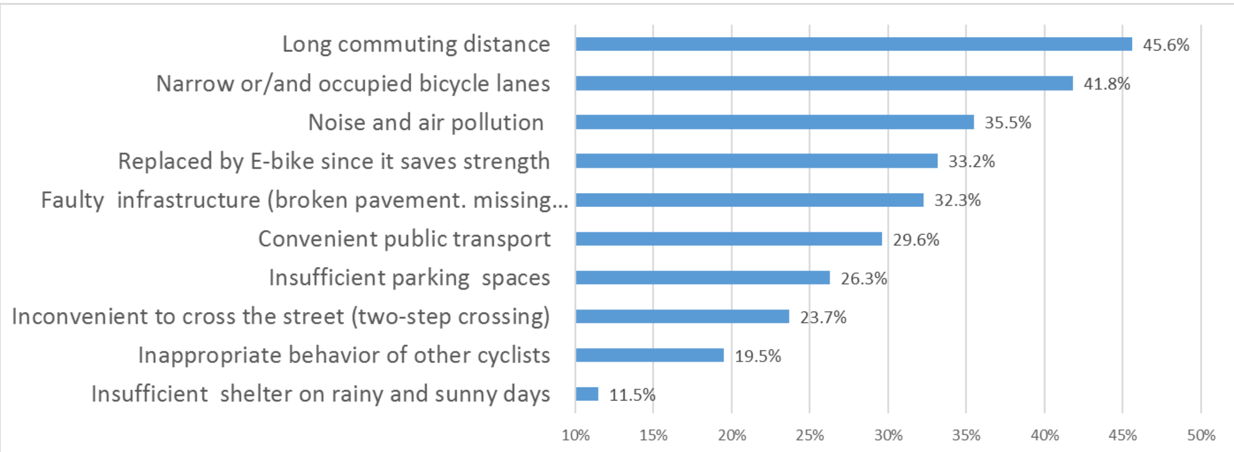


Figure 3-6. A national survey showing the main reasons why travellers no longer choose personal human-powered bicycles

Source. Suzhou Planning Bureau & Jiangsu Institute of Urban Planning and Design (2019)

3.2.3.1 Trip distance

Trip distance is usually determined by city size. It is well accepted that walking, cycling, and driving have their own “advantage distance”. For cycling in China, the ideal “advantage distance” is 3-6 km, which is 20-40 minutes of cycling. Tang, Liu, and Pan (2010) found that the average commuting trip length in China increased from 4.6 km in 1978 to 6.5 km in 2009. Furthermore, in a series of E-bike and non-motor vehicle transport reports, it was revealed that the average commuting trip distance in Shanghai increased from 6.5 km in 2009 to 6.9 km in 2014 (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017a) and in Beijing, it increased from 5.8 km in 2000 to 8.1 km in 2015 (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017b). . As a city grows and trip distance increases, people find it harder to cycle.

In this chapter, the Area of Built District (ABD, green bars in Figure 3-7) is used as an index to indicate city size and urban expansion, which indicates trip length. The National Bureau of Statistics of China uses ABD as an authoritative index to indicate the actual urban area (lakes, mountains, reservation lands excluded). An increase in ABD means that as the city expands, longer travel distances follow. Figure 3-7 shows that as the ABD increased, the usage of human-powered bicycles began to fall. Since no research has been dedicated to this issue, it can be only guessed that there might be a suitable city size threshold that fits with high-level human-powered bicycle ownership. Below that threshold, human-powered bicycle use is less affected by city size while above that threshold, cycling is greatly affected. Overall, increasing city size could be considered to have a potentially adverse effect on the popularity of human-powered bicycle use. This is consistent with national and local survey results shown in Figure 3-5 and Figure 3-6.

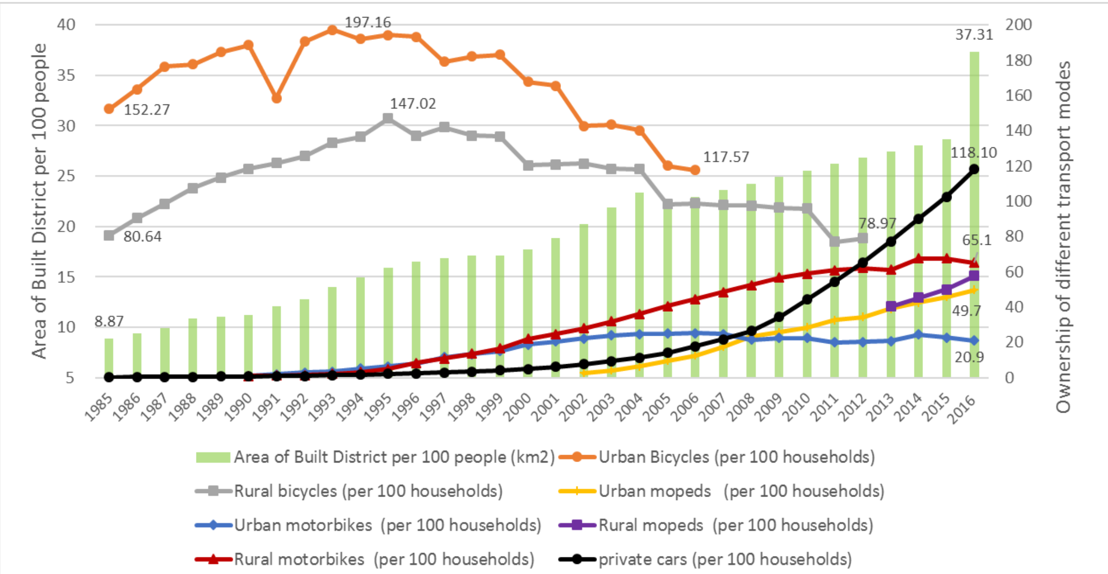


Figure 3-7. The relationship between Area of Built District and ownership of different types of bikes from 1985 to 2016

Note. Before 2013, mopeds comprised both E-bikes and gasoline mopeds, but after 2013, when most cities banned gasoline mopeds, they were replaced with E-bikes. Source: National Bureau of Statistics of China (2018).

Figure 7 shows how urban size (indexed as ABD) has changed in the last three decades and how the rise and fall of human-powered bicycle ownership was influenced by the urban extension (trip distance).

However, this fast urbanization will not last forever. In 2016, the National Development and Reform Commission of China released "The 13th Five-year Plan of New Urbanization (2016-2020)", which set a goal of 60% urbanization growth by the end of 2020 However, Beijing, Shanghai, and most of the large eastern and southern cities had reached 65% or even 70% of urbanization growth by 2019, due to the fast economic growth. With the goal reached and the downturn in economic growth, local governments have specified a strategy called "Controlling Increment and Optimizing Stock" for urban development and released detailed regulations to control urban construction. Therefore, it is reasonable to believe that the urban expansion trend will slow. With trip distance no longer increasing, human-powered cycling ownership might even increase again in the future.

3.2.3.2 Public transport

Since public transport is often considered to "marry" cycling, developments of this marriage are investigated in this component of research at a macro level. It is found that both ownership and the use of bicycles do not share the same trend as public transport development. A general index of bus and urban railway growth (unit: km per capita) is used to represent public transport development. Although this index continues to increase (urban railways have been growing at an annual rate of 20% since 2000), no clear connection can be seen between public transport development and bicycle growth (see Figure 3-8). To determine the mode share at a city-level, four representative cities were chosen, but no positive relationship was found between human-powered bicycles and rapidly growing urban railways, as shown in Figure 3-9. Mainly urban railways have been developed in recent years in selected cities, while human-powered bicycle use has decreased at the same time. It is assumed that as transport networks become more concentrated, people might choose not to cycle. Further studies should consider these co-relations since it is not the topic of this component of research. Overall and unexpectedly, public transport has no positive effect on the popularity of human-powered cycling.

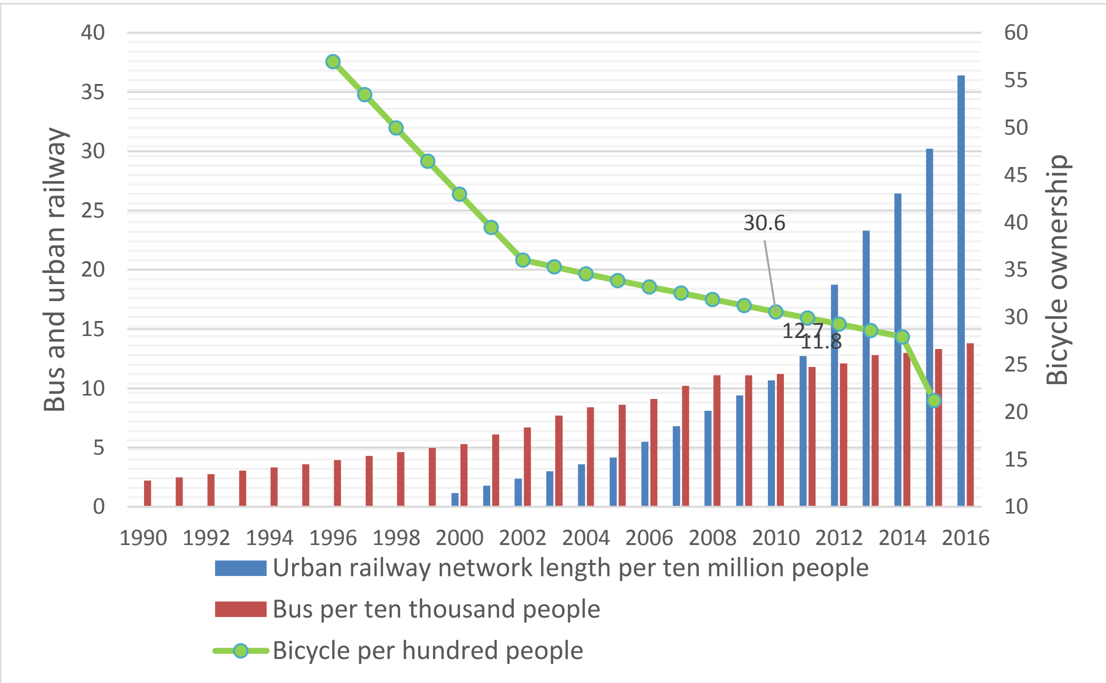


Figure 3-8. Bus and urban railway development vs. human-powered bicycle ownership

Source: National Bureau of Statistics of China (2018), Yin, Wu, and Hao (2017); China Urban Railway Transport Association (2018).

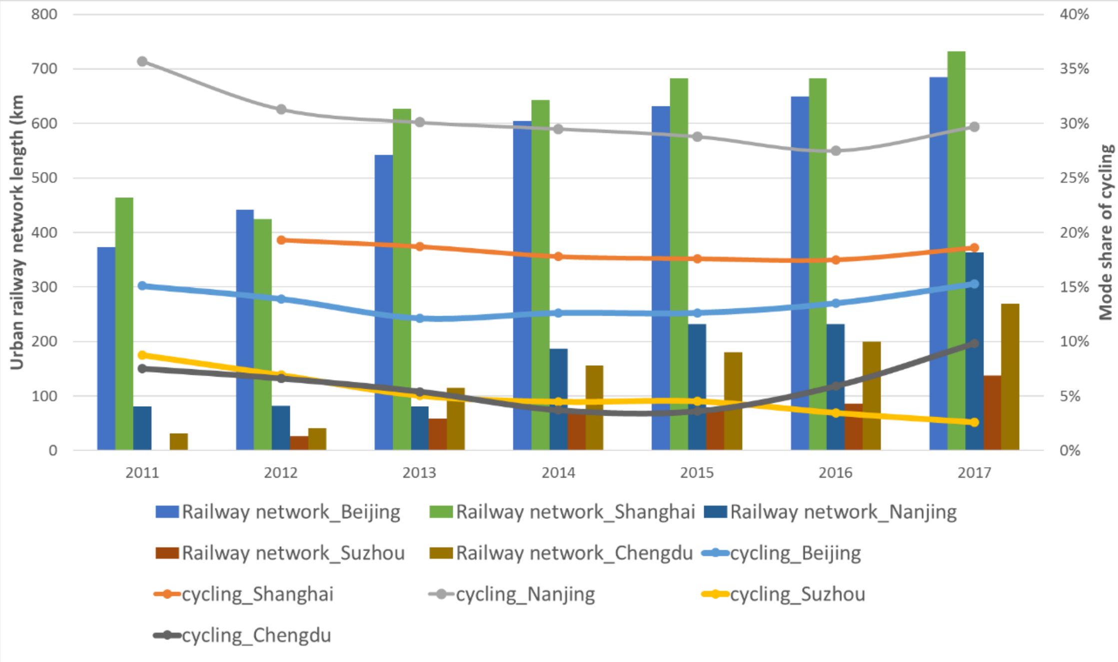


Figure 3-9. Human-powered bicycle transport and urban railway networks mode share

Source: Li, Guo, et al. (2016); Shanghai urban and rural construction and Transportation Development Research Institute (2015); Suzhou Planning Bureau & Suzhou Public Security Bureau (2018); Nanjing Institute of City & Transport Planning Co. (2017); China Urban Railway Transport Association (2018).Long (2012)

3.2.3.3 Health concerns about air and noise pollution

Health is another consideration for cyclists. With concentrated population and increased mobilization in most Chinese cities, pollution caused by cars and motorbikes has become serious, which ultimately affects outdoor activities, including cycling. Although academic research has revealed that car drivers are normally more exposed to road air and noise pollution, from a perceptional view, cyclists might be concerned with the cycling environment if there is heavy traffic. Air and noise pollution was the third (35.5%) most important reason why cyclists did not choose personal bicycles to commute in a recent survey (Suzhou Planning Bureau & Jiangsu Institute of Urban Planning and Design 2019). Although some studies focused on the relationship between air pollution and cycling (MacNaughton et al. 2014; Jarjour et al. 2013; Hatzopoulou et al. 2013), most cyclists are health-conscious. There is little up-to-date research focusing on the impact of air pollution on human-powered bicycle usage in a Chinese context. Chan and Yao (2008) studied air pollution in Beijing, Shanghai, Guangzhou, Shenzhen, and Hong Kong from 1999 to 2007, and pointed out that particulate concentrations of PM2.5 in most Chinese megacities were far above the World Health Organization Air Quality Guidelines. A reasonable assumption is that poor air quality and growing awareness of the harm from air pollution may have a negative impact on cycling. Campbell et al. (2016) investigated the factors affecting mode of transport choice in Beijing, China, with a focus on preferences of BS users and found that poor air quality had a negative effect on BS usage, which is consistent with a study by Li and Kamargianni (2018).

As for the future, the author hold a favorable view that worsening air pollution will be reversed. The air problem is now a national problem that has gained much social attention. With China signing the Paris Agreement in 2016, detailed implementations have been released, including strict regulations for registration of gas automobiles, and taxes to limit the total pollution, especially for companies discharging high levels of pollutants (National Development and Reform Commission 2016).

3.2.3.4 Bicycle infrastructure (safety concern)

Motor-car-oriented urban planning has led to a shrinking of the bicycle infrastructure environment, resulting in more car lanes. This has directly and negatively affected human-powered cycling rates because human-powered bicycles, E-bikes, and motorbikes all share the same cycling space (of which human-powered bicycles have the lowest speed and are the most vulnerable). A narrower bicycle lane means more conflicts among these two-wheeled transports. Moreover, when car parking occupies bicycle lanes, safety concerns grow for all two-wheeled transport modes, which makes cycling unsafe compared to previous times.

Generally, a more significant number of bicycle lanes and spaces contribute to a higher probability of cycling (Moudon et al. 2005; Broach, Dill, and Gliebe 2012). Zhao et al. (2018) studied bicycle-friendly infrastructure planning in Beijing and Copenhagen. They found that due to a 50% surplus of cars compared to parking spaces provided in neighborhoods, drivers in Beijing often parked in bicycle lanes and blocked cyclists. Yang et al. (2015) described human-powered bicycle infrastructure–both lanes and parking places–as “insufficient”. Only 17% of urban streets in Shenzhen have bicycle lanes. Even in Shanghai–a city with a long history of a human-powered cycling culture–five main roads in small, core urban areas have no bicycle lanes (Shanghai Municipal Administration of Planning and Land Resources & Shanghai Municipal Transportation Committee 2016). Furthermore, it is not unusual to see human-powered bicycle lanes cut off, occupied, or even replaced by motor cars (Figure 3-10). Only 24% of streets in core Beijing areas have human-powered bicycle parking places, and only 49 out of 126 railway stations were equipped with bicycle parking facilities. Bicycle racks and rain protection facilities at BS stations are seldom seen in China (Yang et al. 2015; Frame, Ardila-Gomez, and Chen 2017; Zhao et al. 2018). Pucher et al. (2007) also mentioned that in the early stages of rapid urbanization and motorization in the 2000s, cycling and walking facilities in Chinese cities had been worsening: Many pavements and cycle lanes were eliminated or narrowed to accommodate more car lanes. Some streets and districts were off-limits to cyclists. For instance, between 2006 to 2008, over 20 main streets (width >40 m) were reconstructed in Suzhou, most of which were increased to accommodate more car lanes by reducing the bicycle lane width (Huifen 2018), as can be seen in Figure 3-11. Frame, Ardila-Gomez, and Chen (2017) also studied the cycling environment and policy and concluded that from 1992 to 2007 in Wuhan, there was a 100% increase in road length and 315% increase in road area, most of which comprised wide major arterials, typically with eight to ten lanes and single-section roads with no central separation (cyclists had to detour to cross the road). A narrow and occupied bicycle lane is the second highest reason (41.8%) why people did not use personal bicycles in a recent survey conducted in Suzhou–a city with a cycling tradition and large population (Suzhou Planning Bureau & Jiangsu Institute of Urban Planning and Design 2019).

Figure 3-10. A common view showing cars parked in a building entrance blocking the bicycle lane

Photo taken by the authors in February 2018.

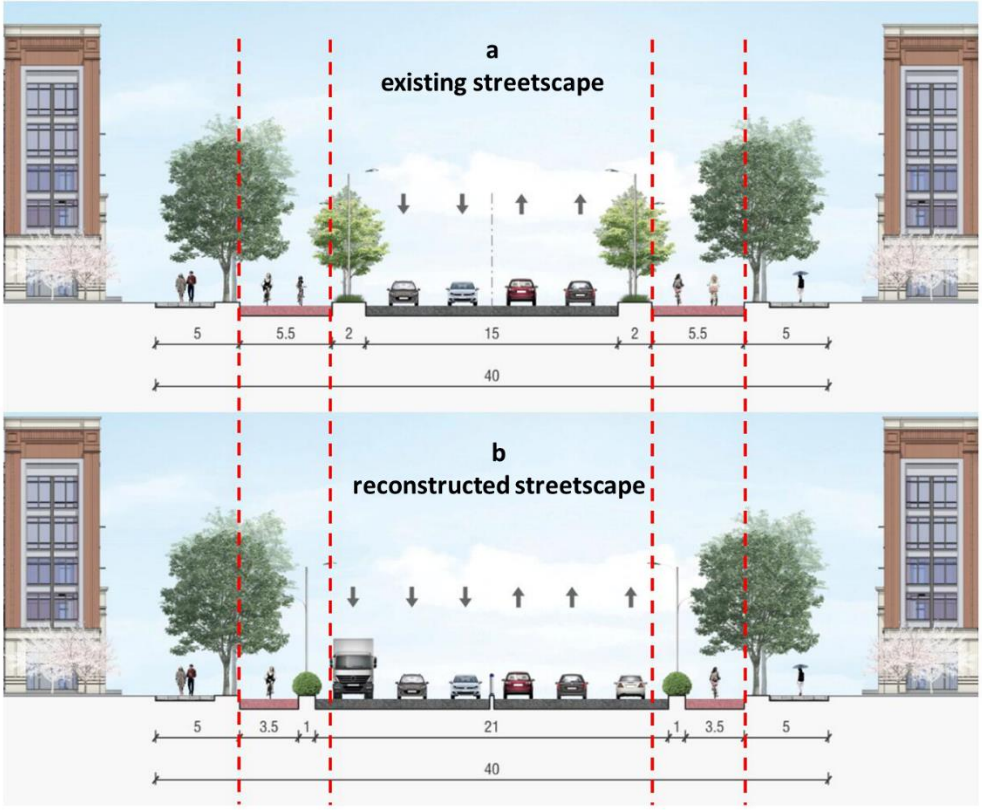


Figure 3-11. Typical main street reconstruction showing reduced bicycle lane width (unit: m)

Source: Huifen (2018)

Per capita road area (as an index to represent road development) and private car and human-powered bicycle ownership (representing cycling space change in past years) are used to determine a national quantitative index of cycling infrastructure or cycling environment in the Chinese context. A comparison between the growth rate of per capita road area and private car ownership (see Figure 3-12) shows that although both increased from 1990 to 2016, the growth of per capita road area (annual growth rate 6.54%) is much lower than the growth of private car ownership (annual growth rate 21.81%). In those 26 years, per capita road area increased five times while private car ownership increased 165 times. Thus, this has led to a decreasing road space for human-powered bicycle users, which in turn may be related to decreasing human-powered bicycle usage.

Similar to city size, governments are changing their attitudes towards urban planning. The strategy discussed before as “Controlling Increment and Optimizing Stock” means urban construction is turning from new construction to renovation of existing infrastructure. With a growing concern for the environment and a worsening traffic environment, bicycles have again gained government support (which will be discussed in the next section). Therefore, it is believed that the situation of shrinking bicycle lanes might be gradually reversed, and the cycling environment for human-powered bicycles will improve.

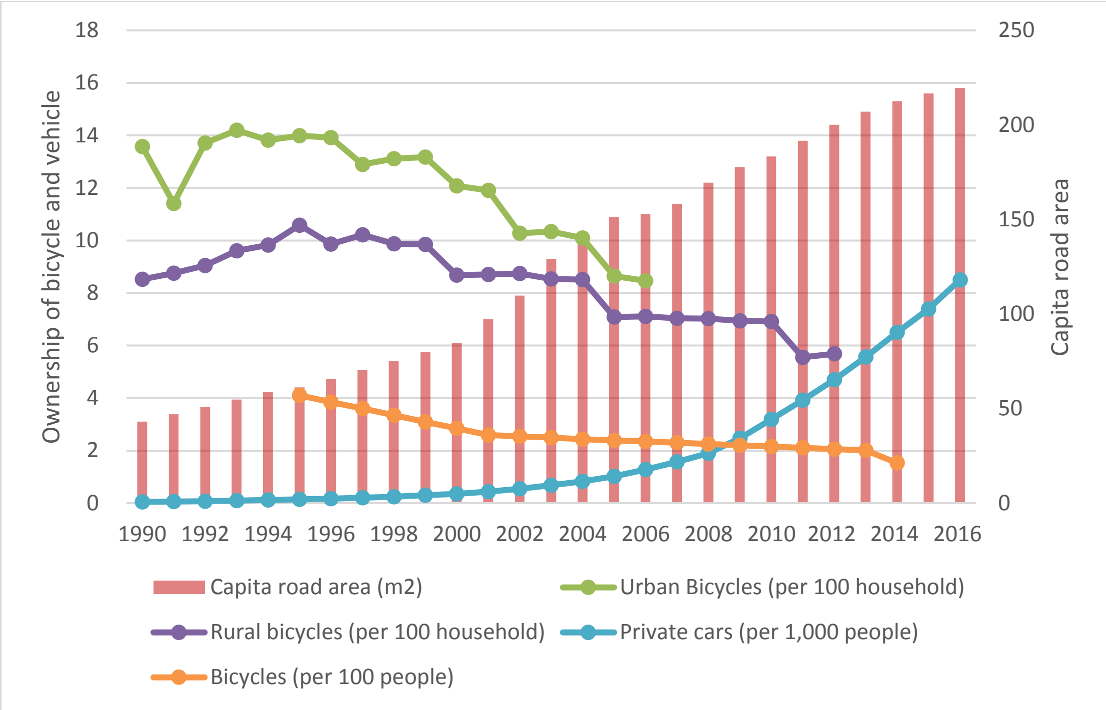


Figure 3-12. The relationship between per capita road area and ownership of human-powered bicycles/private cars

Source: National Bureau of Statistics of China (2018), Yin, Wu, and Hao (2017).

To further understand the relationship among bicycle and other macro factors mentioned above, a simply t-test analysis is conducted to see how they impact the number of human-powered bicycle fleets. Nation-wide potential influential factors as private car, disposal income/GDP, public transport (bus and urban railway included), city size (presented as area of built district, ABD) and capita road area are considered. These variables are extracted from Figure 3, 4, 7, 8, 12 respectively. A summary of the variables is given in Table 3-5. Since the original variables are discrete, normalized process is proceeded before the t-test, where most of the variables are converted into logarithmic form.

Table 3-5. Correlation analysis of factors influencing bicycle usage

Influential Factors	Time	Statistical Description	
private car ownership (per 10 thousand people)	1985-2016	Min:0.269(1985) Max: 118.103(2016)	Mid:5.487 Count:32
bus (per 10 thousand people)	1990-2016	Min:2.2(1990) Max: 13.8(2016)	Mid:11 Count:19
urban railway (network length per 10 million people)	2000-2016	Min:1.2(1990) Max: 36.4(2016)	Mid:8.1 Count:17
Area of built district (ABD) (km2 per 100 people)	1985-2016	Min:8.87(1985) Max: 37.3(2016)	Mid:18.27 Count:32
Capita road area (m2)	1990-2016	Min: 3.1 (1985) Max: 15.8 (2016)	Mid:9.3 Count:27

Table 3-6 shows the results of the t-test. It is found that most of the variables mentioned previously as mass transit, private cars, and ABD had a negative impact on two-wheeled human-powered bicycle development, which is consistent with Figure 3 to 12. Some factors with no significant impact, as bus and captia road area, are removed.

Table 3-6. Correlation analysis of factors influencing bicycle usage

Bicycle	Coefficient	Std. Error.	t	p>t	[95%Conf. Interval]
Railway_length	-0.218	0.089	-2.450	0.027	-0.028***
lgPrivate_car	-0.082	0.036	-2.290	0.037	-0.006***
lgABD	-0.264	0.052	-5.080	0.000	-0.153***
constant	-0.266	0.141	-1.880	0.080	0.036**
*** p<0.01，** p<0.05					

The possible factors influencing human-powered bicycle usage are shown in Table 3-7. These potential factors, which have influenced the change of human-powered bicycle usage over three decades, can be further divided into two major categories, namely **demand-side** factors and **supply-side** factors. While city size and public transport have had a negative or partial negative correlation, infrastructure, policy, and air quality have had a positive correlation. Human-powered bicycle development has led to mixed results; human-powered cycling demand is gradually increasing while the cycling environment supply is gradually decreasing.

Table 3-7. Factors influencing human-powered bicycles

Factors	**Content**	**Index**	**Description**
Demand-side factors	Household income	Disposable income	Within a suitable threshold, human-powered bicycle usage increases. Beyond that threshold, human-powered bicycle usage falls.
	City size	Built areas of districts	
	Public transport	Bus and urban railway ownership	Public transport improves while human-powered bicycle transport decreases.
	Air quality	PM2.5 and PM10	Human-powered bicycle usage decreases as air quality deteriorates.
Supply-side factors	Bicycle infrastructure	Urban road space and bicycle lane space	Bicycle infrastructure continues to worsen while usage declines.
	Policies	National and local policies, regulations and codes	National and local governments have experienced a changing policy towards human-powered bicycle use.

Source: China Urban Railway Transport Association (2018); National Bureau of Statistics of China (2018); Chan and Yao (2008); Yin, Wu, and Hao (2017); Suzhou Planning Bureau & Suzhou Public Security Bureau (2018); Shanghai Urban and Transport Research Institute (2018); Nanjing Institute of City & Transport Planning Co. (2017); Li, Guo, et al. (2016).

3.2.4 Policies and development phases of human-powered bicycle transport

Earlier literature commented that four phases existed before 2012. After reviewing Chinese research and government reports, including grey literature after DBS showed up in 2016, the auhtor re-organize the development phases in this section based on the policy. Because the government attitude towards human-powered bicycles, represented by policies and regulations, is a critical supply-side factor. It can be the most important aspect in a country like China where the government has strong authority. Overall, central and local governments have held a changing attitude towards human-powered bicycles comprising four phases, based on policies and human-powered bicycle development from 1985 to 2016.

In **Phase One** (from 1985 to 1994), relatively compact city size and low income made human-powered cycling the most popular transport mode in China. The government held a limited and positive attitude towards cycling since it consumed less energy, which was precious for industry (Zhang, Shaheen, and Chen 2014; Haixiao 2011). When household income increased shortly after the Economic Reform in 1978, human-powered bicycles were considered valuable assets and experienced a high growth period. Overall, it was the period during which growth and policy were consistent.

In **Phase Two** (from 1994 to 2002), two important national policies were released; one was the “National vehicle industry policy 1994” released by the National Development and Reform Commission in 1994, and the other was the "Code for transport planning on urban road (GB 50220-95)" released by the Ministry of Construction in 1995 (Zhang, Shaheen, and Chen 2014). The former announced that the vehicle industry would be a future key industry in China, and this led to an increase in private car ownership in subsequent years. The latter was the first national transport standard that provided guidance for human-powered bicycle transport: Medium and large cities were required to develop public transport to replace human-powered bicycle transport for long-distance trips. Some local government policies were more radical. For example, Guangzhou released its "1993 Master Urban Plan" and announced its objective was to limit and decrease bicycle usage (Yin, Wu, and Hao 2017; Mackett et al. 2011). During this period, human-powered bicycle transport decreased rapidly and motor cars increased. High-income groups favored motorbikes and motor cars which led to a rise in these two modes of transport. The growing trip distance, expanding city size, worsening human-powered bicycle infrastructure, the poor planning for non-motor transport, as well as a tendency to favor motor cars for government and regular travelers, contributed to a decline of bicycle use. Since the government's attitude towards bicycle transport was negative, and travelers were turning to motorized modes of transport, this period was a **declining stage of human-powered bicycle transport**.

Phase Three (2002 to 2012) was a period where mobilization accelerated in China, and the ownership of private cars boomed (see Figure 3-3) from 12.1 million in 2002 to 88.4 million in 2012, a seven-fold increase in 10 years with an annual rate of 21.5%, while human-powered cycling and ownership decreased. More vehicles provoked more environmental problems (Chan and Yao 2008; Zhang and Mi 2018). However, the attitude towards human-powered bicycle transport subtlety changed from "discouraged" to "re-recognized", especially by local governments.

This conversion began with the release of the "White Book of Shanghai Urban Transport Development" in 2002, which stated that the human-powered bicycle was a complement to public transport (Tang, Liu, and Pan 2010; Zhang, Shaheen, and Chen 2014). In 2004, walking and human-powered bicycle transport were announced in the "Master Urban Plan of Beijing 2004-2020" as essential elements in the future Beijing transport system: "[A] Safe, efficient and comfortable transport environment needs to be built for cyclists and pedestrians". Moreover, from 2008 to 2009, a series of implementing details such as "Walking and bicycle transport mode planning" and "Optimized design guideline of cycling and walking in typical streets" were released in Beijing (Mackett et al. 2011) and followed by other major cities such as Hangzhou, Shenzhen, and Nanjing, which all proposed that their master urban plan would promote a slow mode of transport (Zhang, Shaheen, and Chen 2014). Furthermore, in support of these human-powered bicycle-friendly regulations, Hangzhou established the first government-supported BS system in 2008, rapidly followed by other cities and by the end of 2011, 30 cities had established city BS systems, mostly funded by local governments (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017b; Wei and Wei 2013).

According to some scholars, the reasons behind these changing attitudes was due to concerns related to the growing number of motor cars and the worsening urban environment (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017b). Local governments, rather than the central government, were the first to be negatively impacted by motor vehicle transport and the first to realize the importance of cycle-friendly urban transport. **Therefore, it was the time when local government attitudes towards human-powered bicycle transport were subtlety converted from "opposed" to "re-recognized," although bicycle use continued to decrease.**

Phase Four (2012 to 2016) was a period when mobilization continued to rule China; private vehicle ownership increased from 88.4 million to 163.3 million (16.6% per year) in four years, while human-powered bicycle infrastructure was still relatively low quality and low in quantity (Zhao et al. 2018; Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017b). On the other side, environmental concerns grew, and even the central government realized it had to act and so released nation-wide regulations and guidelines to promote human-powered cycling (Chan and Yao 2008; Zhang and Mi 2018).

In 2012, a national "Guidance to Improve Urban Pedestrian and Bicycle Transport System Construction" was released jointly by the Ministry of Housing and Urban-Rural Development, National Development and Reform Commission and the Ministry of Finance (2012). The guidance proposed a green transport environment, urged local governments to adopt a better slow-transport environment before 2015, and set human-powered cycling goals for local governments as a political performance indicator. Several months later, the China State Council (2013) issued the "Guiding Opinion on Giving Priority to Public Transport Development," and stated that local governments were to "improve walking and cycling environment" and "increase investment on slow-transport infrastructure". In 2012, Beijing and Shanghai initiated a series of reconstruction projects aimed to redeploy and widen human-powered bicycle lanes in central districts (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017b) while more cities began to embrace city BS systems. Then in 2014, the Ministry of Housing and Urban-rural Development released "Guidelines for planning and design of urban pedestrian and bicycle transport systems"; it gave more detailed design and planning specifications and required local governments to produce a slow-transport plan before the end of 2015. Most local governments began to follow the national guidelines and to revive human-powered bicycle infrastructure. By the end of 2015, 215 BS programmers were deployed in China, compared to only 30 in 2011. However, even under the nationwide trend of fast urbanization and what seemed to be unstoppable mobilization, the human-powered bicycle transport mode share in major cities was still low, as shown in Table 3-3. From 2012 to 2016, **policies towards human-powered bicycle transport were "supportive" in every field, while its mode share still lagged.**

Phase Five (2016 to 2019) began with the rise of the private operator-owned DBS in 2016. By the end of 2017, DBS had covered most major cities in China and fundamentally changed the way people traveled. It also led to the first increase in the bicycle mode of transport share in most Chinese megacities, such as Beijing, Shanghai, Guangzhou, and Shenzhen (Gu, Kim, and Currie 2019b).

The release of the "Shanghai Street Design Guideline" in 2016 was a milestone policy, which was different from former local guidelines or regulations for human-powered bicycles. In this guideline, detailed design requirements were proposed to fulfill a complete and living street, in which human-powered cycling was promoted—for the first time in an influential local regulation—at a higher priority than motor car and public transport (Shanghai Municipal Administration of Planning and Land Resources & Shanghai Municipal Transportation Committee 2016).

Policies towards DBS have been changing ever since DBS emerged. The central government held an overall **neutral-positive** attitude towards DBS when it released the "Guidance of encouraging and regulating the development of Internet rental bicycles (dockless bike-share)" in 2017. This document was jointly released by ten national ministries, which was quite unusual. It indicated DBS's influence and the attention it was now drawing (Gu, Kim, and Currie 2019b). Local governments held a changing attitude towards DBS from **neutral-positive** (cautiously-welcomed) to **neutral-negative** (cautiously-controlled) from 2016 to 2018 (Gu, Kim, and Currie 2019b). However, from August 2017, when DBS fleets began to exceed city capacity, Shanghai was the first to limit new DBS fleet development; DBS operators were required to take more effective methods to maintain ordered parking behaviors. This action was instantly followed by Beijing, Guangzhou, and dozens of other cities (see Table 3-8). This stage witnessed a considerable growth of human-powered cycling that was not organized by the government. **Phase Five was a time when DBS policies diverged in different cities although human-powered bicycle usage grew significantly due to DBS.**

Table 3-8 Times when DBS began and was then limited in selected cities

City	Time DBS began (month, year)	Time DBS limited (month, year)	Duration (months) from introduction to limit
Beijing	9, 2016	9, 2017	12
Shanghai	4, 2016	8, 2017	16
Hangzhou	2, 2017	8, 2017	6
Shenzhen	1, 2016	8, 2017	19
Guangzhou	9, 2016	8, 2017	11

Nanjing	1, 2017	8, 2017	7
Wuhan	1, 2017	9, 2017	8
Tianjin	1, 2017	9, 2017	8
Chengdu	1, 2016	1, 2018	12

Source: Gu, Kim, and Currie (2019b)

Table 3-9. Phases of human-powered bicycle usage and policy development (from 1985 to present)

Phase One: Rapid growth, government held a limited and positive view about human-powered bicycles (1985 to 1994)	
Bicycle Usage	Human-powered bicycle usage grew rapidly from 102.5 to 194.3 bikes per 100 households in urban China, and 22.8 to 147.0 bikes per 100 households in rural China from 1978 to 1995. The human-powered bicycle became the main mode of transport for daily mobility. The average cycling rate accounted for 44% in around 1985 in cities shown in Table 3-3.
Government Attitude	Encouraging.
Policy or regulation	No policy was released about human-powered bicycle transport.
Phase Two: Human-powered bicycle usage reduced due to a policy that opposed it (1994 to 2002)	
Bicycle Usage	Human-powered bicycle ownership began to decrease–from 194.3 to 142.71 bikes/100 households in urban China, and 147.0 to 121.32 bikes per 100 households in rural China from 1995 to 2002. The average cycling rate accounted for 35% in around 1997 in cities shown in Table 3-3.
Government Attitude	Discouraging.
Policy or regulation	**National level** "National vehicle industry policy 1994" and "Code for transport planning on the urban road (GB 50220-95)" were released and goals were set to promote motor car transport and to decrease cycling. **Local level** Some local policies were more radical. The "Guangzhou Urban Planning 1993" policy stated that human-powered bicycles should be gradually limited and human-powered bicycle usage would gradually decrease. In Shenzhen, human-powered bicycle lanes were gradually removed from main roads from 1992-1998 and human-powered bicycle transport was marginalized by the local government.
Phase Three: Human-powered bicycle usage continued to decrease, local policy slowly converted to a positive stance (2002 to 2012)	
Bicycle Usage	Human-powered bicycle ownership continued to decline. The average cycling rate accounted for 21% in the 2000s in cities shown in Table 3-3.
Government Attitude	Converting and re-recognizing bicycle use, especially by local governments.
Policy or regulation	**Local level**

	Beginning with the "White Book of Shanghai Urban Transport Development" (2012), local governments gradually reconsidered human-powered bicycle transport as an important part of the urban transport system or even a complement to public transport. A government-supported BS system was first launched in Hangzhou in 2008 and soon adopted by 30 other major cities.
Phase Four: Human-powered bicycle usage continued to decrease, both national and local government promoted human-powered bicycle cycling again (2012- 2016)	
Bicycle Usage	Human-powered bicycle ownership continued but declined slightly. However, most bicycles were no longer used, and active usage was even lower than during the last phase. Average cycling accounted for 13.3% of transport in around 2015 in selected cities as shown in Table 3-3.
Government Attitude	Encouraging.
Policy or regulation	**National level** "Guidance to Improve Urban Pedestrian and Bicycle Transport System Construction"; "Guiding Opinion on Giving Priority to Public Transport Development"; "Guidelines for planning and design of urban pedestrian and bicycle transport systems". The aim was to revive slow-transport and set an increasing human-powered bicycle use goal for local governments. **Local level** Beijing and Shanghai began a series of reconstruction projects to revive cycling in urban areas. City BS systems were widely and rapidly accepted by more than 200 cities.
Phase Five: Dockless bikeshare emerged, and human-powered bicycles use was revived. Cycling was encouraged, yet the attitude towards DBS had been rapidly changing (2016-2019)	
Bicycle Usage	Cycling mode share increased slightly in most cities deploying DBS.
Government Attitude	Towards human-powered bicycle: encouraged. Towards DBS: neutral-positive in central government and neutral-negative in local governments
Policy or regulation	**National level** "Guidance of encouraging and regulating the development of Internet rental bicycles (dockless bike-share)" was released by the central government to encourage and regulate DBS development. **Local level** "Shanghai Street Design Guideline" was released, which promoted human-powered bicycle transport to a higher position than public transport and motor vehicle transport in the urban transport system. From August 2017, megacities began to limit new DBS fleet development, capped the capacities of DBS and released stricter rules to

	regulate DBS operators' operation. E-bikes were "discouraged" in most cities.

Source: Han (2017); Haixiao (2011); Zhang, Shaheen, and Chen (2014); Mobike Global & Beijing Tsinghua Tongheng Planning and Design Institute (2017); World Resouces Institute & Mobike Global (2018); National Bureau of Statistics of China (2018); Technology (2018); Li, Guo, et al. (2016); Tang, Pan, and Shen (2011); Li, Yin, et al. (2016); Mackett et al. (2011); Cherry, Weinert, and Xinmiao (2009); Gu, Kim, and Currie (2019b).

3.3 The development of motorbike, E-bike in China

Generally, E-bikes are electric-assisted bicycles with a similar style to regular human-powered bicycles (Fishman and Cherry 2016). However, in the Chinese context, E-bike covers a relatively large range of vehicles comprising a bicycle-style, a scooter style (see Figure 3-13), and mopeds. According to the Road Traffic Safety Law in the People's Republic of China (released in 2004), E-bikes, despite their small motors, belong to the non-motor vehicle category, which means they share the same cycling lanes with regular human-powered bicycles. On the other hand, motorbikes–powered by gasoline—are considered a motor vehicle and share lanes with automobiles (National People's Congress 2011). Therefore, investigating these modes of transport in this component of research allows a better understanding of the problems associated with these vehicles.

Figure 3-13. Bicycle-style (left) and scooter-style (right) E-bikes

Source: Ling et al. (2015), right-hand figure photographed by one of the authors.

3.3.1 The growth of ownership of motorbikes and E-bikes in China

Compared to the decreasing use of the human-powered bicycle, motorbikes and E-bikes have experienced quite different growth trends between 1990 and 2016 (see Figure 3-14). A steep increase was seen in urban mopeds (from 2.72 to 49.7 bikes per 100 households 1990-2016) and rural mopeds (from 40.3 to 57.7 bikes per 100 households from 2012-2016). However, urban motorbikes reached their peak in 2007 then decreased and have fluctuated since due to the widespread motorbike-banning policy, which will be discussed later. In contrast, rural motorbikes have witnessed a sharp increase in the last 26 years (from 0.89 to 64.21 bikes per 100 households), although that increase has slowed in recent years. Overall, E-bikes have prevailed while motorbikes in urban areas have decreased.

According to Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017a) report about the E-bike Industry, the first E-bikes appeared in Shanghai in 1983. By the end of 2000, E-bike production had begun in China, and then in 2004, a large-scale industry was formed. The E-bike boom in China occurred in 2007 when their production exceeded 20 million per annum in that year, and sales of E-bikes reached 30 million in 2010, which now accounts for more than 90% of the international export market. China has become the largest producer, consumer, and exporter of E-bikes (Ruan, Hang, and Wang 2014; Ling et al. 2015). Industrial reports have argued that E-bikes have had stable production and sales, but as the market has become saturated, the industry might be now at a turning point (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017a).

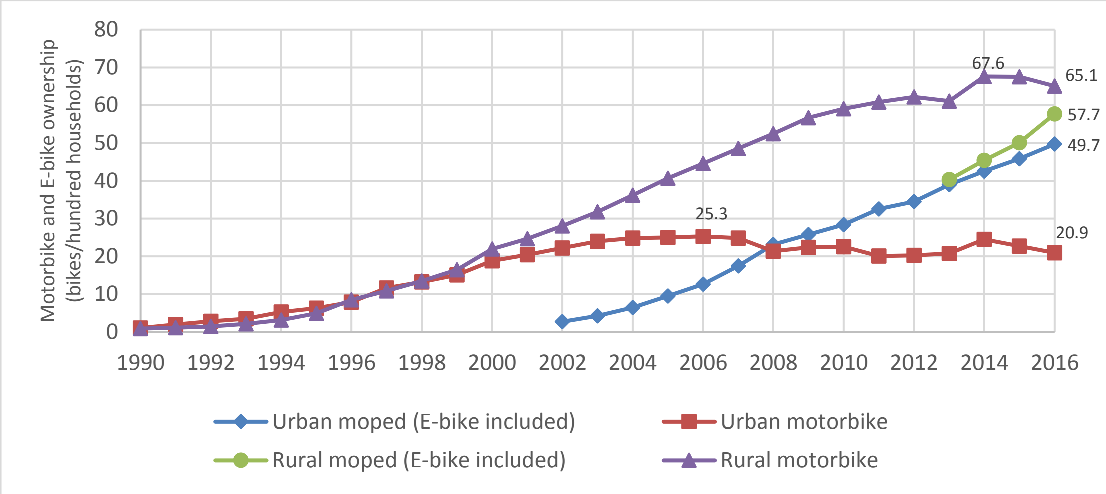


Figure 3-14. Moped (E-bike) and motorbike ownership between 1995 and 2012

Note. Before 2013, mopeds consisted of E-bikes and gasoline mopeds, and after 2013, mopeds were replaced by E-bikes. *Source:* National Bureau of Statistics of China (2018)**.**

3.3.2 Motorbike development phases and policies related

As indicated, motorbikes and gasoline mopeds witnessed a long-term increase before 2000 nationwide. Moreover, overall policies towards motorbikes and gasoline mopeds were neutral during that time (Ling et al. 2015; Zhang, Shaheen, and Chen 2014). However, megacities were the first to realize the disadvantages, such as safety issues and environmental pollution, of motorbikes and gasoline mopeds, and they were gradually banned in urban areas from the mid-1990s. For instance, Guangzhou stopped registering new motorbikes and gasoline mopeds in 1991, followed by Shenzhen in 1993 and Shanghai in 1996. From 2000, major cities such as Beijing, Guangzhou, Shenzhen, and Shanghai began to ban motorbikes and gasoline mopeds on municipal roads. Currently, over 150 cities in China have banned or partially banned motorbikes and gasoline mopeds (Xiaolin 2017; Fishman and Cherry 2016; Shao 2017). However, considerably high motorbike ownership continues in rural China, where regulations are much freer, as can be seen in Figure 3-14.

3.3.3 E-bike development phases and related policies

The prevailing phenomenon of E-bikes has been **demand-driven rather than supply pushed** (Wells and Lin 2015; Lin, Wells, and Sovacool 2017) because not much national or local government support occurred to promote E-bikes and their increase is mostly motivated by user demand. The E-bike boom began in 2005 when E-bike sales exceeded gasoline motorbikes, and the ban on motorbikes and gasoline mopeds began to be noticed. In 2016, the ownership of E-bikes in urban and rural China was 49.7 and 57.7 bikes per 100 households, respectively (National Bureau of Statistics of China 2018). Nationally, an estimated 150 million E-bikes existed in 2013, and this number reached 220 million in 2016 (Ling et al. 2015; Lin, Wells, and Sovacool 2018). Some researchers believe the E-bike boom was directly triggered by the Chinese government's effort to restrict motorcycles, to develop the economy, and to promote E-bikes as zero-emission vehicles (Cherry, Weinert, and Xinmiao 2009; Shao 2017; Ling et al. 2015).

In a wide-ranging review, Fishman and Cherry (2015) argued that E-bikes have the potential to displace cars and convey benefits such as improved health and better air quality. Local studies revealed that E-bikes were not substantially displacing cars (Ling et al. 2015; Lin, Wells, and Sovacool 2018) but in a study conducted in Nanjing, they were displacing the 'benign' transport modes of walking, traditional human-powered cycling, and bus usage (Lin, Wells, and Sovacool 2017). Thus, they are helping to enable motorized-dependent lifestyles that may in the future be supported by cars, rather than offering a real departure from carbon-centered, motorized forms of transport. A growing number of studies have revealed that E-bikes are responsible for a large number of traffic injuries and negative safety issues (Feng et al. 2010; Bai et al. 2013; Ruan, Hang, and Wang 2014), which jeopardizes their position as a promising mode of transport.

At a national level, E-bike policies are few and neutral. Simple technical standards and the transport rights of E-bikes are regulated as set out in the “Road Traffic Safety Law of the People's Republic of China” (released in 2004), which confirms that E-bikes belong to the non-motor vehicle category (National People's Congress 2011). Thus, they operate in bicycle lanes because their road-rights are the same as human-powered bicycles. National standards such as the “Electric bicycles – General technical requirements” and “Safety technical specification for electric bicycle” were set in 1999 (GB 17761-1999), then updated in 2018 (GB 17761-2018) (Technology 2018); they are quite strict in their definition of “E-bike”. However, Shao (2017) stated that 55% of E-bikes in Shanghai weighed over 40 kg, 90% had a speed limit higher than 20 km/h, and 60% had no manual cycling function, that is, they were non-compliant. An industry report (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017a) declared that almost 95% of E-bikes are “out-of-limit” according to existing standards. Even though the new standard has even higher limits (see Table 3-10), many E-bikes have higher speeds and larger mass than that set by the standard. Pedelecs (speed<25 km/h, motor power<250w) are bicycles which have a small electric motor to assist the rider’s pedaling. Note that under the European regulations, pedelecs, are categorized as bicycles whereas in China, they are classified as E-bikes.

Table 3-10. Standards to define “electric bicycle" in some countries

Country		Speed limit (km/h)	Mass limit (battery included) (kg)	Motor Power limit (W)	Human-powered cycling function (pedal equipped)
China-new standard (2018)		25	55	400	Required
China-old standard (1999)		20	40	240	Required
USA		32	N/A	750	N/A
Europe	powered bicycles’	25	N/A	1000	N/A
	mopeds	25-45	N/A	1000-4000	

Source: Technology (2018); Fishman and Cherry (2016).

Policies towards E-bikes have changed in the last two decades. Local government attitudes towards E-bikes are quite divergent due to the confusion and the lagging problems of E-bike standards that have not been solved. The existing national standard is too strict and therefore, is not implemented, which leads to more confounded local standards and policies. There are 185 legislative texts on E-bikes in national and local governments, wherein, there is one law, 20 regulations, two decisions of the National People's Congress, 14 rules and 148 administrative provisions, many of which are contradictory; some cities have banned or have limited the usage of E-bikes while others tacitly approve of E-bikes (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) 2017a). For instance, southern cities in the Pearl River Delta, such as Guangzhou, Shenzhen, and Foshan hold a radically negative opinion about E-bikes as they did with human-powered bicycles.

However, cities in the Yangtze River Delta, such as Shanghai, Suzhou, and Hangzhou, usually hold a favorable positive attitude towards E-bikes, as they did for human-powered bicycles. These cities across the plains in the Yangtze River Delta have a long tradition of cycling over for the last century. Local and central government attitudes are listed in Table 3-11.

Table 3-11. Local government attitudes towards E-bikes

Attitude towards E-bike	Description	Government
Neutral	E-bikes standards are well-defined, and no national banning is stated.	Central government

Accepting	E-bikes may register; registered E-bikes are allowed on the roads.	Shanghai, Chengdu, Hangzhou, Suzhou, Jinan, Chongqing, Wuxi
Limited	E-bikes may register; registered E-bikes are only allowed in certain areas or roads in urban areas.	Beijing, Fuzhou, Xi'an, Wuhan, Kunming, Changsha
Banned	E-bikes cannot be registered and are banned in most urban areas.	Guangzhou, Zhuhai, Shenzhen, Xiamen, Foshan

Source: Technology (2018); Fishman and Cherry (2016); Suzhou Planning Bureau & Suzhou Public Security Bureau (2018); National People's Congress (2011); Xiaolin (2017); Zhiying (2016); Haixiao (2011); Shao (2017).

Central and local governments all share a negative attitude of all for shared E-bikes. In August 2017, 10 national ministries (Ministry of Transportation, Ministry of Industry and Information Technology, Ministry of Housing and Urban-Rural Development, People's Bank of China, and another six ministries.) jointly endorsed and issued the "Guidance of encouraging and regulating the development of Internet rental bicycles (dockless bike-share)". Notably, shared E-bikes were clearly "not encouraged" in this "Guidance" (Gu, Kim, and Currie 2019b). Local governments such as Beijing and Shanghai soon followed and banned shared E-bike operators from deploying fleets on their streets (Li 2018).

3.3.4 Other electronic modes of transport

It will be interesting to see if other unique two-wheeled modes of transport like kick scooters or even single rider electric-powered vehicles (e.g. the Renault Twizy, which is an electric-powered quadricycle) find their place in China. These vehicles have never been mainstream, and there is no giant company such as Lime in China to operate them. They serve in a very marginal way and have extremely limited functions in urban transport. According to traffic safety law, these kick scooters, along with single rider electric-powered vehicles, are in a grey or unknown regulation zone (National People's Congress 2011). Although there is no precise national regulation, scooters are usually not allowed on municipal roads due to safety concerns. The primary users of kick-scooters are car drivers who need light and e-powered transport that can be carried in a car. These sub-car vehicles are subject to harsher regulations. They are not big, safe, or qualified as normal e-automobiles and they are not two-wheeled. This means they cannot use car lanes or bicycle lanes. Thus, local traffic laws have banned the usage of sub-car vehicles in urban areas with one exception—they can be registered as exclusive vehicles for drivers with a physical disability (Dowling 2018).

Although in other countries kick scooters and sub-car vehicles are considered a flexible type of transport, able to complete a mid-term trip, they face challenges from regulations, technical standards, and user acceptance in China. Moreover, their function overlaps substantially with E-bikes; there is no reason to use new and risky scooters when there are technically developed and abundant E-bikes.

3.4 The future of the two-wheeled mode of transport in China

3.4.1 Human-powered bicycles

As discussed in former sections, some of the influential factors behind the use of two-wheeled human-powered bicycles might not be the same as they have been over the last three decades. Table 3-12 is a summary of the factors influencing human-powered cycling, most of which have become beneficial to this mode of transport.

Table 3-12. Factors influencing the use of human-powered bicycles

Factors		Change in the future	Impact on cycling
Demand-side factors	Household income	Stable	Neutral or positive
	City size	Stable	Neutral or positive
	Public transport	Improved	Neutral
	Air quality	Improved	Neutral or positive
Supply-side factors	Bicycle infrastructure	Improved	Positive
	Policies towards cycling	Favorable	Positive

Following the latest policy and development phase, bicycle transport continues to increase due to the changing attitudes from all levels of government and the increasing concerns about the deteriorating environment. Moreover, bicycle transport will continue to exist as more people realize that fast mobilization brings congestion as well as pollution. However, challenges within DBS contribute to the latest revival of individually owned human-powered cycling. DBS's prevalence is mainly due to substantial and direct investment rather than from user fees. There is no guarantee of sustainable profit in the future, which makes the DBS industry fragile and unstable (Gu, Kim, and Currie 2019b). Stricter policies and negative attitudes towards DBS might add to its risk unless more effective technology is used to prevent streets suffering from "bicycle-congestion" (Zhou 2018).

While DBS offers excellent convenience to users, it usually charges more and is not as user-friendly for many elderly people (smartphones are usually needed to unlock DBS bikes). DBS typically costs 4 RMB/hour compared to BS, which is free-to-use for the first hour. While DBS has the advantage of higher potential profit for operators and less supervision pressure from the government, the risk from vandalism is higher. The massive capital investment needed for DBS also means only a limited number of operators can run DBS, and they take substantial investment risks, which make this relatively immature (DBS only emerged three years ago) market fragile. By early 2019, the former giant company ofo was bankrupted due to cash-flow problems, sending a warning to other operators. Gu, Kim, and Currie (2019b) initiated a DBS empirical study and concluded the feasibility of DBS for different cities. A summary is shown in Table 3-13.

Table 3-13 Recommendations for bikeshare systems in cities with different characteristics

	Docked bikeshare (BS)	**Dockless bikeshare (DBS)**
The predominant mode of transport	Cities with low cycling rate and a large number of motor vehicles	Cites with high cycling rate
City finance	Abundant government budget	Limited government budget
Market scale (population)	Medium and small market (population)	Large market (population)
Cycling infrastructure	Limited cycling infrastructure and public space for cycling	Good cycling infrastructure and public space for cycling
Government capability of controlling and supervising operators	Limited government power to control BS operators	Strong government power to control DBS operators

3.4.2 E-bikes, motorbikes, mopeds and other electronic modes of transport

E-bikes, which are a flexible and affordable mode of transport, are a highly competitive and promising form of transport especially in hilly cities. While user demand exists, a challenge occurs mainly in policies determined by governments, which covers issues such as safety and the adverse environmental hazard of batteries. As the regulations and technical standards become more precise and pragmatic, and driver awareness grows, it is believed safety issues will decrease. Moreover, as new eco-friendly techniques are introduced (e.g., lithium batteries replace lead batteries), government attitudes may become even more favorable to E-bikes. Therefore, undemanding regulations can be expected. Overall, the authors hold a positive attitude towards E-bikes.

Motorbikes and mopeds have lost their attraction to users and have been gradually replaced by E-bikes and automobiles, as can be seen from the usage rates. The governments have been responsible for some of this decline as they are banned in some cities. The inherent character of gasoline makes it eco-unfriendly, particularly in large cities. Therefore, although there is still a small proportion of motorbike usage in remote rural areas, the position of motorbikes and mopeds will continue to be marginal.

Currently, kick scooters and sub-car vehicles are quite marginal and have few users except for those with a physical disability. Without actively endorsed manufacture and favorable government policies, it is tough for them to prevail as they have in Europe and to a lesser extent in the US.

3.5 Chapter conclusion

Through up-to-date empirical analysis, this component of research discussed the development of two-wheeled transport, especially human-powered bicycle transport in China from 1900 to 2019. A series of demand-side factors (such as rapid urbanization) and supply-side factors (such as obsolete human-powered bicycle infrastructure) were analyzed to investigate their impact on two-wheeled transport in China. While city size and public transport had a negative or partial negative correlation with human-powered cycling's popularity, infrastructure, policy, and air quality were found to have a positive correlation. The impact of household income was relatively neutral. Human-powered bicycle development showed a mixed result; the demand has been gradually declining, and infrastructure supply has been falling behind.

The development of human-powered bicycle transport in China, from 1985 to 2019, has seen five phases where policies towards human-powered cycling have changed from "encouraged", "discouraged", "converted and re-recognized", supportive" to "encouraged" due to environmental concerns along with rapid mobilization. Human-powered cycling fell from 1995 until DBS emerged in 2016. Due to its enormous scale and capacity to attract users, DBS has helped to revive human-powered cycling in China. E-bikes and motorbikes witnessed an independent growth trend similar to human-powered bicycles. Following their popularity in the 1990s, the number of motorbikes has gradually decreased, and they are now largely banned due to their lack of safety as well as environmental pollution concerns, while E-bikes have been diversely treated in different cities. A clear regional difference in the E-bike policy was seen in southern cities of the Pearl River Delta, where a negative attitude towards E-bikes exists while cities in the Yangtze River delta have a positive attitude towards them. The rapid growth of E-bikes is found to be demand-driven rather than supply-pushed.

After discussing the change of the influential factors over three decades, it is concluded that the future of two-wheeled transport in the form of human-powered bicycles and E-bikes is promising while motorbikes will become a thing of the past. Once the infrastructure has been updated within a healthy and sustainable model, which has been planned and designed safely with consideration given to user convenience, and a proper and innovative business model is introduced, people will choose two-wheeled transport, especially human-powered bicycles.

The development of two-wheeled human-powered bicycles, along with E-bikes and motorbikes, has followed a zigzag path. The most significant influence on urban transport development is the power exerted by the strong central government. As shown in Table 3-6 and 3-11, factors such as policy is directly determined by government, while infrastructure, city size, and air pollution are indirectly affected by government. Therefore, in the mid-term (10 years) as these Five-year Plans continue, if policies support cycling, if user-friendly infrastructure is provided, and if the cycling environment is improved, there will be an even greater revival of two-wheeled human-powered bicycles. E-bikes and motorbikes are treated differently based on their respective policies. Of course, in the long run, usually user-demand rather than administrative order will prevail. However, user-demand could also be satisfied by new forms of transport. The world is experiencing rapid changes in transport and communication such as self-driving vehicles, shared mobility, telecommuting and the concept of Mobility as a Service (MaaS). As these evolve and become mature, alternative modes of transport will be developed. Hence, it is hard to predict cycling or E-bike's position in say 20 or 30 years from now. The authors of this paper believe that bicycles will continue to hold an essential place for a long time to come.

Urban planners and government officers from the same background as China, might benefit from this research on how to set goals and policies to promote cycling. As for scholars, since this is a review, factors influencing bicycle development have been discussed superficially. Future work could investigate in-depth how these factors affect cycling. For instance, studies may investigate the relationship between income and choice of mode of transport, ideal city size, or trip distance for a cycle-only trip or an interchanging cycle trip with public transport. Other examples of future studies include how public transport and bicycles (especially personal bicycles) can integrate and enhance travel, and the impact of air pollution on cyclists. Furthermore, in this chapter, policies have been discussed for their impact on two-wheeled transport mode development. Future work could focus on how these policies function in every field; this might be inspiring for other countries to follow and to learn how they may support a particular mode of transport. Moreover, in this chapter, the born of DBS is mentioned as one of the main reasons that cycling revives. Which leads to detailed DBS investigation in the next chapter. The influential factors as public transport and infrastructure are discussed in a macro point of view, which would be further discussed in Chapter 5 and Chapter 6.

CHAPTER 4: AN EMPIRICAL STUDY OF DEVELOPMENT OF BS, DBS IN CHINA

4.1 Overview

The first step to understanding how BS/DBS interact with mass transit systems is to understand how it develops. In less than 3 years, dockless bike-share emerged and prevailed in China and other countries, fundamentally changed the way people live. As a matter of fact, DBS reached its peak in early 2018 at 2 million fleets deployed in more than 200 cities. This innovation now has spread to overseas countries including the US, UK and Australia, bringing convenience along with the downside known as fleet "congestion" (casual parking of bikes blocking pedestrian access). A better understanding of BS and DBS development, policy and users' characteristics in China – the largest and most rapidly changing DBS market in the world – could help other countries to devise appropriate policies and avoid potential negative impacts.

However, related studies are few since its fast rise. Although China holds the largest BS and DBS market by far compared to other countries, little is known and understood about how BS and DBS have been implemented, developed, and supported in China. BS and DBS development and the governments' policy in different phases of its development require solid, up-to-date information based on both national and city levels, which is hard to find in the existing literature. Therefore, this component of research reviews both traditional BS development in China and the implementation of DBS.

This chapter conducts an empirical analysis of the development of BS and DBS based on up-to-date literature (not covering the time DBS prevailed) and from domestic and international reports. It is important to point out that some of these documents are still in the drafting stage and written in Chinese. To the best of our knowledge, this study is the first attempt to address the DBS development. The research gap and objective are described in Table 4-1.

Table 4-1 Research gap and objective of Chapter 4

Research topic	Research gaps	Research objective
An Empirical study of BS and DBS development in China	➢ Exiting BS literature is limited and not covering the time DBS prevailed, in a developing community-context. ➢ No literature had systematically reviewed DBS so far.	➢ Organize the development of BS and DBS in China; ➢ Investigate DBS users' characteristics, influential factors and feasibilities of DBS and BS.

The chapter includes the following paper:
***Gu, Tianqi**, Kim, I. *, & Currie, G. (2019). To be or not to be dockless: Empirical analysis of dockless bikeshare development in China. Transportation Research Part A: Policy and Practice, 119, 122-147. (SCI, IF: 3.693)*

4.2 Paper 1: To be or not to be dockless: Empirical analysis of dockless bikeshare development in China

This chapter gives an up-to-date empirical analysis on the development of bikeshare programs in China, especially the innovative dockless bikeshare (DBS) system. Bicycle sharing programs had existed in China since 2008. However, overall bicycle mode share kept decreasing until 2016 when DBS emerged. A comparison of classical city docked bikeshare (BS) programs found that government-oriented operators and a low financial threshold for users were the keys to the success of docked BS in China. In less than two years, a new, innovative, flexible, shared bicycling system - the DBS - had grown from nothing to a substantial 23 million fleets system. It covers over 200 cities and regions, makes docked BS insignificant. As a highly capital-driven, privately-operated business model, DBS are largely deployed in cities in conjunction with urban railway systems and has achieved high penetration in mega cites (e.g., 0.135 fleet/resident in Beijing). The development of DBS has experienced "free growth", "regulated" and "limited" phases in a short time. While the central government initially held a "neutral-positive" policy towards it, the rapid expansion of dockless fleets soon exceeded cities' limits and resulted in local government policies changing from "neutral-positive" to "neutral-negative". From August 2017, forceful limiting regulations have been implemented. DBS systems have advantages such as easy access using a smart phone, convenience of pickup and park and low cost. These merits attract its main users, who are found to be young, highly educated with almost equal numbers of males and females. DBS trips are mainly short, with high frequency and used for commuting purposes. DBS systems have burgeoned due to three factors: (1) those promoting user demands, (2) those winning partial support of the government, and (3) those promoting operators' supply. The results show that the rapid growth of dockless bikeshare programs is mainly "supply-driven by operators" rather than by "user demand" or "triggered by government policy". Financial sustainability, vandalism and threat to bicycle industry by DBS are the three main challenges that require investigation, especially, the fact that the booming DBS market may cause low profitability for local bicycle manufacturers and thus make the entire industry fragile. The feasibility of docked bikeshare and dockless bikeshare are compared and concluded at the end of this component of research. This component of research would help us to get a macro perspective of how BS/DBS promote public transport before digging the data-driven methodology to study BS/DBS and mass transit integration in Chapter 5 and 6.

The published version could be seen on https://doi.org/10.1016/j.tra.2018.11.007.

Transportation Research Part A 119 (2019) 122–147

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

To be or not to be dockless: Empirical analysis of dockless bikeshare development in China

Tianqi Gu, Inhi Kim, Graham Currie

Institute of Transport Studies, Dept. of Civil Engineering, Monash University, Clayton, VIC 3800, Australia

ARTICLE INFO

Keywords:
Docked bikeshare
Dockless bikeshare
China
Policy
Users' characteristics
Challenge
Feasibility

ABSTRACT

This paper discusses the development of shared bike programs in China, especially the innovative dockless bikeshare (DBS) system, using up-to-date empirical analysis. Bicycle sharing programs had existed in China since 2008 but overall bicycle mode share decreased until 2016 when DBS emerged. A comparison of classical city docked bikeshare (BS) programs found that government-oriented operators and a low financial threshold for users were the keys to the success of docked BS in China. In less than two years, a new, innovative, flexible, shared bicycling system – the DBS – has grown from nothing to a substantial 23 million fleets, covering over 200 cities and regions, making docked BS appear insignificant. It is a highly capital-driven, privately-operated business model, largely deployed in cities in conjunction with urban railway systems and has achieved high penetration in mega cites (e.g., 0.135 fleet/resident in Beijing). The development of DBS has experienced "free growth", "regulated" and "limited" phases in a short time. While the central government initially held a "**neutral-positive**" policy towards this new system, the rapid expansion of dockless fleets soon exceeded cities' limits and resulted in local government policies changing from "**neutral-positive**" to "**neutral-negative**", and from August 2017, forceful limiting regulations have been implemented. DBS systems have advantages such as easy access using a smart phone, convenience of pickup and park and low cost. These merits attract its main users, who are found to be young, highly educated with almost equal numbers of males and females. DBS trips are mainly short, with high frequency and used for commuting purposes. DBS systems have burgeoned due to three factors: (1) those promoting user demands, (2) those winning partial support of government, and (3) those promoting operators' supply. The results show that rapid growth of dockless bikeshare programs is mainly "**supply-driven by operators**" rather than by "**user demand**" or "**triggered by government policy**". Financial sustainability, vandalism and threat to bicycle industry by DBS are the three main challenges that require investigation, especially, the fact that the booming DBS market may cause low profitability for local bicycle manufacturers and thus make the entire industry fragile. Feasibility of docked bikeshare and dockless bikeshare are compared and concluded in the end.

1. Introduction

In 10 years, China built the world's leading classical city docked bikeshare (BS) market. However, the dramatic growth of the new innovative dockless bikeshare (DBS) system has quickly overtaken the BS market. Private operators introduced DBS in China in 2016 and since then it has dramatically spread across mainland China and fundamentally changed the way people travel and therefore their lives. DBS in China has grown from 2 million in 2016 to 23 million in 2017 and made itself one of the most significant shared

E-mail addresses: tianqi.gu@monash.edu (T. Gu), inhi.kim@monash.edu (I. Kim), graham.currie@monash.edu (G. Currie).

https://doi.org/10.1016/j.tra.2018.11.007
Received 3 August 2018; Received in revised form 1 November 2018; Accepted 11 November 2018
Available online 20 November 2018
0965-8564/

transport modes. This innovation now has spread to overseas countries including the US, UK and Australia, bringing convenience along with the downside known as fleet "congestion" (casual parking of bikes blocking pedestrian access). Since China owns the largest BS and DBS markets and has witnessed rapid expansion of DBS, a better understanding of BS and DBS development, policy and users characteristics in China – the largest and most rapidly changing DBS market in the world – could help other countries to devise appropriate policies and avoid potential negative impacts. For instance, overseas cities like Melbourne are experiencing vandalism and improper parking of dockless fleet bikes (David King, 2018), which have already been experienced and counter-measured by many Chinese cites. Lessons can be learnt from China's experience of DBS.

Studies of cycling development in China in recent years are either out-of-date, or have focused only on a small part of cycling development in China. It is important to understand the rise of DBS. Zhang et al. (2014) systematically studied bicycle transport evolution including BS in China from 1900s to 2012. Frame et al. (2017); Zhao et al. (2018) compared cycling policy and infrastructure between Wuhan and Amsterdam, and Beijing and Copenhagen, respectively. Another study by Yang et al. (2015) suggested how to revive bicycle transport in China. However, although case studies of BS in China are frequent, recent research has mostly focused on answering technical questions about BS's impact on other urban transport modes or investigating factors that influence BS usage (Andrew Archibald Campbell, 2012; Qin et al., 2018; Yang et al., 2018). Research on development and policy of BS in the Chinese context is not as glaring as its position in the world BS market (Fishman, 2016), let alone the research on DBS. Wei and Wei (2013) investigated BS operation and the scope of application in China. Few papers have been published in international journals about DBS because it is a new model that began in China. Spinney and Lin (2018) studied DBS's impact on society and urban environment, while Du and Cheng (2018) conducted a survey on DBS in Nanjing, China to find factors influencing DBS usage. Although China holds the largest BS and DBS market by far compared to other countries, little is known and understood about how BS and DBS have been implemented, developed, and supported in China. BS and DBS development and the governments' policy in different phases of its development require solid, up-to-date information based on both national and city levels, which is hard to find in the existing literature. Therefore, this paper reviews both traditional BS development in China and the implementation of DBS.

This paper conducts an empirical analysis of the development of BS and DBS based on up-to-date literature and from domestic and international reports. It is important to point out that some of these documents are still in the drafting stage and written in Chinese. The next sections are organized as follows. Section two investigates BS development and related policies in China, whereby four operator modes are categorized. The BS program in China is compared with other metropolitan cities in the US and UK. More importantly, the third section investigates aspects of DBS – its scale, business model, central government and local government policy, users' characteristics and challenges to the system. Conclusions and suggestions for further study complete the paper.

2. Development of docked bikeshare

2.1. Bikeshare's emerge in China and its scale

Zhang et al. (2015) presented an empirical study and analyzed bike-sharing systems in five Chinese cities. They concluded that well-planned configurations of transport, system design and choice of business model are key to a sustainable and successful city bikeshare system. Tang et al. (2017) and Karki and Tao (2016) studied BS in Shanghai and Suzhou during the development and policy introduction of BS in early 2010s. Zhang et al. (2014) also evaluated BS and its role in promoting cycling in China and concluded there were four development phases of bicycle evolution in China from 1900s until 2012. Reviews of BS development in China-context are limited. As Fishman (2016) stated in his review paper "no country has the bikeshare scale of China, yet research activity does not reflect this". Thus, the current paper appears to be the only one that discusses development and the policy background of BS and DBS in the Chinese context.

It is widely accepted that there are four generations of bikeshare development (Fishman, 2016). The first generation was Amsterdam's "White Bike" in 1965 while Copenhagen's coin-deposit BS in 1995 was considered second generation. These generations generally lacked the necessary security devices (Parkes et al., 2013; Zhang et al., 2014). The third-generation of BS, developed in Lyon, France, in 2005, included kiosks and user interface technology. This system operated successfully because it solved the theft problem by punishing users when they did not return the bicycles (Parkes et al., 2013). Manzi and Saibene (2018) stated that "a real boom of BSs all over the world has been experienced". Rebalancing the number of bicycles among different stations motivated the fourth-generation system. Some scholars (Fishman, 2016; Parkes et al., 2013; Shaheen et al., 2010) considered that the highly flexible dockless system with its use of GPS and a personal smart phone, easier installation, and power assistance is the fourth generation system.

The earliest BS in China, a second-generation system, appeared in 2005 in Beijing. It was owned and operated by a private company and reached its peak in 2008 with 100 stations and 8000 bicycles. As a market economy activity, it was short of government support, failed to profit, and soon was bankrupted in 2009. This also happened to a private BS system in Changzhou (2000 fleets). During this period of 2000s, the ownership of private vehicles boomed from 12.1 million in 2002 to 88.4 million in 2012, a 7-fold increase in 10 years with an annual rate of 21.5% while cycling decreased (National Bureau of Statistics of China, 2018).

While facing worsening pollution and congestion caused by automobile growth (Chan and Yao, 2008; Zhang and Mi, 2018), local governments turned to shared cycling. In 2008, Hangzhou, a city with tradition of cycling, built its own BS, the first government BS in China (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China), 2017b; Shaheen et al., 2011). It was a third-generation BS and grew from 61 stations and 2,500 fleets in 2008 to 3,833 stations and 86,800 fleets by the end of 2017. There was an average of over 300,000 daily trips in 2016 (96% of the trips were free), and for each fleet, the average daily rental reached 4.5 times in 2017 (Ltd. Hangzhou Public Bicycle Service and Development CO., 2017), which was a sound turnover rate especially when

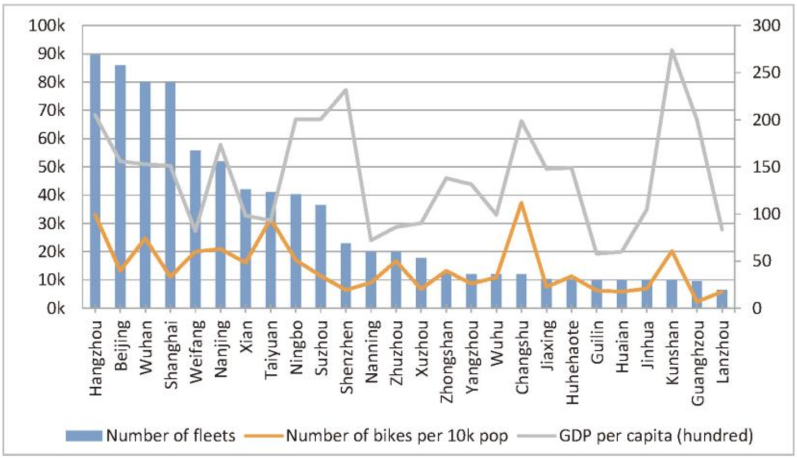


Fig. 1. Bikeshare market scale in Chinese cities by the end of 2017. *Source*: http://www.itdp-china.org/bikesharing, statistical yearbook of provinces related.

considering the huge number of cycle trips (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China), 2017b; Gauthier et al., 2013). Due to Hangzhou BS's huge success and its contribution to sustainable transport, it received the international Ashden Award in 2017 (The Ashden Awards, 2017).

After the implementation of a third generation BS system in Hangzhou, cities including Shanghai, Wuhan and Beijing set up their own BS systems in 2009, 2011, and 2012, respectively. Fig. 1 shows the market scale of leading BS markets in China. It demonstrates absolute/ per capita numbers of BS fleets in the leading 26 Chinese cities by the end of 2017, along with GDP per capita in each city. High consistency could be seen in these two indices – cites with stronger economies tended to have larger BS scale. This might be because more affluent cities normally have more financial support for public matters, which includes BS. In Fig. 1, the number of bikes per 10,000 residents and GDP per capita share the same left Y-axis.

The four largest cities, considered mega cities with a residential population over 10 million, Hangzhou, Beijing, Shanghai and Wuhan, owned a BS fleet of over 80,000 (not including the DBS fleet) by the end of 2017. After accounting for population, medium sized cities, such as Changshu, Ningbo, and Kunshan, with large economic productivity and flat topography, have better BS market penetration (indexed as the number of bikes per 10 k population). It has been shown that BS penetration is closely related to economic performance (GDP). An exception is Taiyuan, a northern Chinese city with relatively low GDP per capita, where the state-owned bus company operates a successful BS. In this case, not only has BS received direct financial support, but also it is integrated with transport planning and the regular bus services (interchange discount policy). This is in contrast to other cities where independent commercial operators run the BS. Besides, medium-size cities like Taiyuan might also have more flexible opportunities to deploy BS in terms of policy, financial support, residents' acceptance as well as construction conditions. Another interesting finding lies in one of the mega cities, Guangzhou, which appears second last in Fig. 1. Guangzhou has the poorest cycling infrastructure among the Chinese mega cities. Many Guangzhou roads have no independent bicycle lanes, which in part explains this low ranking. Currently, the Wuhan BS is closing due to the impact of DBS (Guodong and Jun, 2017).

According to the "Bike Sharing World Map", BS systems increased from 101 to 1328 at an annual rate of 152.8% from 2010 to 2017. By the end of 2016, China had the most BS (430), accounting for over one third of BS worldwide, followed by Italy and USA, as shown in Fig. 2.

From 2010 to 2016, BS fleets increased from 139,000 to 2,294,600 worldwide, an increase of 16.5-fold, of which China contributed 1,900,340 bikes in 2016 (Bikesharingmap, 2017; Demaio, 2017). Almost 83% of the fleet are deployed in China. However, when considering population scale, France and Spain also had a BS fleet penetration of over 6 bikes per 10,000 population in 2015, as can be seen in Fig. 3. They were followed by mainly European countries such as Belgium and Ireland although Taiwan also is shown in this ranking.

Since France has a cultural background of cycling, it was one of the earliest markets to deploy third generation BS and thus leads the BS market. For similar reasons, many northern and western European countries are included in this list. China and Taiwan are the only Asian regions in the top 10 BS markets.

2.2. Policy towards docked bikeshare and operators

Government attitudes towards BS are encouraging – not only do they provide guidance and assist by relaxing or changing regulations to promote the BS industry, they also subside BS in an indirect or direct way. In 2012, the Ministry of Housing and Urban-rural Development released "Guidelines for planning and design of urban pedestrian and bicycle transport systems" and encouraged

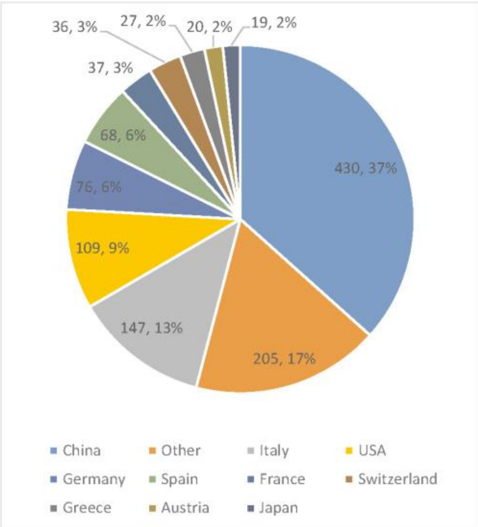


Fig. 2. Top 10 bikeshare system countries (by the end of 2016). *Source*: www.bikesharingmap.com, Langford, Chen et al. (2015), Demaio (2017).

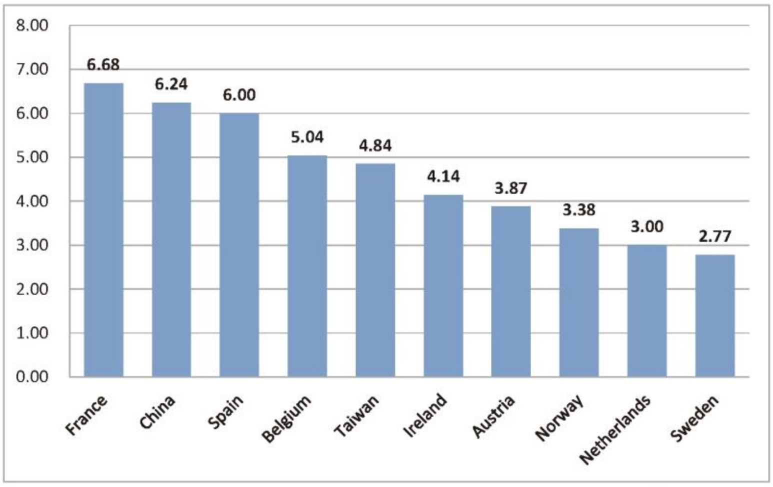


Fig. 3. Top 10 shared bike markets considering population, unit: bikes per 10,000 people, 2016. *Source*: www.bikesharingmap.com, Demaio (2017), population data from http://www.populationpyramid.net/.

local government to promote development of BS and offer necessary subsidies (Ministry of Housing and Urban-rural Development, 2014). Some scholars have stated that governmental input is one of the most important elements that makes BS implementation successful; its ultimate goal of building a BS is to reduce environmental impact, lessen traffic congestion and finally improve public health (Demaio, 2009; Mateo-Babiano, 2015). A counter-argument is that a profitable business is necessary to maintain a sustainable development of a BS market (Beroud et al., 2010; Susan Shaheen et al., 2010). Most city BS systems in China follow the former statement. Normally, BS systems are welcomed and supported by local governments in most cases in China. Governments provide direct financial subsidies or indirect privileges to operators; most local governments treat BS as a form of public service rather than as an economic industry or business. Zhang et al. (2015) stated that stakeholders, city governments, communities, even advertising agencies should be carefully organized in a localized way to ensure the success of BS. Wei and Wei (2013) studied BS business models in China and suggested three models: (a) Single Circular Model run totally by private operators, (b) Complex Circular Model run by a public-private-partnership (e.g., Paris, Lyon, Wuhan, Shanghai), and (c) Straight Line Model under strong control of local governments (e.g., Hangzhou). However, the potential risks of solo or multiple operators in the second model were not fully revealed.

Therefore, by collecting the most up-to-date information (June 2018) of BS systems deployed in major cities in China, operator models have been organized into four categories in this paper. Most operators received government subsides (pure private operators without government support are neither failed or on a break) (Wei and Wei, 2013). The number of BS fleets, stations and turnover rate were acquired by the time this paper was published yet were only available for the period from 2016 to 2017. Due to the impact of DBS (since 2016), the actual BS operation index as turnover rate or operation stations in some cities has decreased (though no detailed data is available) while the BS service in Wuhan, Shenzhen and Chengdu has ceased.

The four categories of BS systems are Model A – one private operator with low-level or indirect governmental subsidy; Model B – several operators (private operator and state-owned operator) with various governmental subsidies; Model C – one state-owned operator with high-level government funding and Model D – one private operator with high government funding under full government supervision (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China), 2017b; Cai, 2017; Guodong and Jun, 2017; Ltd. Hangzhou Public Bicycle Service and Development CO., 2017; Li, 2017; Liang, 2017; Jiapeng et al., 2017; Zhu, 2017). The turnover rate is collected through different sources (Gauthier et al., 2013; Médard de Chardon et al., 2017; Tang et al., 2017; Yang et al., 2015; Zhang et al., 2015), and there are some inconsistent data in Beijing, Suzhou and Chengdu. These data were carefully checked with the latest authorized source and data from the more credible source used. Despite this step, these data should be used with caution.

Due to the lack of unified management, Model B normally had problems with different operators' fleets in the same city (e.g., Shanghai, Shenzhen) whereby rent and return cannot be unified, in other world, users could only return bicycles to particular stations rather than all the stations, which makes using BS more inconvenient and compliant by users. For instance, separate BS systems are deployed in Shenzhen with different pricing and thus different levels of patronage; the one in Yantian District (daily ridership 10.3 rides per bike per day) is fully funded by the city government and offers a lower renting price to riders with a first-hour-free policy, while the one in Nanshan District is operated by a private operator with limited subsidies and no free riding time and thus has a much lower ridership (3.7 rides per bike per day) (Yang et al., 2015). Moreover, another problem lies in the public-private-partnership contract (PPP) or Built-Operate-Transfer contract (BOT) in Model B as mentioned before. For example, Wuhan- once the largest BS in China that reached 60 thousand fleets in 2009, signed an 8-year BOT contract with a private operator named Xinfeida, and were awarded CNY0.3 billion (16% in cash and 84% in advertisement equivalent) by the government. After the company manipulated the advertisement revenue and made profits without properly operating the BS, the government closed Wuhan BS temporarily in 2011 and then installed a state-owned operator. Therefore, it changed from Model B to Model C. Cities with Model C and Model D operators (supported and supervised directly by local governments) have larger, more stable BS services, and therefore can resist the impact of DBS compared to cities with Model A and Model B systems.

Strong support from government causes two beneficial outcomes regardless of profit. One is the low financial threshold that attracts more potential users. The other is offering a rapid BS expansion strategy (see Table 1).

One significant outcome of government-controlled operation is the low financial threshold that attracts potential users to access BS in China. In Table 2, a range of financial data for BS in China and selected overseas cities is compared. BS customers in China have 1–2 h of free ride time while overseas counterparts usually have 30 min. This is believed to have a significant positive influence on BS performance (Zhang et al., 2015). In fact, over 96% of travel on BS systems in Hangzhou is free (Shaheen et al., 2011) and in Suzhou, 98% of trips are free of charge with no monthly subscription fee, whereas in overseas cities, free-riding times are either shorter, or non-existent. Moreover, the financial requirements to gain access to the system in western countries are much higher than in China. For Paris, Washington, D.C. and Mexico City, over USD200 deposit is required plus a subscription fee ranging from USD31-75p.a. London does not require a deposit, although it has the highest subscription fee (USD123 p.a.). In contrast, only a small deposit and no subscription fee are needed in China. Rental cost in China is on average 5% to 20% of that in western cities. Still, lower manufacturing costs in China also helps to lower the fees of BS - the average cost of procuring a bicycle in China is around 3% to 10% of the cost of BS bikes in western cities (see Table 2).

Another benefit along with financial support from government is the rapid expansion of BS. For instance, Hangzhou's city BS was operated by a state-owned operator with little concern for profit. In less than 10 years, its scale increased 62 times (annual growth rate 58.2% at stations) and 35 times (annual growth rate 58.2% of fleet) (Ltd. Hangzhou Public Bicycle Service and Development CO., 2017). Similarly, Suzhou city's BS increased from 11 stations, 200 fleets in 2010 to 2,200 stations and 45,600 fleets in 2017 – 20 times growth in 7 years (annual growth rate 53.4%) (Suzhou Planning bureau, 2018). With support from government subsidies and with less profit concern, local governments and their commercial company partners can rapidly expand BS into new areas, even though there are fewer users (lower profit) now. In 2012, 50 cities in China had BS systems, which increased to 215 cities by March 2015 (Institution for Transportation & Development Policy, 2017).

Notwithstanding, rapid expansion can be a heavy burden on city finances, which raises doubt on the sustainability of a government-controlled operation. Some scholars fear local governments spend too much on promoting BS. They argue that this policy is not only a heavy burden on local governmental finance, but also may lead to an unhealthy competition between BS and private bicycles (Yin et al., 2017). This is experienced mainly in of Chinese context could and should be treated with caution when applied to other places.

Table 2 shows that China has a strong government-supported BS system, which performs better than a profit-oriented BS system. Strong government control (from direct funding or forming a state-owned operator) is key to both easy access for potential BS users and rapid expansion of BS. As can be seen, financial threshold (e.g. the deposit or usage fee) in China is much lower than overseas counterparts. Even though the Chinese turnover rate seems to be lower when compared to turnover rates of its overseas counterparts (6.9 in Paris, 8.3 in Lyon), if the larger scale is considered, most BS in Chinese cities show high-penetration and high performance

Table 1
Details of BS operation in selected major cities in China and some overseas counterparts.

City	Population (10 k)	BS start time	Fleets (10 k)	Number of stations	Turnover rate (trips/bike/day)	Operator model	Important information
Beijing	2170.7	2011	8.6	2588	4.4	Model A	N/A
Shanghai	2418.3	2010	3.03	688	4.2	Model B (two operators)	No unified management
Guangzhou	1449.8	Jun, 2010	1	N/A	4.2	Model B	N/A
Shenzhen	1252.8	Sep, 2012	2.2	790	Yantian District: 10.3 Nanshan District: 3.7	Model B (two operators)	Ceased to operate in Jan, 2018
Wuhan	1089.3	2009	8	806	2 (after 2012)	Model A - before 2011 Model C - after 2011	Ceased to operate in Nov, 2017
Taiyuan	429.9	Jun, 2010	4.1	1285	> 10	Model C	
Chengdu	1604.5	Dec, 2010	0.18	153	2.4	Model B	Ceased to operate in 2017
Hangzhou	946.8	May, 2008	8.96	3833	4.5	Model C	Largest BS in the world, kept growing in 2017 after DBS entered
Nanjing	833.5	Nov, 2015	4.15	1074	N/A	Model C	N/A
Suzhou	1068.4	Aug, 2010	4.65	2200	6.2	Model D	Banned DBS
Zhuzhou	110	May, 2011	2	1015	10.6	Model C	Highest turnover rate in the world
Paris	–	2007	2.36	1750	6.9	Model A	Known as the first large-scale 3rd generation BS in the world
Lyon	–	2005	0.4	346	8.3	Model A	–

Source: Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017b); Cai (2017); Guodong and Jun (2017); Ltd. Hangzhou Public Bicycle Service and Development CO. (2017); Li (2017); Liang (2017); Jiapeng et al. (2017); Tang et al. (2017); Zhu (2017), and statistical yearbook of related cities.
Note. The data related to BS were updated by the time the paper was published and cover the period 2016 to 2018.

Table 2
Information of BS financial index in selected cities.

City	Cost per bicycle (USD)	Deposit (USD)	Subscription fees (USD)	Usage fee (USD)
Beijing	N/A	45	No subscription fee is needed	0–1 h: free
Shanghai	N/A	free		> 1h: 0.15/h
Chengdu	N/A	15		
Hangzhou	66	30		
Nanjing	80	45		
Suzhou	80	30 or free*		
Paris	N/A	199	Daily: 3 Weekly: 13 Annual: 123	0–0.5 h: free 0.5–1 h: 1.3 1–0.5 h: 5.1 1.5–2 h: 7.7
London	N/A	N/A	Daily: 2 Weekly: 11 Annual: 38	0–0.5 h: free 0.5–1 h: 1.1 1–1.5 h: 2.2 > 1.5 h: 4.48/30 min
Washington, D.C.	890	202	Daily: 7 Weekly: 25 Annual: 75	0–0.5 h: free 0.5–1 h: 2 1–1.5 h: 4 > 1.5 h: 8/30 min
Mexico City	573	393	Daily: 7 Weekly: 24 Annual: 31	1 day: 90 3 days: 180 7 days: 300 Annual: 400

Source: Suzhou Planning bureau (2018); Fishman (2016); Gauthier et al. (2013); Shaheen (2013); Yang et al. (2015). *Note.* The data related to BS were updated at the time of paper publication and cover 2016 to 2018. All BS systems listed are free for the first hour and have no membership fee or subscribtion fee. For the Suzhou BS, users with high Alipay (a popular online payment app) credits may have free access to BS.

(Gauthier et al., 2013), and are considered successful (Institute for Transportation & Development Policy (ITDP), 2018).

The reason behind government support, as stated in the last section, is the concern caused by rapid mobilization since 2002 (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China), 2017b). BS is an ideal "last-mile" service that feeds the urban railway system (Alex, 2018; Fishman, 2016; Ji et al., 2017; Institution for Transportation & Development Policy, 2017), which also boomed in 2000s (China Urban Railway Transport Association, 2018). Out of 34 cities that have metro systems, 33 had deployed BS by the end of 2017 (China Bicycle Association, 2017). The only exception is Chongqing, a mountain city that is renowned for its vertical topography. The director of the Suzhou Urban Administration Department, the bureau supervising Suzhou BS, noted that many BS in China were initiated to enhance urban railways by providing an interchange service while aiming at renovating cycling as well.

3. Development of dockless bikeshare

As a new innovation, DBS studies are very rare. Du and Cheng (2018) pointed out four characteristics of DBS: (1) no fixed stations; (2) users tend to be mobile internet users while BS users are more likely to be local residents who hold BS cards; (3) DBS systems are normally private, entrepreneurial, venture capital projects, while BS are normally funded or invested in by governments. These two have different operational management models; and (4) most DBS fleets have GPS devices which is convenient for redistribution and maintenance. It appears no empirical analysis about the development of DBS in China has been conducted before. Therefore, it is important to present such a study in this paper.

3.1. DBS development and market scale

In 2014, a group of Peking University graduates established ofo (the first DBS company in China) to serve internal transportation demands on campus. By June 2015, 2000 ofo fleets had been deployed at Peking University. In April 2016, Mobike (another leading DBS operator in China founded in January 2015) began the first version of the Mobike fleet in Shanghai. It was the first time that DBS had penetrated urban transport, therefore 2016 was called "the first year of the DBS era". After attracting attention from investors, the DBS market boomed across the entire country as can be seen in Fig. 4. Known investment in DBS companies worldwide amounted to an incredible USD2.6 billion in 2017 (compared with only USD290 million in 2016), of which most investment was attributable to DBS in China. Within China more than USD1 billion was attributable to ofo, and another USD800 million to Mobike. In March 2018, ofo raised USD866 million in new financing led by the Alibaba Group. In April 2018, China's Meituan Dianping (China's largest provider of on-demand online services) bought Mobike for USD2.7 billion excluding debt. This trend towards shared mobility has extended globally. Very recently, a shared scooter startup, Lime, raised USD250 million led by Uber investor GV (formerly Google Ventures) (Lynley, 2018).

It is difficult to determine the exact DBS market scale due to its rapid expansion and multiple data resources. According to Mr. Liu Xiaoming, Vice Minister of the Ministry of Transportation, 57 DBS operator companies had deployed 23 million fleets on the streets of

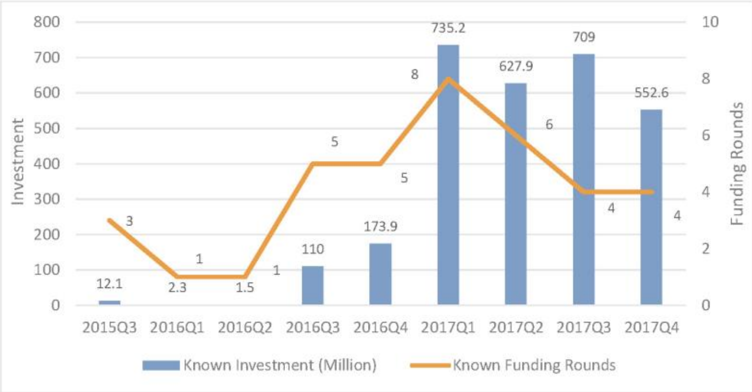


Fig. 4. Investment of DBS in China from 2015 to 2017. *Source*: Savannah Dowling (2018).

China by January 2018. Total estimated DBS ridership so far has reached a combined 17 billion, with the highest peak use hitting 70 million rides a day (Hong Mo, 2018). This figure is consistent with data presented in some third-party consulting institutes and by DBS operators, who also revealed rapid growth in both users and fleets from 2016 to 2017 (see Table 3). The number of DBS fleets deployed rose from 2 to 23 million in one-year while the number of cities with DBS also increased from 33 to 200. DBS users and trip length grew more than 10 times during the same time, which means that there is one registered DBS user in every 6.5 people in China. Considering the huge population of China, this is an astonishing number, especially when it occurred over 18 months (ofo & China information and Communication Research Institute, 2018a, 2018b).

Mobike and ofo are currently the two biggest DBS operators in the industry with a combined market share of 90% in China. In December 2017, Mobike already had more than 8 million fleets and more than 200 million registered users in 200 cities (mostly in China). ofo, with similar users and cities penetrated, had 10 million fleets by January 2018. This means that these two giants increased their DBS ownership from around 5 million in April 2017 to 18 million fleets by the end of 2017 (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China), 2017a; AllTechAsia, 2018; European Bicycle Manufacturers Association, 2018).

To indicate temporal change of DBS at a city-level, data from mega cities with the highest DBS volume are collected in Fig. 5 and are shown as two stages (the orange bar indicating an earlier stage, and the grey bar indicating a later stage). In Fig. 5 Hangzhou and Guangzhou's earlier DBS data were collected in 2017Q1 while others were recorded in 2017Q2. Shenzhen's later DBS data were collected in 2017Q4, Guangzhou, Nanjing, Wuhan were collected in 2017Q3 while the remaining cities' data were collected in 2018Q1. The capacity of each city is collected from local government reports or policy statements about DBS.

Three implications can be seen from Fig. 5. Firstly, it shows that the numbers of city DBS outweigh the numbers of city BS. The difference varies from 10 times (Hangzhou) to 60 times (Shanghai) or even higher in those with few BS (Chengdu). Secondly, in a very short time (one year or less), DBS grew significantly in each city and reached a peak in 2017Q3/Q4, 2018Q1. Thirdly, most of the DBS deployed had already exceeded city capacities. For instance, according to a Shenzhen DBS assessment report, Shenzhen has parking places for 0.43 million DBS and bicycle lanes for 0.8 million DBS, while 0.89 million DBS were already deployed by the end of 2017 (Transport Commission of Shenzhen Municipality, 2018).

Moreover, in many DBS assessment reports, indices expressed as fleets over population are widely used to indicate penetration of DBS. Table 4 shows "penetration" for selected cities and for some overseas counterparts. (Washington, D.C., Montreal, Berlin and Paris are the top overseas countries with BS penetration and that their data were collected in August 2017). Thus, DBS has superior penetration, and the combined DBS and BS penetration in Chinese cities are higher than their overseas counterparts. As the capital of China, Beijing has a BS penetration of 0.40%, which means 0.4 BS bicycle exists for every 100 residents. This is not a small number

Table 3
Growth of DBS market in China (2016–2017).

Year	Supply-end			Demand-end	
	Fleets (million)	Cities with DBS	Number of DBS operator	Number of registered users (million)	Accumulated trip length (billion km)
2016Q4	2	33	25	18.86	2.50
2017Q1	4	43	N/A	N/A	N/A
2017Q2	10	70	45	100	N/A
2017Q3	16	N/A	77	130	N/A
2017Q4	23	200	57	221	29.95

Source: Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017b); European Bicycle Manufacturers Association (2018); iiMedia Research Institute (2017); Wang Lin et al. (2017); ofo and China information and Communication Research Institute (2018a, 2018b).

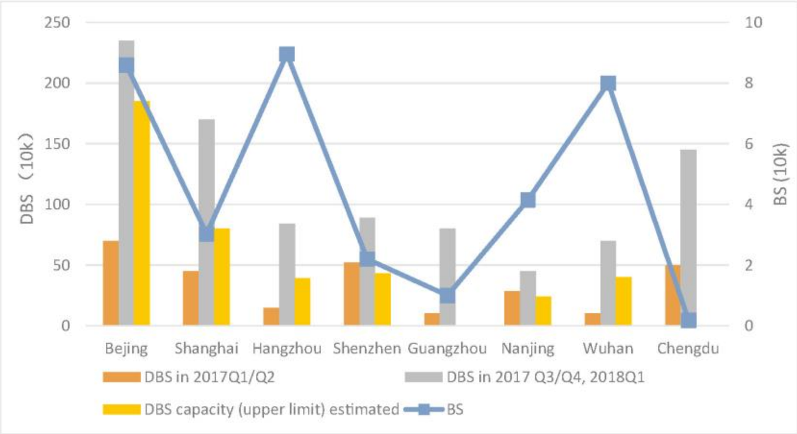


Fig. 5. DBS and BS use in selected cities, note that DBS and BS have different Y-axis value. *Source*: Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017a, 2017b); Nanjing Trasnport Bureau (2018); Hangzhou Comprehensive Transportation Research Center (2018); Beijing Municipal Institute of City Planning & Design (2018); Shanghai Urban and Transport Research Institute (2018); Li (2018); Transport Commission of Shenzhen Municipality (2018); Yi (2017).

Table 4
Critical indices of cities with greatest DBS volume.

City	Population urban (million)	BS (10 k)	DBS (10 k)	Entering time of DBS	Penetration of DBS (fleets/pop)	Penetration of BS (fleets/pop)
Beijing	21.7	8.6	235	2016.9	10.83%	0.40%
Shanghai	24.2	3.03	170	2016.4	7.02%	0.13%
Hangzhou	9.5	8.96	84	2017.2	8.84%	0.94%
Shenzhen	12.5	2.2	89	2016.1	7.12%	0.18%
Guangzhou	14.5	1	80	2016.9	5.52%	0.07%
Nanjing	8.3	4.15	45	2017.1	5.42%	0.50%
Wuhan	10.9	8	70	2017.1	6.42%	0.73%
Chengdu	16	0.18	145	2016.1	9.06%	0.01%
Suzhou	10.7	4.65	No DBS existed			0.43%
Washington, D.C.	0.68	3.7	*	2017.9	*	0.5%
Montreal	1.7	6.3	–	–	–	0.4%
Berlin	3.7	8.5	–	–	–	0.2%
Paris	10.6	18.2	–	–	–	0.2%

Source: Cities statistical yearbook related; Nanjing Trasnport Bureau (2018); Hangzhou Comprehensive Transportation Research Center (2018); Beijing Municipal Institute of City Planning & Design (2018); Fratila (2018); Shanghai Urban and Transport Research Institute (2018); Li (2018); Transport Commission of Shenzhen Municipality (2018); Yi (2017). *Note that Mobike entered Washington, D.C. by Sep. 2017, while no figures about the market scale is revealed so far.

considering the huge population base of 21.7 million. Its DBS penetration is substantially high at 10.83%, that is, every 100 residents have more than 10 DBS fleets. It is 25 times compared to its own BS penetration, one or two orders of magnitude more than overseas counterparts, such as Washington, D.C. and Montreal. When considering such a high penetration occurred in less than 2 years by private operators, it becomes even more surprising.

3.2. Policy towards DBS

As a new innovative BS mode, DBS drew great attention from all levels of governments in a very short time. Overall, the central government holds a neutral-positive attitude while local governments hold more cautious attitudes. In 2 years, as a private operator-oriented transport mode, the scale of DBS grew fast. Local government attitudes have lagged yet kept changing. Policies and regulations gradually formed from nothing to a systematic method at local and central government levels. For instance, at the beginning of DBS (May 2016 to March 2017), no significant policies or regulations existed towards DBS, so DBS enjoyed a free and unlimited growth period which largely drove its development. In a short time, three phases could be distinguished based on policy and scale changes as can be seen in Table 5, which will be elaborated in the following sections.

Table 5
Phases of DBS development.

Phase	DBS scales	Local governments	Central Government	Description
1 (2016.5–2017.3)	4 million fleets 45 cities	No regulations		Rapid growth with little limitation;
2 (2017.4–2017.8)	About 14 million fleets, 120 cities	Neutral-positive attitude	Neutral-positive attitude	Regulations are issued; DBS scale increased rapidly;
3 (2017.8-present)	23 million fleets, 200 cities (by the end of 2017)	Neutral-negative attitude	Neutral-positive attitude	Tougher regulations are issued to directly limit new increase of DBS; DBS scale fell slightly to an unknown degree;

3.2.1. Central government

In May 2017, China's national Ministry of Transportation and the National Development and Reform Commission jointly drafted the first national framework for regulating DBS, in which internet-bicycle-rental services are considered a "complement to urban green transport", and should be "encouraged and regulated" (Qi, 2017). The official document regulated bicycle and traffic standards, punished individuals for illegal behavior and required local governments to ensure an even distribution of DBS fleets and to set up designated parking spaces. It is very rare that 10 national ministries (e.g. Ministry of Transportation, Ministry of Industry and Information Technology, Ministry of Housing and Urban-Rural Development, People's Bank of China) jointly endorsed and issued the "Guidance of encouraging and regulating the development of Internet rental bicycles (dockless shared bike)". In this important "Guidance", central government confirmed a positive attitude towards DBS and considered DBS "a part of green transport system", "a convenient transport mode that serves short-term trips and offers interchange service to public transport" that "should develop coordinately". It also stated that "regular bikeshare (BS) and internet-bicycle-rental services (DBS) should be integrated" to form "a multi-level, multi-choice urban transport system" (Jiang, 2018). However, it was not a total encouragement of DBS. However, in these national regulations and guidance central government has stated that local regulations should be established and optimized to prevent misuse of DBS. It also clarified the responsibilities of each participant (local governments, operators and users) in DBS activity where local governments were the main bodies of DBS management (Ministry of Transportation et al., 2017) as shown in Table 6. Central government did not specify DBS's scale limitation but left this authority to local governments. It is notable that shared E-bikes were clearly stated as "not encouraged" in this "Guidance".

3.2.2. Local governments and development phases of DBS

The DBS first emerged in Shanghai in April 2016 and spread to over 40 cities before March 2017. However, no local regulations were issued in this time frame. This was a time (Phase One) for DBS operators to deploy fleets unwittingly which caused a boom in DBS in China (4 million by March 2017). Two more phases followed that witnessed changing attitudes of local authorities.

Phase Two started in March 2017 and ran to August 2017. In March 2017, Chengdu released the first local drafted regulation about DBS – "Tentative guiding opinions on encouraging DBS development". For the first time, DBS operators were made responsible for parking of DBS bikes and avoiding DBS "congestion". Most major cities, such as Jinan (March 2017), Shanghai (March 2017), Shenzhen, Beijing, Tianjin (April 2017), Guangzhou (June 2017), Wuhan, Nanjing, Zhengzhou (July 2017), followed rapidly with their own regulations for DBS. In these drafted local regulations, DBS operators were required to take responsibility for their bicycles. They were required to routinely check the bikes, undertake maintenance work and ensure users' physical and personal information safety. In some cities, DBS fleet capacities and limits were estimated (Shenzhen) while user requirements including a real-name register were specified (Shanghai). Some detailed requirements of DBS operators' entrance into particular cities were issued as well (Jinan). Overall, local governments issued a series of draft regulations, cautiously encouraged DBS and tried to regulate the management of DBS operators during this stage (before August 2017) (see Table 7). These local regulators held a general neutral-positive

Table 6
Responsibilities of participants of DBS.

Participants	Responsibilities
Local governments	Main body of DBS management; Make regulations and policies towards DBS; Assess DBS market scales, set necessary limits and control the expansion of DBS; Supervise DBS operators; Promote cycling infrastructure construction including bicycle lanes and parking spaces;
Operators	Offer DBS service, optimize management and improve user experience; Be responsible for orderly fleet parking; Build real-name-registration, a credit-system mechanism and purchase insurance for users; Secure the safety of users' financial and personal information;
Users	Use the fleets and park responsibly; Follow real-name-registration and credit-system regulations and mechanisms;
Industry associations & organizations	Encourage set standards and promote technology development;

Source: Ministry of Transportation et al. (2017).

Table 7
Details of local policies for second phase of DBS (March 2017 to July 2017).

City	Released time	Name of regulations	Main contents
Chengdu	March 3, 2017	Guiding opinions on encouraging DBS development; Further opinions on regulating DBS management (draft)	DBS operators are responsible for issues and problems related to DBS, under the supervision of local authority; Basic requirements for DBS operators in Chengdu are set up
Shanghai	March 23, 2017	Regulations for dockless shared bike service	Guide bike-sharing's production, operation and maintenance; Requirements of potential users (height, age) are specified – those below 12-years-old are not allowed to use DBS
Jinan	March 2017	Jinan's guiding opinions on encouraging DBS development; Jinan's access requirement of DBS operators (draft)	Guide bike-sharing's production, operation and maintenance; Specify the access requirements of DBS operators
Shenzhen	April 6, 2017	Guiding opinions on encouraging and regulating DBS development (draft)	Guide bike-sharing's production, operation and maintenance; Scale of DBS fleets are supposed to meet the demands of travelers, the capacity of cycling infrastructure as well as operators' management capacity. Special deposit account is required to ensure users' deposit security
Wuhan	May 27, 2017	Wuhan's guiding opinions on promoting DBS's healthy development (draft)	Guide bike-sharing's production, operation and maintenance; Deposit security and users' registering requirements are specified
Beijing	April 24, 2017	Guiding opinions on encouraging and regulating DBS development (draft)	Guide bike-sharing's production, operation and maintenance; Districts are required to set DBS capacities and supervise operators' operation. Users' credit system is required to be established
Guangzhou	Jun 20, 2017	Guiding opinions on encouraging and regulating DBS development (draft)	Guide bike-sharing's production, operation and maintenance; Operators are required to register on a governmental supervision platform to share real-time operation data; Different local bureaus' responsibilities (urban planning, urban management, urban transportation, public security) towards DBS are explained
Nanjing	Jun 21, 2017	Nanjing's guiding opinions on promoting DBS's healthy development (draft)	Guide bike-sharing's production, operation and maintenance; Deposit security and users' real-name registering requirements are specified

Source: Local governments' regulations organized; Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017b); Bo (2017); Wenting Zhou (2018).

attitude towards DBS as can be seen from the titles.

Then in Phase Three, as the DBS grew even more rapidly (from 10 million in 2017Q2 to 16 million in 2017Q3), serious urban problems such as DBS "congestion" (scenes of clogged sidewalks no longer fit for pedestrians and piles of mangled bikes that had been illegally parked (Haas, 2017)) caused public alarm. Although parking guidelines had been issued they had not been properly enforced. In August 2017, local governments issued stricter rules to limit this rapid expansion. For instance, Nanjing government decided to make licenses mandatory for operators starting in 2018. Shanghai released a new formal regulation to "…push local authorities to integrate bike parking with city planning requirements. It requires operators, government officials and agencies to - control the city's bike fleet, such as requiring bike plate registration, banning shared electric bikes, and guaranteeing better parking by using electronic Geo-fence technology" (Jing, 2017). In January 2018, Shenzhen banned bikeshare service provider Didi Chuxing's Bluegogo branded bikes because the bikes and users' deposits were not up to standard (European Bicycle Manufacturers Association, 2018). In the spring of 2018, Beijing implemented electronic Geo-fence to make sure that the bikes were parked in an orderly fashion (Jao, 2018).

Most importantly, caps were set on the maximum number of DBS fleets allowed in many cities (Horwitz, 2017; Wenting Zhou, 2018). For instance, Beijing was said to have a 1.72–2 million DBS fleet capacity, but there was already 2.2 million DBS fleets by the end of September 2017 (Beijing Municipal Institute of City Planning & Design, 2018; Mo Hong, 2017); Shenzhen had 0.89 million bikes on the road while its parking capacity was only 0.43 million (Transport Commission of Shenzhen Municipality, 2018). The estimated DBS capacities of selected cities can be seen in Fig. 5. From August 2017, Shanghai began to limit new DBS fleets and required DBS operators to take more effective methods to maintain ordered parking behaviors (see Fig. 6). Beijing, Guangzhou, and other cities instantly followed suit (see Table 8). Tougher regulations continued until very recently when Shanghai released a draft paper, "Measure of Dockless Shared Bike", which required mandatory GPS devices, a maximum 3-year service time of a single fleet and banned fleet advertisement. Generally, although DBS are still allowed in most cities, higher standards and limited deployment are required by local governments (see Table 9).

Therefore, the number of active city DBS fleets has decreased slightly and has remained stable. The news has reported that Hangzhou DBS numbers have fallen from almost 800,000 to 690,000 (CCTV finance and Economics, 2018), while Beijing also reduced its active DBS to 190,000 (by 20%) (Yue, 2018; Zhao, 2018). The European Bicycle Manufacturers Association also reported that active DBS has reduced in Shanghai. However, since this DBS "congestion" was mainly reported in large cities, little is known about the actual level of active DBS decrease nationally. Overall, local DBS policies are becoming **neutral- negative**.

Based on DBS development and policy change, three phases are categorized based on the above discussion. Since DBS is still in rapid development, policies and scales could change dramatically in the near future, and new phases may be added or adjusted.

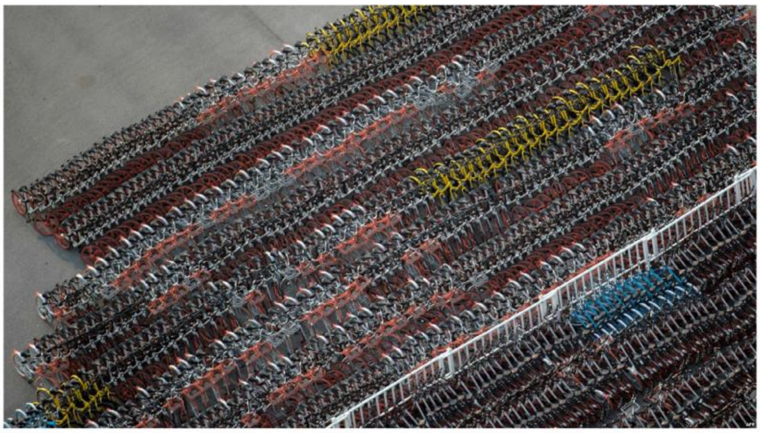


Fig. 6. Impounded bicycles from bike-sharing schemes Mobike and ofo in Shanghai, China. *Source:* Dierking (2017).

Table 8
Entering and limiting time of DBS in selected cities.

City	Entering time of DBS	Time of limiting new increase
Beijing	Sep, 2016	Sep, 2017
Shanghai	Apr, 2016	Aug, 2017
Hangzhou	Feb, 2017	Aug, 2017
Shenzhen	Jan, 2016	Aug, 2017
Guangzhou	Sep, 2016	Aug, 2017
Nanjing	Jan, 2017	Aug, 2017
Wuhan	Jan, 2017	Sep, 2017
Tianjin	Jan, 2017	Sep, 2017
Chengdu	Jan, 2017	Jan, 2018

Source: BBC (2017); Bo (2017); Cai (2017); Beijing Municipal Institute of City Planning & Design (2018); Li (2018); Luojun (2017); Ma (2017); Justin Spinney et al. (2018); Tang et al. (2017); Yi (2017).

3.3. Why it is loved?

Many factors, including weather, calendar events, built environments, users' demographic characteristics, pricing policy, cycling infrastructure, etc., can influence bicycles and BS usage, (Böcker et al., 2013; Bachand-Marleau et al., 2012; Buehler et al., 2017; Ding, 2016; Fishman, 2016; Fishman et al., 2015; Kim, 2018). Since DBS shares the same natural and most of the infrastructure factors as BS and private bicycles, some exclusive factors promoting its popularity will be discussed.

Compared with traditional BS with fixed parking docks, DBS refers to the bike-renting service provided by companies in public areas without fixed stations. It can be accessed through an on-board GPS, and a mobile payment to lock/unlock and pay by scanning the QR code on bikes via smartphone apps, which gives the users greater convenience and flexibility (Shen et al., 2018). In January 2017, in a survey (n = 10,732) conducted in Tianjin, in, DBS users were asked to state the reasons they chose DBS. The convenience to rent and return bicycles, and the easy payment process with a smartphone were listed as the leading two reasons (see Fig. 7).

The reasons behind the rapid growth of DBS could be mainly related to three factors. One factor, **promoting user demands,** includes easy access by smart phone, convenience of park and pick, relatively low price to use and unique demographic characteristics. Another factor is **winning partial support of government.** As a green transport mode, DBS helps to reduce green gas emissions, optimizes transport structure, and promotes interchanging between public transports. The third factor, which is relatively rare yet more important, is **promoting operators' supply.**

3.3.1. Factors promoting user demands

- Easy access to the DBS system

Previous research suggests that being unable to undertake on-the-spot renting in/out by ID or credit card can be inconvenient and this is considered a barrier to the use of BS systems (Fishman et al., 2012). Most BS in European and North American cities rely on personal credit cards in the payment process (Demaio, 2009; Susan A. Shaheen et al., 2010). In China, with the involvement of electronic payment, the processes of registering and payment of DBS are easier. Almost all DBS operators rely on smartphone apps

Table 9
Phases of DBS development and related policy (from May 2016 to present).

Phase one: Rapid growth without regulated supervision. (May 2016 to March 2017)	
DBS growth	Grew from nothing to 4 million fleets in 43 cities
Government Attitude	N/A
Policy or regulation	No policies were issued during this period.
Phase Two: Rapid growth. Governments' attitudes inclined to be cautiously positive. (March 2017 to August 2017)	
DBS growth	Grew from 4 million fleets in 43 cities to 13 million fleets in 60 cities by the end of July 2017
Government Attitude	**Neutral- positive** from local governments
Policy or regulation	**National level** "Guidance of encouraging and regulating the development of Internet rental bicycles (dockless shared bike)" (draft) was issued, the overall attitude was "encouraged". E-bikes were "discouraged". **Local level** Over 20 cities released "Guiding opinions on encouraging DBS development" or similar regulations to cautiously encourage DBS, regulate the management of DBS operators and protect users.
Phase Three: Growth at a national level, fall in some mega cities. Central and local government attitudes tended to diverge. (August 2017 till present time)	
Bicycle Usage	Scale grew from 13 million fleets in 60 cities to 23 million fleets in 200 cities. However, Beijing, Shanghai, Guangzhou began to witness decline in DBS use. "Sleepy" fleets (those broken or abandoned ones) were increasing
Government Attitude	**Neutral- positive** from central government **Neutral- negative** from local governments
Policy or regulation	**National level** "Guidance of encouraging and regulating the development of Internet rental bicycles (dockless shared bike)" was formally issued. DBS was considered an important part of urban transport and a complement to public transport. Local governments were required to take responsibility for managing DBS and no standard limitations were given by central government. **Local level** Mega-cities began to limit fleets, cap the capacities of DBS and issue stricter rules to regulate DBS operators' operation. E-bikes were "discouraged" in most cities.

Source: Local governments' issues organized; Cities statistical yearbook related; Nanjing Trasnport Bureau (2018); Hangzhou Comprehensive Transportation Research Center (2018); Beijing Municipal Institute of City Planning & Design (2018); Fratila (2018); Shanghai Urban and Transport Research Institute (2018); Li (2018); Transport Commission of Shenzhen Municipality (2018); Yi (2017); Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017b); Bo (2017).

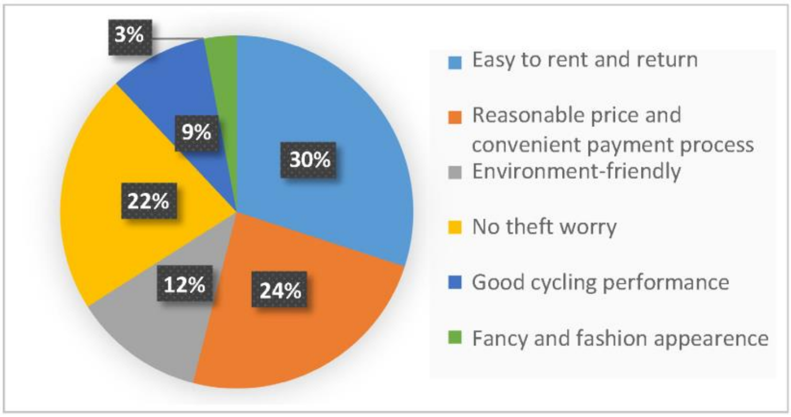


Fig. 7. Reasons to use DBS. *Source:* Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017b).

and social media rather than smart cards. Through Alipay (an online payment platform, popular in East Asia, similar to PayPal) or Wechat (a social media app, popular in East Asia, similar to WhatsApp), a new DBS user could easily complete registering in a few minutes and the renting/returning process in a few seconds by scanning a QR code. Also, users can conveniently withdraw the deposit anytime they want using an app.

- Convenience to park and pick

Convenience to park and pick is another factor affecting usage. Low convenience has been identified as a major cause of low BS performance (Fishman, 2014; Fishman et al., 2012; Fishman et al., 2014b). Traditional BS with fixed stations are often maligned since

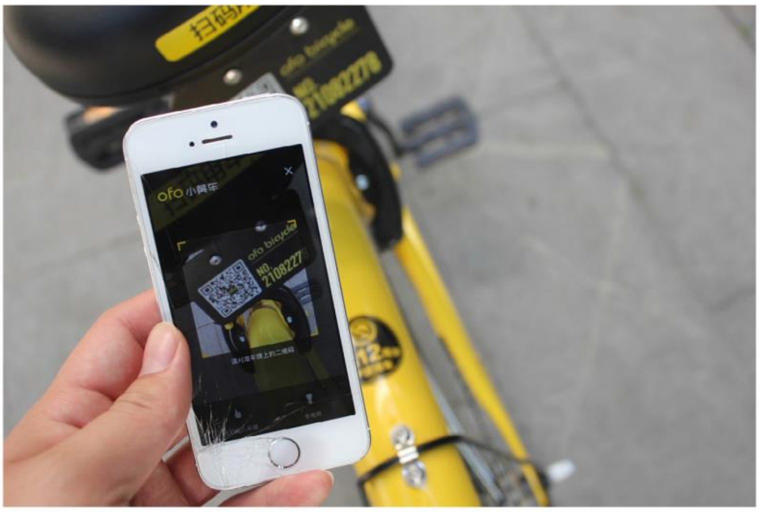


Fig. 8. A user scanning a QR code to unlock an ofo bike. *Source*: https://princeoftravel.com/blog/chinas-amazing-bike-sharing-apps.

stations are inclined to be full when users want to return bikes while they tend to be empty when users want to rent bikes. In a survey conducted in Suzhou, the two main complaints against BS were no stations to rent (26%) and no stations to return (20%), which was consistent with the conclusion of a local transport's annual report (Suzhou Planning bureau, 2018; Karki and Tao, 2016).

However, the most distinguishing feature favored by DBS users was its flexibility, see Fig. 7. As mentioned earlier, DBS have better spatial coverage because they do not require fixed bike stations. Moreover, since DBS normally have high penetration (Fig. 5), users can easily find available bicycles and park wherever they want (see Fig. 8).

- Relative low price to use

Pricing of top four DBS brands is shown in Table 10. Mobike standard has the highest usage fee, deposit and bike cost because it is equipped with an extra power supply to assist cycling, GPS and an automatic lock. It is followed by Mobike Lite, Bluegogo, Hellobike and ofo. Moreover, incredible promotions occur frequently with reduced usage prices of next to nothing for regular users due to fierce competition among DBS operators (Liao, 2018). Even the official deposit and usage fee (without promotion) is cheaper compared to DBS in overseas countries, as shown in Table 2. Bluegogo was bankrupted at the end of 2017 due to a cash shortage, and later acquired by Meituan (an online shopping giant in China) in February 2018.

- Attracting young generation and female uses (DBS users' characteristics)

Table 10
A comparison of basic information of different dockless shared bike brands – China.

Specification	Mobike		ofo	Hellobike	Bluegogo
	Mobike standard	Mobike Lite			
Weight	25 kg	17 kg	15 kg	16 kg	15 kg
Extra power supply	Pedal-powered	Solar panel	No	No	Solar panel
Lock	Automatic lock	Automatic lock	Manual lock for majority	Automatic lock	Automatic lock
Basket	Yes	Yes	No	Yes	No
GPS	Yes	Yes	No	Yes	Yes
Usage fee	CNY1/30 min	CNY0.5/30 min Hellobike offers free ride from 23:00 to 06:00			
Deposit	CNY299		CNY199	CNY199	CNY299
Manufacture cost per bike	CNY3000	CNY1000	CNY300	CNY900	CNY2000
Promotion	CNY20 for monthly membership - unlimited and free usage; ofo offers free deposit for campus users			CNY2 for monthly membership	N/A

Source: Information collected on homepage of DBS operators.

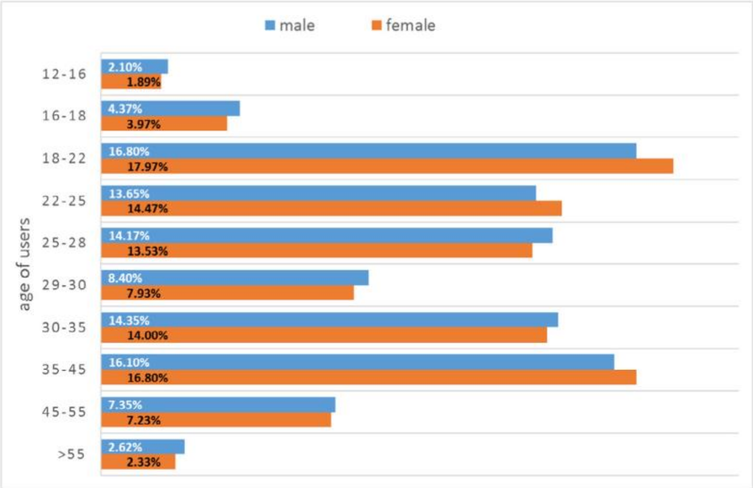


Fig. 9. Age distribution of national ofo users. *Source:* ofo and China Academy of Transportation Science (2018).

Globally, DBS seem to attract a particular profile of user: male, white, and employed compared to the average population in which BS are implemented. Younger, more affluent and more educated people are also more likely to be already engaged in cycling independent of bike sharing (Campbell et al., 2016; Fishman et al., 2014a; Shaheen et al., 2014; Shaheen et al., 2012). Murphy and Usher (2015) found that 70% of BS users in Dublin belonged to higher-income groups and acted positively to inspire cycling awareness.

Little academic research has been conducted to study users' characteristics of the new inovative DBS in the Chinese context. It appears that only one journal paper has been published that discusses DBS users' characteristics. Du and Cheng (2018) conducted a survey in Nanjing during a two-week period in October 2017 where a total of 4,939 valid questionnaires were analyzed. Overall, the gender difference was relatively slight; an overwhelming percentage of younger users was observed; over half the users had an undergraduate degree or above; users' educational background was higher than traditional BS users; and students and employees with less than CNY5000 month income were the main force of DBS users. This might be because young people with higher educational background are inclined to embrace new innovations and are more familiar with smart phone and social media use (which are highly integrated with DBS usage).

Additionally, the two leading DBS operators, Mobike and ofo, published their own industry reports, which also revealed users' characteristics. Considering the large number of users and fleets these two operators have (200 million users each, 8 and 10 million fleets, respectively, covering over 200 cities as of February 2018), their reports are substantially representative and persuasive.

According to ofo's annual report of 2017, their users comprised 57% males and 43% females (ofo & China Academy of Transportation Science, 2018), aged 18–45 years, which is almost the same as Du and Cheng (2018) found in Nanjing (for more details see Fig. 9).

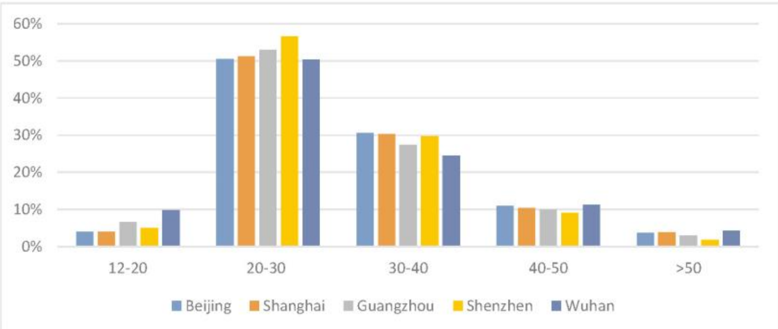


Fig. 10. Age distribution of Mobike users in selected cities. *Source:* Mobike Global et al. (2017); World Resources Institute et al. (2018); Mobike and Guangzhou Transport Institute (2017); Mobike and Wuhan Transport Institute (2017).

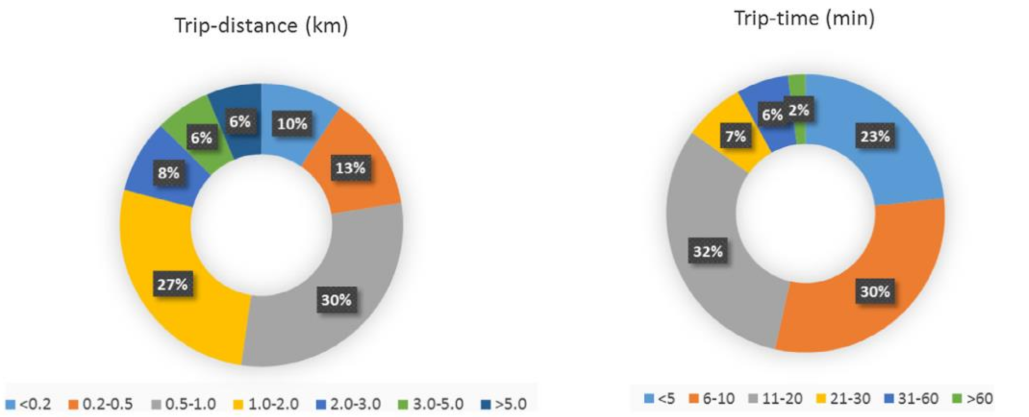


Fig. 11. Trip-distance and time distribution of ofo users. *Source*: ofo and China Academy of Transportation Science (2018).

In Mobike's newly published report, a more balanced gender distribution (51% male vs 49% females) was seen by analyzing its 200 million users in China (World Resources Institute et al., 2018). Age distribution in major cities was 20–40 years, as shown in Fig. 10, which is similar to ofo's findings.

Interestingly, these findings of gender difference are relatively balanced, which is inconsistent with some BS studies (Campbell et al., 2016; Karki and Tao, 2016) conducted recently in China, where male BS users comprised 62% and 72%, respectively. In a very recent study conducted in the same city, Nanjing (Ji et al., 2017), female users were found to use BS much less. One reason, stated by the author, is that females usually are engaged in household tasks such as grocery shopping and chauffeuring children and BS have no back seats or baskets for these tasks. The other reason is that women may have additional safety concerns when it comes to walking to bicycle docking stations and/or additional comfort-related concerns because all public bicycles in Nanjing have solid rubber tires with which any bumps or irregularities in the road may cause discomfort (Ji et al., 2017).

However, since the majority of DBS are equipped with baskets (see Table 10) and they are flexible to park and ride anywhere with a relatively comfortable cycling experience, it does attract more female users and this makes the cycling statistics more equal.

ofo's annual report revealed that the majority of trips are short (see Fig. 11) – 88% of the trips occurred within 3 km and 85% within 20 min (ofo & China Academy of Transportation Science, 2018). Mobike reported and analyzed 6 months of trip data (n = 120 million) to July 2017 in Wuhan. It revealed that most of the trips occurred within 3 km, 20 mins and at a speed lower than 15 km/h. This finding is very similar to ofo's report.

Wuhan users cycled twice a day by Mobike (Mobike & Wuhan Transport Institute, 2017), which was far more frequent than BS usage in both other cities China and at an international level (Fishman and Cherry, 2016) (see Table 11 Results of Mobike's report for Wuhan and Fig. 12 Daily Mobike trips per person in Wuhan. *Source:* Mobike and Wuhan Transport Institute (2017)).

A report covering 22 cities in South China (500 million trip records) revealed that 45% trips occurred during peak hours (7:00–9:30, 17:00–20:00) (Josh, 2017). Wuhan and Shanghai also witnessed two clear DBS usage peaks, indicating DBS are often used for commute-purposes (Mobike & Wuhan Transport Institute, 2017; Zhang and Mi, 2018).

The combination of easy access by smart phone, convenience to pick and park and the low cost of DBS usage attracts users from young, highly educated background groups, promotes a more gender equal cycling behavior, triggers more frequent bicycle trips of which most are short and for commuting purposes.

3.3.2. Factors winning partial support of government

BS is considered an environmentally-friendly transport mode that normally is subsidized by governments (Demaio, 2009). DBS increase cycling usage, enhance public transport and reduce motor-vehicle usage and green gas emissions; therefore, they were partially supported by governments. However, no systematic academic research has been conducted on DBS benefits. The conclusions cited below are mainly based on industry and government reports, which should be used cautiously.

Table 11
Results of Mobike's report for Wuhan.

Index	Value	Note
Average trip-distance (km)	1.69	86% of the trips are within 3 km
Average trip-time (min)	12.4	83% of the trips are 20 mins or less
Average trip-speed (km/h)	8.2	90% of the trips are within 15 km/h

Source: Mobike and Wuhan Transport Institute (2017).

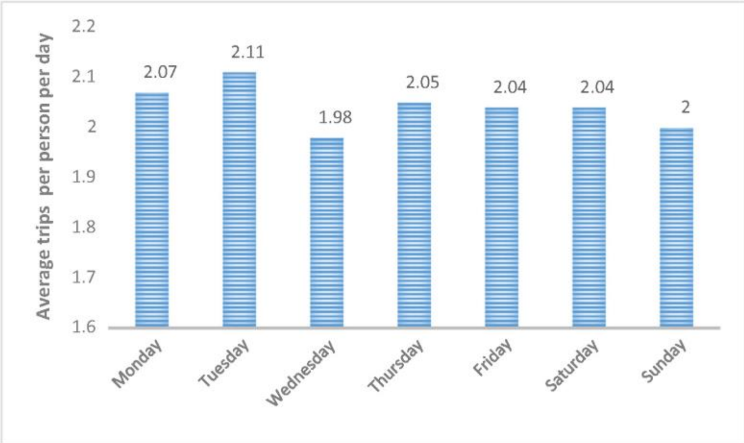


Fig. 12. Daily Mobike trips per person in Wuhan. *Source:* Mobike and Wuhan Transport Institute (2017).

- Revive cycling mode share

Interestingly, although the cycling share rate continued to decrease in major cities in China before 2016, cities with DBS, such as Beijing and Shenzhen, have witnessed an increase in cycling share rate since 2016 when the first DBS appeared in China. In Shenzhen and Beijing, from 2015 to 2017, the bicycle mode rose from 8% to 10.7% (see Table 12), and 9.8% of cyclists (over 1% of the total travelers) were once private automobile drivers (Yin et al., 2017). This finding is consistent with industry and government reports. In April 2017, Mobike and Beijing Tsinghua Tong Heng Planning and Design Institute (an urban planning consultancy) jointly released an industry report, which presented the change of cycling share. By surveying Mobike users and collecting urban transport data, cycling share doubled from 5.5% to 11.6% from 2016 to 2017 (Mobike Global et al., 2017). A report from Shenzhen's Transport Commission said that the city's 500,000 bike-share bicycles had replaced nearly 10% of travel by private car, and 13 percent of petrol consumption (Reid, 2018). Therefore, it is safe to conclude that DBS's emergence helps to substantially revive urban cycling.

- Enhance interchanging with public transport

In a survey (n = 4,939) conducted in Nanjing, 51.13% of the users were found to use DBS to transfer to subway stations (Du and Cheng, 2018). According to a series of Mobike city reports, 81% of the Mobike trips in Beijing started around a bus station and 44% trips started near a subway station (within a 500 m catchment), while in Shanghai, the number was 90% and 51%, respectively (Mobike Global et al., 2017). In Guangzhou, 63% of Mobike trips were to interchange with public transport. The analysis of 120 million trip records in Wuhan found that among all the interchange modes to subways, cycling increased significantly after DBS was introduced, as can be seen in Fig. 13. It is stated that for 48% of all the subway stations, 10% of the subway passenger flow are fed by Mobike users (Mobike Global et al., 2017). This finding is consistent with what happened when DBS was introduced in Shanghai (Shanghai Urban and Transport Research Institute, 2018).

- Reduce motor-vehicle usage and green gas emissions

Table 12
Bicycle mode split in some Chinese cities over 3 decades.

Beijing		Shanghai		Guangzhou		Wuhan		Nanjing		Suzhou		Shenzhen	
Year	Mode split	Year	Mode split	Year	Mode split	Year	Mode split	Year	Mode split	Year	Mode split	Year	Mode split
1986	67.0%	1981	30.5%	1984	34.1%	1987	35.3%	1986	44.1%	N/A	N/A	1985	44%
1995	41.18%	1995	41.2%	1998	21.5%	1998	29%	1999	41.0%	1996	63.7%	1995	21.8%
2005	30.3%	2005	30.3%	2006	14.0%	2003	19.2%	2007	40.1%	2009	11.1%	2001	14.3%
2015	12.6%	2015	12.6%	2015	8%	2016	18%	2015	28.8%	2015	4.5%	2015	8.0%
2016	13.5%	2017	N/A	2016	N/A	2017	N/A	2015	N/A	2017	2.6%	2017	10.7%

Note. The mode split of Nanjing comprises both bicycles and E-bikes. In cities with available 2017 data, Beijing and Shenzhen had DBS while Suzhou has no DBS. *Source:* Dayi et al. (2001); Frame et al. (2017); Shanghai urban and rural construction and Transportation Development Research Institute (2015); Ltd. Nanjing Institute of City & Transport Planning Co. (2017); Gao et al. (2016); Beijing Municipal Commission of Trasnport (2016); Zhang et al. (2014); Suzhou Planning Bureau (2018); Qian and Zheng (2012); Yin et al. (2017).

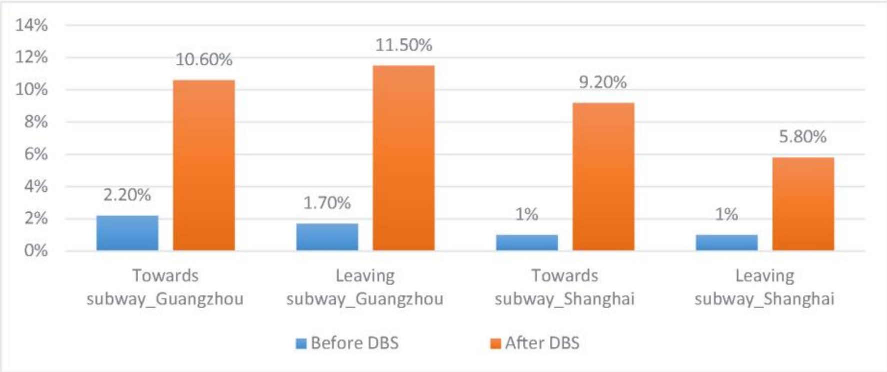


Fig. 13. Cycling share to interchange and to subway before and after the introduction of DBS. *Source:* (Shanghai Urban and Transport Research Institute, 2018); Mobike and Wuhan Transport Institute (2017).

There are many grey papers in the literature about DBS's substitution of motor vehicles and its benefit to the environment in China, however, few academic papers have been produced. By analyzing the Mobike data in Shanghai (1,023,603 trip records made by 306,936 users for 17,688 fleets in August 2016), a quantitative evaluation of environmental benefits of DBS was produced, which found DBS in Shanghai saved 8,358 tonnes of petrol and decreased CO2 emissions by 25,240 tonnes in August 2016 (Zhang and Mi, 2018).

A report of traffic analysis in major cities in 2017Q1, produced by AMAP, a major online map provider, indicated that short distance trips (5 km or less) by motor vehicles in Beijing and Shanghai reduced sharply 9 months after the introduction of DBS (Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China), 2017a). A report from Shenzhen's Transport Commission said that the city's DBS had replaced nearly 10 percent of travel by private car, and 13 percent of petrol consumption (Reid, 2018). A series of surveys of Mobike users in Shanghai and Beijing indicated a significant decrease in car usage after DBS was introduced; users reported that the number of trips by car (including trips by private cars, taxi, and car-hailing apps) decreased by 55% (Mobike Global et al., 2017).

By April 2017, cycling by Mobike was reported to reduce carbon emissions by 0.54 tonnes, save 460 million liters of petrol while the reduction in carbon emissions rose to 4.4 million tonnes by the end of 2017 (Mobike Global et al., 2017; World Resources Institute et al., 2018). By the end of 2017, cycling by ofo was reported to reduce carbon emissions by 4.22 million tonnes and saved 1.41 million tonnes of petrol (ofo & China information and Communication Research Institute, 2018a).

3.3.3. Factors promoting operators' supply

There is no denying that the rapid growth of DBS was mainly a consequence of commercial activities. As a commercial activity, DBS operators are undoubtedly profit-oriented. If there is profit gained by increasing their fleet, operators are inclined to over-supply DBS fleets. Taking Shanghai as an example and based on official data, DBS operators deployed 1.7 million DBS bicycles in Shanghai as of Sep, 2017. Experts from the Shanghai Bicycle Association said that the city only had capacity for up to 0.8 million bicycles (Yamei, 2017; Wenting Zhou, 2018). The existing fleets far exceeded the capacity and caused DBS "congestion". The question is why operators kept deploying new fleets. The major reasons behind the increases were the lure for new deposits and users, and the effort to reduce maintenance costs.

Undoubtedly, DBS operators distribute bicycles to make money, that is, by attracting new investment, by charging a rental fee and by attracting more new users to get deposit in which the first one is highly dependent on the latter two. However, many analysts have stated that DBS companies are unable to make a substantial profit from a rental fee alone (Scott, 2017; Tao, 2017). Some financiers argued in the early days of the industry that each new bicycle in a company's inventory would bring in between six and 10 new users. This rate has dropped, however, as more brands entered the DBS market. A report issued by the China Internet Network Information Center in August 2017 estimated that users may have paid CNY10 billion (USD1.6 billion) in deposits for BS (Zheng, 2018). Mobike, for instance, held around CNY900 million in customer deposits at the end of 2016 (Tao, 2017). This huge pool of idle funds could make interest to help companies improve their services or to reinvest. Also, the withdrawal process for users to retrieve their deposits is usually very complicated and time-consuming. Meanwhile, users are normally unwilling to pay multiple deposits. In other words, once they choose a brand of DBS, they usually remain loyal to it. Therefore, to maintain high growth rates, the industry's real battle is the fight for new users. Therefore, BS companies must constantly expand to new areas. That explains why DBS companies continue to distribute DBS regardless of real demand.

On the other hand, a simple operating financial model also helps to increase new bicycles. It is accepted that while manufacturing expenses vary by company, shared bikes cost from CNY300 to 3,000 (USD45 for ofo, USD400 for Mobike's regular version). However, the majority of bicycles are actually cheaper (CNY < 500). Since there is an inverse relationship between manufacturing costs and maintenance costs, cheaper bikes break more easily and repairing them often costs more than a new bicycle (Tao, 2017). In other words, for a lot of cheap fleets, such as ofo and Mobike lite, it is cheaper to buy a new bicycle than to fix a broken one, which makes the whole system grow bigger and bigger.

To sum up, despite user factors, governments are inclined to promote DBS development, because they function as indirect drivers of DBS growth, but more importantly, they take a relatively long time to make any effect. The direct, dramatic rapid growth of DBS is mainly activated by commercial actors driven by profits. This statement could be indirectly proven when DBS supply began to exceed the capacity and users' demand, because at that time DBS operators had been already losing local government support and complaints had already been made about DBS "congestion". From both a quantitative study of city DBS supply and capacity given in last section (see Fig. 5) and inferential reasons behind rapid expansion of DBS operators discussed above, it is safe to argue that the rapid growth of DBS is **mainly supply-driven by operators rather than by user demand or triggered by government policy.**

3.4. Challenges of DBS development

3.4.1. DBS "congestion" and its impact on DBS development

The rapid growth of DBS also caused some problems. The most common criticism was DBS "congestion" — the appearance of bikes scattered randomly outside subway stations and office buildings, blocking the sidewalks and forcing pedestrians to walk among traffic on busy roads (Tao, 2017; Wenting, 2017). It is due to the over-supply of DBS operators as was shown in Fig. 5. For example, the official data found there were 1.7 million shared bicycles in Shanghai as of Sep, 2017. Experts from the Shanghai Bicycle Association said that the city only has a capacity for up to 800,000 bicycles (Yamei, 2017; Wenting Zhou, 2018). Therefore, from August 2017, Shanghai began to limit the deployment of new DBS fleets (policies will be discussed in the next section), which was instantly followed by cities such as Beijing, Guangzhou, and others. Meanwhile, although the base number of DBS fleets is still huge, a growing number of "sleepy" fleets emerged when old DBS fleets were broken, or operators bankrupted. As a consequence of decreasing fleets and new government reinforcement and limitations on new bicycles, the number of active city DBS fleets decreased slightly and has remained stable since the end of 2017. The news has reported that active DBS bikes in Hangzhou have fallen to 690,000 from almost 800,000 (CCTV finance and Economics, 2018), while Beijing also reduced its active DBS bicycles to 190,000 (by 20%) (Yue, 2018; Zhao, 2018), and the European Bicycle Manufacturers Association also reported that active DBS reduced in Shanghai (European Bicycle Manufacturers Association, 2018). However, since DBS "congestion" is mainly reported in large cities (see Fig. 14), little is known about the exact reduction of active DBS bicycles nationally.

3.4.2. Financial sustainability

The biggest challenges that stop further DBS development are DBS "congestion" and the industry's financial sustainability. As discussed before, the negative impact of casual parking of DBS bikes that impede the urban environment and block pedestrian and bus/train station access could be seen as a violation of non-DBS users' rights. If DBS operators cannot control this random parking, tougher regulations are inevitable from local governments. Counter-measures include setting up a close communication mechanism between authorities and DBS operators, regulating and enhancing maintenance and adopting hi-tech applications such as electronic-fences (particular areas where shared bikes are allowed to park, and if parked beyond these areas, shared bikes are disabled or users fined when parked) (Wenting, 2017).

However, to truly answer this "congestion" problem caused by over-supply, operators must find a sustainable way to make money other than with over-supply of fleets. Otherwise, DBS will continue to jeopardize urban space, but more importantly, more bankrupt fleet owners will occur due to unsustainable financial issues (this has already happened to over 20 operators, including the third

Fig. 14. Residents try to pedal through a sidewalk crowded with bicycles from the DSB operators ofo, Mobike and Bluegogo in Beijing, China, March 23, 2017. Source: Dierking (2017).

biggest one Bluegogo) in 2017. Therefore, business and financial models must be well-studied before DBS systems are implemented in the future.

3.4.3. Vandalism and sleepy fleets

Theft and vandalism problems occurred when the first generation of shared bikes known as 'white bikes' were launched in 1965 (Demaio, 2009; Susan A. Shaheen et al., 2010). The adoption of third generation BS with locking mechanisms and smart card technology has reduced theft and vandalism. Studies have shown that theft and vandalism are not regarded as major barriers to current BS systems (Shaheen et al., 2014). Third generation BS systems in Hangzhou and Montreal have experienced relatively low theft and vandalism problems (Midgley, 2011).

Since there are no fixed stations for DBS, the vandalism phenomenon seems to be more serious. It has been reported that in the first month of introduction of Mobike, about 10% of the 20,000 Mobike bikes in Guangzhou had been damaged to varying degrees (Xiaoxi, 2016). Even overseas DBS operators, such as Obike, suffered similar problems in Melbourne during the first month they began operation, and finally they chose to close their Melbourne business rather than pay to retrieve the abandoned bikes (King, 2018). It was also reported that more than a third of the fleet was vandalized in the first 10 days of Mobike's operation in Stockport, UK (Angus, 2018).

However, it seems this only happens in the early phase of DBS development. In one of the few academic studies, Spinney and Lin (2018) analyzed the impact of the new DBS on social, spatial and environmental development. They mentioned that although the scale of the vandalism problem had led to the highly publicized collapse of some DBS operators such as WuKong bike (one operator that was bankrupted in 2017) that had 90% of its fleet damaged or lost within 5 months of operation, none of the operators the authors interviewed had problems of this magnitude, although the scale of fleet loss is largely unknown. As a matter of fact, when cases of vandalism are well publicized the vandalism may reduce because people see DBS fleets as part of everyday life. ofo in Shanghai was reported to have had a much lower vandalism rate in 2018 compared to a year earlier (Yan Zhou, 2018), which might be the consequence of mature regulations. Overall, vandalism is often serious in the first stage of DBS development, but long-term it is largely unknown while some evidence suggests it might decrease. Since it is a common problem and usually draws abundant social attention, more studies should be initiated to answer the reasons and give reasonable suggestions to improve the problem.

3.4.4. Threat to bicycle industry

Against many people's instinct, the DBS boom did not result in high profits to local bicycle manufacturing. It is reported that some traditional Chinese bicycle manufacturing factories have claimed that the spectacular growth of DBS has disrupted their supply chain and has placed constraints on their business models (Ben, 2017). For example, ofo ordered 5 million bicycles from the producer Phoenix in 2018 which made them Phoenix's largest customer with a position of advantage in this contract (Fehr and Macho, 2018). This causes overcapacities in the market due to the large number of DBS operators and could lead to two risks – **low profits for local manufacturers and fragility of the entire industry**.

Since DBS operators have a stronger position in negotiating prices with manufacturers, they could ask for lower prices. According to a report from the European Bicycle Manufacturers Association, overall sales of bicycles have decreased in China. In some regions the total sales volume in the local market declined by 60 or even 70 percent, forcing providers to shut down or to look overseas to make profits (European Bicycle Manufacturers Association, 2018). More importantly, the entire bicycle industry in China is highly connected to DBS now. By the end of 2017, 23 million DBS fleets were deployed on the streets, while the overall manufacturing productions of all two-wheeled bicycles was 58.99 million (see Table 13). Since most of the DBS fleets are domestic made, it means new DBS fleets increased 10 times in 2017 while total bicycle products only rose 11.2%, and the total amount of products slightly increased to 11.23%. In other words, DBS took up a large proportion of manufacture which was once occupied by other bicycle types. It brings potential but great risks to maintain a healthy market. If any disturbance (harsher policy for instance) happens to DBS, the whole industry-chain would be affected. When Bluegogo went bankrupt in November 2017 it left behind a debt of USD1.51 million for a local bicycle supplier (Reid, 2017). After all, who can guarantee that Mobike and ofo, the two biggest operators holding the largest manufacturing contracts, can stay forever in this market?

3.4.5. Suggestions on development of DBS

Policy makers play a critical role to maintain a healthy DBS and overall transport development. Based on the challenges presented in the above section, some general suggestions are made here to promote a sustainable DBS development.

For central government of China, it is well-advised to set some general national guidelines. For instance, central government could

Table 13
Manufacturing production of bicycle and DBS fleets deployed in 2016 and 2017.

Year	DBS fleets deployed (million)	Total two-wheel bicycle products (million)	Percentage
2016	2	53.03	3.8%
2017	23	58.99	39.0%
Growth rate	1050%	11.23%	926%

Source: China Bicycle Association (2017) and China Statistic Yearbook (1985–2012); Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China) (2017b).

promote a general guide on how to evaluate the feasibility of DBS, to estimate the proper scale of DBS, and release national regulations on important and general issues (e.g. mandatory insurance to protect users; market access rules; deposit return policies, etc.)

For local governments of China, for urban planners, they are well-advised to do more detailed work on evaluating suitable DBS program, coordinate public transport, BS and DBS operators to promote a positive interact between these three. For instance, they should evaluate feasibility of DBS, estimate the market scale and make proper plan before DBS floods in. If the DBS have been already over-supplied, local authorities need to restrain the scale to a proper level and supervise the operators to avoid bike "congestion". Besides, they are to coordinate DBS and public transport operators, promote DBS and public transport interchange by giving price discount or offering convenient service (e.g. integrate DBS and public transport in the same APP). Furthermore, local regulations should be studied and released on safety and operation issues before DBS opens (e.g. penalties on DBS blocking the pedestrians, assigning places for depositing bikes, etc.).

Urban planners should guide DBS operators to deploy bikes in remote areas (normally with limited traffic mode choice but sufficient public space supplies) to complement public transport service. In central areas, where traffic mode options are abundant but public space are usually limited, DBS bike supplies should be controlled to avoid bike "congestion". Government should ask DBS operators to provide necessary data for future research and policy-making decision to make this guide more reliable.

It is also local governments' responsibility to balance the development between BS and DBS, especially subside and support BS if necessary (e.g. in communities with aged users, BS are more popular than DBS since many old people cannot use smart phones)."

As for overseas counterparts, some of them (e.g. Melbourne) are suffering problems as vandalism. Normally as time goes by, these problems will mitigate. Still, some general suggestions are given here. The first one is to carefully evaluate the feasibility of docked or dockless bikeshare and choose a suitable one (see the following Section 3.5). A pre-evaluation is crucially important, once the city is open to DBS without regulations, it could be flooded in very short time, as we could see from cities in China. Some effective methods that have already been used in China (e.g. electric fence to restrain parking areas and avoid random parking behaviors) could be introduced in advance to avoid bike "congestions". The legislation should also be optimized, especially in safety issues. For instance, the minimum age to rent DBS as well as the participants' (users, operators, supervision authorities) responsibility in DBS accidents should be clarified. Moreover, for those automobile-dominated cities with insufficient bike lanes and limited parking spaces, they are well-advised to build much safer cycling infrastructure to embrace a higher cycling rate that usually comes along with DBS. Finally, city authorities are suggested to coordinate and promote the integration between DBS and public transport operators.

3.5. Comparison between docked and dockless bikeshare

When dockless bikeshare (DBS) prevailed, it shocked the docked bikeshare (BS) market and brought different consequences. Some cities, as Shenzhen, Wuhan, Chengdu, etc., which used to have substantial BS scales (as indicated in Table 1), ceased BS operation in less than one year after DBS entered. However, Hangzhou and Zhuzhou, on the hand, while open to dockless bikeshare market, maintained a high docked bikeshare usage rate and kept increasing BS scales. For instance, as shown in Table 4, Hangzhou has the 3rd highest DBS penetration while it owns the highest BS penetration as well among top BS and DBS cities.

Since docked and dockless bikeshare now co-exist in many cities, and dockless bikeshare keeps emerge in new cities, it is meaningful to discuss these two systems' feasibility in terms of different conditions. Based on case studies we discussed before (cities in China and overseas countries as well), a brief, general comparison between docked and dockless bikeshare is firstly proposed in this section and feasibility discussion is followed.

Firstly, based on what we discussed before, main characteristics (merits and demerits included) of these two systems are summarized in Table 14. Dimensions from the markets, governments, users and operators are successively listed in this table.

Overall, DBS is growing fast in these two years and have a much larger market scale. BS have overall merits in public affairs areas except for larger financial burden for local governments, which has been elaborately indicated in former Section 2.2. As for users, while the DBS offers great convenience, it usually charges more and is not so friendly to the elderly. For operators, while DBS has the advantage of higher potential profit and less supervision pressure from government, the risk from vandalism is higher. Huge capital investment needed in DBS also means only limited operators could run DBS, and they take large investment risks which makes the immature (DBS only emerged two years earlier) DBS market fragile.

According to the table above, some conclusion could be made about the feasibility of these two systems. The author organized a table (see Table 15) and give a general recommendation. For instance, for cities with low cycling rate and high motor vehicles rate, it is better to choose BS. As a public service, the lower price and stronger governmental control could ensure BS aims to improve a sustainable and green transport environment. In cities with mature cycling tradition, to promote more cycling, new DBS might be more attractive. Besides, DBS are normally deployed in mega cities to achieve more profits. This is also proven from a global point of view - Mobike entered London, Singapore, Washington, D.C., Obike entered Melbourne, etc., while no small cities or towns with low population had DBS so far (Mobike, 2017; Shen et al., 2018). Furthermore, as could be seen in Tables 2 and 4, low pricing policy is higher related to prevalence of BS market, e.g. higher pricing cities as Paris, Washington, D.C. has lower BS penetration compared to China's cities. Therefore, in cities deployed with BS, to ensure it is successful, low pricing policy should be made. For governments, as could be seen in Tables 2 and 4, low pricing policy is higher related to prevalence of BS market, e.g. higher pricing cities as Paris, Washington, D.C. has lower BS penetration compared to China's cities.

4. Conclusion

Based on up-to-date empirical analysis, this paper discussed recent development of bicycle transport in China, especially the new

Table 14
Comparison between docked and dockless bikeshare.

Entity	Section	Docked bikeshare (BS)	Dockless bikeshare (DBS)
Market	Market scales and development	Relatively small and slow - 430 programs and 1.90 million bikes in China - 1.328 programs and 2.29 million bikes globally - Average penetration rate 0.38% in top BS cities in China (see Table 4) - Annual growing rate at 152.8% since 2010	Relatively large and rapid - 200 programs, 23 million bikes, 221 million registered users in China - 225 programs, 227 million registered users globally - Average penetration rate 7.53% in top BS cities in China (see Table 4) - Annual growing rate at 152.8% since 2010 - Emerged in April 2016
Government	Public service function	Strong - Most of the successful BS are non-profit-oriented, subsided - Dedicated to improve urban transport, e.g. to promoting cycling and reducing automobile usage	Weak - Most of the DBS are profit-oriented - They don't have the responsibility to fulfill green and sustainable urban transport
	Environment impact (e.g. "bike congestion")	Low	High
	Governmental attitude	Positive	Neutral-negative
	Financial burden for governments	High - Need substantial subsides	Low - Run by private operators
	Requirement of transport infrastructure	Low - Limited changes on present infrastructure	High - More public space (streets, pedestrians) to park and cycle
	Market scales (population) threshold	Low - All scales cities inducing medium and small cities	High - Mostly in mega cities due to scale economy effect to sustain private operation
	Legislation challenge	Easy - Mature legislation	Complicated - Market access, safety issue, punishment for impacting urban environment
User	Convenience for users	High - Limited stations, long walking distance required	Low - Flexible paring and picking places, less walking distance
	Usage price for users	Cheap or Free - Most users used BS in less than 1 h, which is within free cycling time.	Relative Expensive - No free cycling time - Usage fee and deposit are higher than BS
	Elderly friendly	Yes - Swipe cards, easy for old people	No - Mobile phones and APP needed, not easy for old people
Operator	Government supervision	Strong	Relative weak
	Potential profit	Low	High
	Capital scale	Low	High
	Risk of vandalism	Low	Very High

Table 15
Recommendation of bikeshare system in different cities.

Recommendation	Docked bikeshare (BS)	Dockless bikeshare (DBS)
Mode share rate	Low cycling rate and high motor vehicles rate cities	Higher cycling rate cites
City finance	Abundant government budget	Limited government budget
Scales of market (population)	Medium and small scales of market (population)	Large scales of market (population)
Cycling infrastructures	Limited cycling infrastructure and public space conditions	Good cycling infrastructure and public space conditions
Government capability on controlling and surprising DB operators	Limited government power to control and surprise DB operators	Strong government power to control and surprise DB operators

innovative DBS programs.

The first government-oriented DBS program was initiated in Hangzhou in 2008 and 10 years later it is the largest in the world. In fact, China has the largest bikeshare in the world (2 million fleets, covering 400 cities and regions). By comparing classic city bikeshare in China with its overseas counterparts, it is found that a government-oriented operator model plus a low financial threshold to users are the keys to the success of city bikeshare.

However, in less than 2 years, a new DBS system in China grew from nothing to a substantial size (23 million fleets, covering over 200 cities and regions) making the docked BS system insignificant. This innovative, flexible, shared cycling mode is a highly capital-driven, privately-operated business mode, largely deployed in cities with urban railway systems and has achieved high penetration in mega cites. Three growth phases have been identified based on government policy and DBS's development, namely the "free growth" phase, the "regulated" phase and the "limited" phase. While the central government initially held "**neutral-positive**" policy towards this new industry, the rapid expansion of dockless fleets soon exceeded cities' limits, and local government policies changed from "**neutral-positive**" to "**neutral-negative**", and finally a number of banning regulations were issued from August 2017 to stem the ever-growing number of bikes.

DBS systems are found to have penetration advantages such as easy access by smart phone, convenience of pick and park and low cost. These merits successfully attract its main users, who are found to be young, highly educated and almost equally male and female. The trips are mainly short, highly frequent and for commuting purposes. To understand the reasons behind the burgeoning of DBS systems, three factors have emerged: (1) those promoting user demands, (2) those winning partial support of government, and (3) those promoting operators' supply are analyzed. The results show that this rapid growth is mainly supply-driven by operator rather than by user demand or triggered by government policy. Financial sustainability, vandalism and the threat of DBS to the bicycle industry are the three main challenges that require investigation in the future, especially, the booming DBS market that may cause low profitability for local bicycle manufacturers and thus make the entire industry fragile.

By a general comparison between BS and DBS, we conclude that BS and DBS have their own merits and demerits. Cities with different background (finances, population scales, aims, etc.) need to find the suitable one. For instance, in medium, rich cities with high motor-vehicle share rate, BS could be a better choice to attract cycling and promote green transport. However, in mega cities with abundant transport choices and good cycling facilities, if local governments have strong supervision and control ability over DBS operators, DBS might be a better opinion.

Overall, Pucher and Buehler (2008) stated in "Making Cycling Irresistible: lessons from The Netherlands, Denmark and Germany", "The success of cycling does not depend on poverty, dictatorial regimes or the lack of motorized transport options to force people onto bikes". When we look back at the evolution of human mobility, cycling has always found a place. As a healthy and sustainable mode of transport, once an appropriate and innovative business model for DBS is found and introduced, people will choose to cycle, and cycling will continue.

Acknowledgments

This work was supported by Jiangsu Industrial Technology Research Institute.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tra.2018.11.007.

References

Alex, Baca, 2018. What Cities Need to Understand About Bikeshare Now. Retrieved from. https://www.citylab.com/transportation/2018/04/a-complete-taxonomy-of-bikeshare-so-far/558560/.

AllTechAsia, 2018. Can popular Chinese bike-sharing startups Mobike & Ofo replicate their success overseas? AllTechAsia. Retrieved from. https://medium.com/@actallchinatech/can-popular-chinese-bike-sharing-startups-mobike-ofo-replicate-their-success-overseas-d2ecb42bd537.

Andrew Archibald Campbell, 2012. Factors Influencing the Choice of Shared Bicycles and Electric Bicycles in Beijing–A Stated Preference Approach.

Angus, Mcneice, 2018. Vandalism a bump in road for bike-sharing. China Daily. Retrieved from http://www.chinadaily.com.cn/a/201804/17/WS5ad538c0a3105cdcf6518a09.html.

Bachand-Marleau, Julie, Lee, Brian, El-Geneidy, Ahmed, 2012. Better understanding of factors influencing likelihood of using shared bicycle systems and frequency of use. Transportation Res. Rec. J. Transportation Res. Board 2314, 66–71.

BBC, 2017. Beijing bans new bikes as sharing schemes cause chaos. BBC. Retrieved from https://www.bbc.com/news/business-41197341.

Beijing Municipal Commission of Trasnport, 2016. Beijing's fifth comprehensive traffic survey report. Retrieved from. http://www.bjjtw.gov.cn/.

Beijing Municipal Institute of City Planning & Design, 2018. Report of preliminary assessment of Beijing Internet Rental Bike and E-Bike 2018 (in Chinese). Retrieved from.

Bland Ben, 2017. China's bicycle-sharing boom poses hazards for manufacturers. Financial Times. Retrieved from https://www.ft.com/content/bfba9f6e-299c-11e7-9ec8-168383da43b7?mhq5j=e3.

Beroud, Benoit, Clavel, Robert, Le Vine, S., 2010. Perspectives on the growing market for public bicycles focus on France and the United Kingdom. Paper Presented at the European Transport Conference. Glasgow, Scotland. 11th October.

Bikesharingmap, 2017. The Bike-sharing World Map Retrieved from www.bikesharingmap.com. www.bikesharingmap.com.

Bo, Tan, 2017. A reflection on municipal regulations to supervise "bike- sharing"—— a comparative study of a dozen cities. J. Jianghan Univ. (Social Sci. Ed.).

Böcker, Lars, Dijst, Martin, Prillwitz, Jan, 2013. Impact of everyday weather on individual daily travel behaviours in perspective: a literature review. Transport Rev. 33 (1), 71–91.

Buehler, Ralph, Pucher, John, Gerike, Regine, Götschi, Thomas, 2017. Reducing car dependence in the heart of Europe: lessons from Germany, Austria, and Switzerland. Transport Rev. 37 (1), 4–28. https://doi.org/10.1080/01441647.2016.1177799.

Cai, Minjie, 2017. Guangzhou Shared Bike has reached 8 million, new increase is officially banned. Sina News. Retrieved from http://news.sina.com.cn/o/2017-08-03/doc-ifyitayr8906690.shtml.

Campbell, Andrew A., Cherry, Christopher R., Ryerson, Megan S., Yang, Xinmiao, 2016. Factors influencing the choice of shared bicycles and shared electric bikes in Beijing. Transportation Res. Part C: Emerging Technol. 67, 399–414. https://doi.org/10.1016/j.trc.2016.03.004.

CCTV finance and Economics, 2018. Dockless shared bike - from madness to the rational development. CCTV finance and Economics. Retrieved from http://op.inews.qq.com/m/20180610A1KJUA00?refer=100000355&chl_code=kb_news_hotnews&h=0.

Chan, Chak K., Yao, Xiaohong, 2008. Air pollution in mega cities in China. Atmos. Environ. 42 (1), 1–42. https://doi.org/10.1016/j.atmosenv.2007.09.003.

China Bicycle Association, 2017. Bicycle Industry Report 2016. Retrieved from. http://www.china-bicycle.com/.

China Urban Railway Transport Association, 2018. Annual Statistical Report of China Urban Railway Transport Retrieved from http://www.camet.org.cn/.

Dayi, Qu, Zhongchen, Yu, Jinsong, Zhuang, 2001. Study of Suzhou presidents' transport characteristics (in Chinese). J. Southeast Univ. (Natl. Sci. Ed.) 31.

Demaio, Paul, 2009. Bike-sharing: History, impacts, models of provision, and future. J. Public Transportation 12 (4).

Demaio Paul, 2017. The bike-sharing blog. The Bike-sharing World at the End of 2016.

Dierking, Phil, 2017. New Bike Share Apps in China Create Bike 'Revolution'. VOA. Retrieved from https://learningenglish.voanews.com/a/new-bike-share-apps-n-china-create-bike-revolution/3894394.html.

Ding, Wei, 2016. The Relationship of Built Environment and Weather with Bike Share–Evidence from the Pronto Bike Share System in Seattle.

Dowling, Savannah, 2018. Regulation looms in booming, competitive bike-sharing space. Crunchbase News. Retrieved from https://news.crunchbase.com/news/regulation-looms-booming-competitive-bike-sharing-space/?utm_source = cb_daily&utm_medium = email&utm_campaign = 20180108&utm_content = intro&utm_term = content&send_email = –Email–.

Du, Mingyang, Cheng, Lin, 2018. Better understanding the characteristics and influential factors of different travel patterns in free-floating bike sharing: evidence from Nanjing China. Retrieved from. Sustainability 10 (4), 1244. http://www.mdpi.com/2071-1050/10/4/1244.

European Bicycle Manufacturers Association, 2018. BIKE SHARING IN CHINA - Chinese Market Situation. Retrieved from. http://ebma-brussels.eu/bike-sharing-in-china/.

Fehr, von Mark, Macho, Andreas, 2018. Der Leihrad-Boom erfasst die Großstädte. Retrieved from. WirtschaftsWoche.

Fishman, Elliot, 2014. Bikeshare: barriers, facilitators and impacts on car use. Bicycle.

Fishman, Elliot, 2016. Bikeshare: A review of recent literature. Transport Rev. 36 (1), 92–113.

Fishman, Elliot, Cherry, Christopher, 2016. E-bikes in the mainstream: reviewing a decade of research. Transport Rev. 36 (1), 72–91. https://doi.org/10.1080/01441647.2015.1069907.

Fishman, Elliot, Washington, Simon, Haworth, Narelle, 2012. Barriers and facilitators to public bicycle scheme use: A qualitative approach. Transportation Res. Part F Traffic Psychol. Behav. 15 (6), 686–698.

Fishman, Elliot, Washington, Simon, Haworth, Narelle, Mazzei, Armando, 2014b. Barriers to bikesharing: an analysis from Melbourne and Brisbane. J. Transp. Geogr. 41, 325–337.

Fishman, Elliot, Washington, Simon, Haworth, Narelle, 2014a. Bike share’s impact on car use: Evidence from the United States Great Britain, and Australia. Transportation Res. Part D: Transport Environ. 13–20.

Fishman, Elliot, Washington, Simon, Haworth, Narelle, Watson, Angela, 2015. Factors influencing bike share membership: An analysis of Melbourne and Brisbane. Transportation Res. Part A: Policy Practice 71, 17–30.

Frame, Gladys, Ardila-Gomez, Arturo, Chen, Yang, 2017. The kingdom of the bicycle: what Wuhan can learn from Amsterdam. Transp. Res. Procedia 25, 5040–5058. https://doi.org/10.1016/j.trpro.2017.05.203.

Fratila, Sabina, 2018. 2017 – the year bike sharing went crazy. Retrieved from. https://www.donkey.bike/2017-bike-sharing-went-crazy/.

Gao, Song, Zheng, Meng, Yang, Zhao-zhao, Wang, Wei, 2016. The implementation of planning management to promote pedestrian and bicycle transportation system rejuvenation —— development strategies for pedestrian and bicycle transportation system in Wuhan (in Chinese). Traffic Transportation.

Gauthier, A., Hughes, C., Kost, C., Li, S., 2013. The bike-share planning guide. ITDP Report.

Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China), 2017a. The Development and Policy Recommendations for Dockless Bike Share (DBS) in China. Retrieved from http://www.itdp-china.org/dbs/index/#/getcompany/2.

Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China), 2017b. Non-motro vehicle transport bluepaper. Retrieved from http://www.itdp-china.org/enpublication/?lang = 0.

Guodong, Feng, Jun, Chen, 2017. Wuhan public bike service closed - due to the dockless shared bike (in Chinese) Retrieved from. Xinhua.

Benjamin Haas, 2017. Chinese bike share graveyard a monument to industry's 'arrogance'. The Guardian. Retrieved from https://www.theguardian.com/uk-news/2017/nov/25/chinas-bike-share-graveyard-a-monument-to-industrys-arrogance.

Hangzhou Comprehensive Transportation Research Center, 2018. Research Report of Hangzhou Internet Rental Bike Development (in Chinese). Retrieved from. http://www.zj.gov.cn/art/2018/4/9/art_13104_2273829.html.

Hong Mo, 2017. Beijing gears up technical, parking rules for shared bikes. China Daily. Retrieved from http://www.chinadaily.com.cn/china/2017-11/01/content_33969945.htm.

Horwitz, Josh, 2017. Chinese cities are saying "enough already" to bike-sharing services run rampant. Retrieved from. https://qz.com/1058438/chinese-cities-saying-enough-already-to-chaos-generated-by-bike-sharing-services-like-ofo-and-mobike/.

iiMedia Research Institute, 2017. 2017 Q1 China Shared Bike Market Research Report. Retrieved from. http://www.iimedia.cn/50357.html.

Institute for Transportation & Development Policy (ITDP), 2018. The Bikeshare Planning Guide (2018 edition). Retrieved from https://www.itdp.org/publication/the-bike-share-planning-guide/.

Institution for Transportation & Development Policy, 2017. Shared Bike System Information Institution for Transportation & Development Policy.

Jao, Nicole, 2018. Beijing rolls out electronic fences and reinforces parking guidelines for bike rentals. Retrieved from. TechCrunch.

Ji, Y., Fan, Y., Ermagun, A., Cao, X., Wang, W., Das, K., 2017. Public bicycle as a feeder mode to rail transit in China: The role of gender, age, income, trip purpose, and bicycle theft experience. Int. J. Sustain. Transportation 11 (4), 308–317. https://doi.org/10.1080/15568318.2016.1253802.

Jiang, Hui, 2018. http://www.wri.org/blog/2018/01/chinese-cities-aim-rein-bike-sharing-boom. Retrieved from http://www.wri.org/blog/2018/01/chinese-cities-aim-rein-bike-sharing-boom.

Jiapeng, Liu Chen, Qian, Chen, Boquan, 2017. Public bike might get retired because of dockless shared bike? (in Chinese). Retrieved from http://shenzhen.sina.com.cn/news/s/2017-12-24/detail-ifypxrpp3634020.shtml.

Jing, Shi, 2017. Shanghai tries to limit shared bikes. China Daily. Retrieved from http://www.chinadaily.com.cn/china/2017-08/22/content_30944519.htm.

Josh, Ye, 2017. Why China's bike-sharing boom is causing headaches, South China Morning Post. Retrieved from. http://www.scmp.com/news/china/society/article/2085751/chinas-bike-sharing-boom-puts-pressure-planners.

Karki, Tej Kumar, Tao, Liu, 2016. How accessible and convenient are the public bicycle sharing programs in China? Experiences from Suzhou city. Habitat Int. 53, 188–194. https://doi.org/10.1016/j.habitatint.2015.11.007.

Kim, Kyoungok, 2018. Investigation on the effects of weather and calendar events on bike-sharing according to the trip patterns of bike rentals of stations. J. Transp. Geogr. 66, 309–320. https://doi.org/10.1016/j.jtrangeo.2018.01.001.

King, David, 2018. oBikes pulls out of Melbourne. THE AUSTERALIAN. Retrieved from https://www.theaustralian.com.au/news/nation/obikes-pulls-out-of-melbourne/news-story/08e6de562eff56472007b68065e5c552.

Li, Dan, 2018. Shared Bike in Chengdu has reached 1.45 million. Retrieved from. Sichuan News.

Li, Bo, 2017. Beijing welcomes its "public bike day" (in Chinese). Beijing Evening. Retrieved from http://www.takefoto.cn/viewnews-1139837.html.

Liang, Xianduan, 2017. Future of the Chengdu public bike. Retrieved from. Sichuan Daily.

Liao, Shumin, 2018. Mobike, Ofo End Price War at Top of China's Bike-Sharing Food Chain. Yicai Global. Retrieved from https://www.yicaiglobal.com/news/mobike-ofo-end-price-war-top-china%E2%80%99s-bike-sharing-food-chain.

Lin, Wang, Di, Ning, 2017. Dockless shared bike is over-supplied? - Ministry of Transportation replys: local governments are authorized to manage themself and the central govenrment will not take in charge. China Youth Daily. Retrieved from http://news.cyol.com/content/2017-05/23/content_16106571.htm.

Ltd. Hangzhou Public Bicycle Service and Development CO, 2017. Hangzhou Public Bicycle's Development History Retrieved from http://www.ggzxc.cn/index.aspx.

Ltd. Nanjing Institute of City & Transport Planning Co, 2017. Nanjing Transport Development Annual Report. Retrieved from http://www.nictp.com/.

ofo, & China information and Communication Research Institute, 2018BBb. Industry report of dockless shared bike 2017 (in Chinese). Retrieved from. https://mobike.com/global/.

Luojun, Duan, 2017. How many dockless shared bikes are there in Hangzhou? Zhengjiang News. Retrieved from https://zj.zjol.com.cn/news/585237.html.

Lynley, Matthew, 2018. Scooter startup Lime is reportedly raising $250M led by Uber investor GV (formerly Google Ventures). Techcrunch.

Ma, April, 2017. Shanghai Puts Brakes on Shared Bikes Flooding City Streets. Retrieved from. http://www.caixinglobal.com/2017-03-16/101066418.html.

Manzi, Giancarlo, Saibene, Giorgio, 2018. Are they telling the truth? Revealing hidden traits of satisfaction with a public bike-sharing service. Int. J. Sustain. Transportation 12 (4), 253–270. https://doi.org/10.1080/15568318.2017.1353186.

Mateo-Babiano, Iderlina, 2015. Public bicycle sharing in Asian cities. J. Eastern Asia Soc. Transportation Stud. 11.

Médard de Chardon, Cyrille, Caruso, Geoffrey, Thomas, Isabelle, 2017. Bicycle sharing system 'success' determinants. Transportation Res. Part A: Policy Practice 100, 202–214. https://doi.org/10.1016/j.tra.2017.04.020.

Midgley, Peter, 2011. Bicycle-Sharing Schemes: Enhancing Sustainable Mobility in Urban Areas.

Ministry of Housing and Urban-rural Development, 2014. Release of "Guidelines for planning and design of urban pedestrian and bicycle transport systems", local plannings and guidenlines are required to make before 2015. Retrieved from. http://www.mohurd.gov.cn/zxydt/201401/t20140116_216890.html.

Ministry of Transportation, Ministry of Industry and Information Technology, National Development and Reform Commission, Propaganda Department of the Central Committee of the CPC, Ministry of Housing and Urban-Rural Development, Cyberspace Administration of China, & People's Bank of China, 2017. Guidance of encouraging and regulating the development of Internet rental bicycles (dockless shared bike). Retrieved from http://www.gov.cn/xinwen/2017-08/03/content_5215640.htm.

Xiaoxi, Deng, 2016. Bike-sharing firms struggle with preventing damage, theft. Retrieved from http://www.globaltimes.cn/content/1020051.shtml.

Mobike Global, Beijing Tsinghua Tongheng Planning and Design Institute, & China New Urbanization Research Institute, 2017. The Mobike White Paper: Bike-Share in the City. Retrieved from https://mobike.com/global/blog/post/mobike-white-paper.

Mobike & Wuhan Transport Institute, 2017. Report of Mobike in Wuhan 2017. Retrieved from. https://mobike.com/global/.

Mobike, & Guangzhou Transport Institute, 2017. Report of Mobike in South China 2017. Retrieved from. https://mobike.com/global/.

Mobike, 2017. Retrieved from http://mobike.com/cn/.

Murphy, Enda, Usher, Joe, 2015. The role of bicycle-sharing in the city: Analysis of the Irish experience. Int. J. Sustain. Transportation 9 (2), 116–125.

Nanjing Trasnport Bureau, 2018. Report of Shared Bike development assessment 2017.

National Bureau of Statistics of China, 2018. China Statistical Yearbook (1985–2017). Retrieved from. http://www.stats.gov.cn/tjsj/ndsj/.

ofo, & China Academy of Transportation Science, 2018. Cycling report of major cities in China 2017 (Q4) (in Chinese). Retrieved from. http://www.motcats.com.cn/newsitem/278161930.

ofo, & China information and Communication Research Institute, 2018BBa. 2017 Economic and social impact report of shared bike. Retrieved from. https://mobike.com/global/.

Parkes, Stephen D., Marsden, Greg, Shaheen, Susan A., Cohen, Adam P., 2013. Understanding the diffusion of public bikesharing systems: evidence from Europe and North America. J. Transp. Geogr. 31 (7), 94–103.

Pucher, John, Buehler, Ralph, 2008. Making cycling irresistible: lessons from The Netherlands, Denmark and Germany. Transport Rev. 28 (4), 495–528. https://doi.org/10.1080/01441640701806612.

Qi, Zhu, 2017. Ministry of Communications ask for advice on the development of public bike sharing expert advice: government should do more on the development of it. Retrieved from. http://china.cnr.cn/yaowen/20170522/t20170522_523765874.shtml.

Qian, Kun, Zheng, Jingxuan, 2012. Study on Shenzhen's cycling characteristic and development (in Chinese). Paper Presented at the Annual National Urban Transport Conference.

Qin, Huanmei, Gao, Jianqiang, Kluger, Robert, Yao-Jan, Wu., 2018. Effects of perception on public bike-and-ride: A survey under complex, multifactor mode-choice scenarios. Transportation Res. Part F: Traffic Psychol. Behav. 54, 264–275. https://doi.org/10.1016/j.trf.2018.01.021.

Reid, Carlton, 2017. China's 3rd largest dockless firm collapses. bikebiz. Retrieved from https://www.bikebiz.com/news/chinas-3rd-largest-dockless-firm-collapses.

Shaheen, Susan A., Martin, Elliot W., Cohen, Adam P., Finson, Richard S., 2012. Public Bikesharing in North America: early operator and user understanding. Paper Presented at the European Conference on Antennas and Propagation.

Reid, Carlton, 2018. Cycle miles double in China thanks to dockless bike sharing. bikebiz. Retrieved from https://www.bikebiz.com/news/dockless-booming-in-china.

Scott, Cendrowski, 2017. Wait, Chinese bike-sharing doesn't make any sense. Forture. Retrieved from http://fortune.com/2017/03/21/chinese-bike-sharing/.

Shaheen, Susan A., 2013. Introduction shared-use vehicle services for sustainable transportation: carsharing, bikesharing, and personal vehicle sharing across the globe. Int. J. Sustain. Transportation 7 (1), 1–4.

Shaheen, Susan A., Zhang, Hua, Martin, Elliot, Guzman, Stacey, 2011. China's Hangzhou Public Bicycle: Understanding Early Adoption and Behavioral Response to Bikesharing.

Shaheen, Susan, Guzman, Stacey, Zhang, Hua, 2010b. Bikesharing in Europe, the Americas, and Asia: past, present, and future. Transportation Res. Rec. J. Transportation Res. Board 2143, 159–167.

Shaheen, Susan A., Guzman, Stacey, Zhang, Hu.a., 2010a. Bikesharing in Europe, the Americas, and Asia: past, present, and future. Transportation Res. Rec. J. Transportation Res. Board 2143 (1316350), 159–167.

Shaheen, Susan A., Martin, Elliot W., Chan, Nelson D., Cohen, Adam P., Pogodzinski, Mike, 2014. Public Bikesharing in North America during a period of rapid expansion: understanding business models, industry trends, and user impacts. Mineta Transportation Institute.

Shanghai Urban and Transport Research Institute, 2018. 2017 Shanghai Transport Report. Retrieved from. http://www.shjjw.gov.cn/gb/node2/index.html.

Shanghai urban and rural construction and Transportation Development Research Institute, 2015. 5th Shanghai Comprehensive Transport Survey. Retrieved from.

Shen, Yu, Zhang, Xiaohu, Zhao, Jinhua, 2018. Understanding the usage of dockless bike sharing in Singapore. Int. J. Sustain. Transportation 1–15.

Spinney, Justin, Lin, Wen-I., 2018. Are you being shared? Mobility, data and social relations in Shanghai's Public Bike Sharing 2.0 sector. Appl. Mobilities 3 (1), 66–83. https://doi.org/10.1080/23800127.2018.1437656.

Suzhou Planning bureau, 2018. Suzhou Annual Transport Report_2017. Retrieved from. http://www.szghj.gov.cn/.

Tang, Yang, Pan, Haixiao, Fei, Yibo, 2017. Research on users' frequency of ride in Shanghai Minhang bike-sharing system. Transp. Res. Procedia 25, 4979–4987. https://doi.org/10.1016/j.trpro.2017.05.376.

Tao, Lixing, 2017. The wheels are about to come off China's shared bike industry. Sixth Tone.

The Ashden Awards, 2017. Hangzhou Bicycle Service and Transport Development Co Ltd/The biggest public bike share scheme in the world. Retrieved from. https://www.ashden.org/winners/hangzhou-bicycles.

Transport Commission of Shenzhen Municipality, 2018. Report of preliminary assesment of Shenzhen Internet Rental Bike 2018 (in Chinese). Retrieved from. http://www.sz.gov.cn/jw/jtzx/wycx/dccx/cxtx/201803/t20180322_11419959.htm.

Wei, Wang, Wei, Wei, 2013. Comparative study of commercial operation mode of public bicycle systems worldwide: based on perspective of institutional economics. Urban Planning Int. 3, 024.

Wenting, Zhou, 2017. Authorities move against shared bike 'congestion'. China Daily Retrieved from http://www.chinadaily.com.cn/china/2017-11/01/content_33969945.htm.

World Resources Institute, & Mobike Global, 2018. How Cycling Changes Cities – Mobike's Second White Paper Goes Global. Retrieved from. https://mobike.com/global/blog/post/cycling-changes-cities.

Zhao, Xiaochun, 2018. 50% of dockless bikes in Beijing are left idle. KrASIA. Retrieved from https://kr-asia.com/50-of-dockless-bikes-in-beijing-are-left-idle/.

Yamei, 2017. China Focus: New guidelines to keep China's bike sharing on track. Xinhua. Retrieved from http://www.xinhuanet.com/english/2017-08/03/c_136496955.htm.

Yang, Jiawen, Chen, Junxian, Zhou, Meng, Wang, Zhenmin, 2015. Major issues for biking revival in urban China. Habitat Int. 47, 176–182. https://doi.org/10.1016/j.habitatint.2015.01.022.

Yang, Xu-Hua, Cheng, Zhi, Chen, Guang, Wang, Lei, Ruan, Zhong-Yuan, Zheng, Yu-Jun, 2018. The impact of a public bicycle-sharing system on urban public transport networks. Transportation Res. Part A: Policy Practice 107, 246–256. https://doi.org/10.1016/j.tra.2017.10.017.

Yi, Zhu, 2017. Dockless shared bike in Wuhan reached its limit. Wuhan Evening. Retrieved from http://news.hbtv.com.cn/p/623161.html.

Yin, Zhifang, Wu, Hongyang, Hao, Meng, 2017. Development status and suggestion of China urban bicycle transport. J. Eng. Stud. 9.

Yue, Li, 2018. Dockless shared bike reduced 20% in Beijing, Monitoring platform is established (in Chinese). IFENG. Retrieved from http://finance.ifeng.com/a/20180525/16317115_0.shtml.

Zhou, Yan, 2018. Interview from a ofo maintenance worker - the rate of vandalism is decreasing. Tencent Tech Retrieved from http://tech.qq.com/a/20180102/001273.htm.

Zhang, Yongping, Mi, Zhifu, 2018. Environmental benefits of bike sharing: A big data-based analysis. Appl. Energy 220, 296–301. https://doi.org/10.1016/j.apenergy.

2018.03.101.
Zhang, Hua, Shaheen, Susan A., Chen, Xingpeng, 2014. Bicycle evolution in China: From the 1900s to the present. Int. J. Sustain. Transportation 8 (5), 317–335. https://doi.org/10.1080/15568318.2012.699999.
Zhang, Lihong, Zhang, Jun, Duan, Zheng-yu, Bryde, David, 2015. Sustainable bike-sharing systems: characteristics and commonalities across cases in urban China. J. Cleaner Prod. 97, 124–133.
Zhao, Chunli, Carstensen, Trine Agervig, Nielsen, Thomas Alexander Sick, Olafsson, Anton Stahl, 2018. Bicycle-friendly infrastructure planning in Beijing and Copenhagen - between adapting design solutions and learning local planning cultures. J. Transp. Geogr. 68, 149–159. https://doi.org/10.1016/j.jtrangeo.2018.03.003.
Zheng, Caixiong, 2018. Shared-bike company ordered to refund deposits, apologize. China Daily.
Zhou, Wenting, 2018. Authorities introduce new measure to deal with bike congestion. China Daily.
Zhu, Ming, 2017. Nanjing public bike and its next development plan (in Chinese). Urban Public Transport 6, 9–10.

4.3 Chapter conclusion

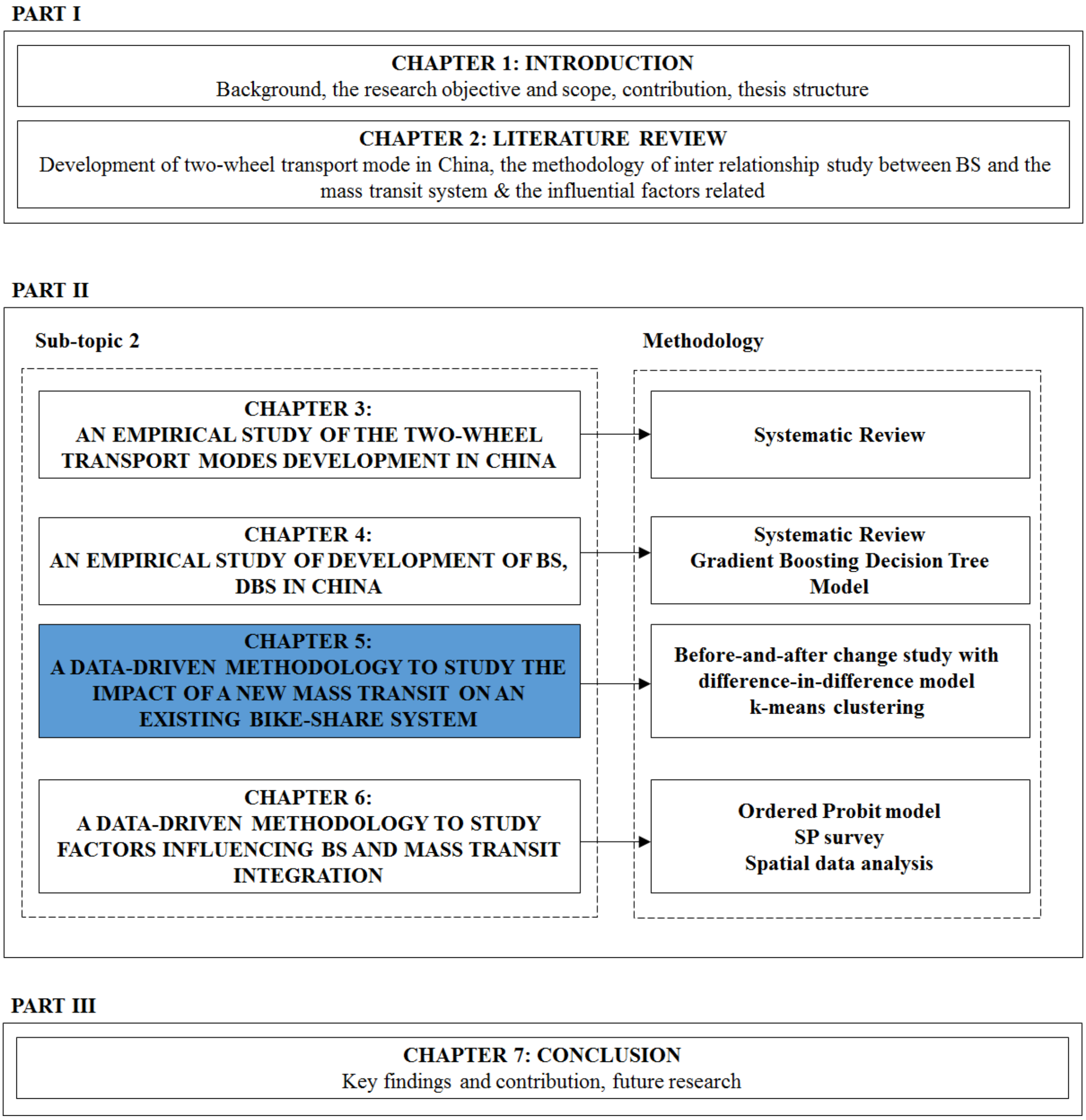
Based on up-to-date empirical analysis, this component of research discussed recent development of bicycle transport in China, especially the new innovative DBS programs. Three growth phases have been identified based on government policy and DBS's development, namely the "free growth" phase, the "regulated" phase and the "limited" phase. While the central government initially held "**neutral-positive**" policy towards this new industry, the rapid expansion of dockless fleets soon exceeded cities' limits, and local government policies changed from "**neutral-positive**" to "**neutral-negative**", and finally a number of banning regulations were issued from August 2017 to stem the ever-growing number of bikes.

DBS systems are found to have penetration advantages such as easy access by smart phone, convenience of pick and park and low cost. These merits successfully attract its main users, who are found to be young, highly educated and almost equally male and female. The trips are mainly short, highly frequent and for commuting purposes. To understand the reasons behind the burgeoning of DBS systems, three factors have emerged: (1) those promoting user demands, (2) those winning partial support of government, and (3) those promoting operators' supply are analysed. The results show that this rapid growth is mainly supply-driven by operator rather than by user demand or triggered by government policy. Financial sustainability, vandalism and the threat of DBS to the bicycle industry are the three main challenges that require investigation in the future, especially, the booming DBS market that may cause low profitability for local bicycle manufacturers and thus make the entire industry fragile. By a general comparison between BS and DBS, it is concluded that BS and DBS have their own merits and demerits. Cities with different background (finances, population scales, aims, etc.) need to find the suitable one. For instance, in medium, rich cities with high motor-vehicle share rate, BS could be a better choice to attract cycling and promote green transport. However, in mega cities with abundant transport choices and good cycling facilities, if local governments have strong supervision and control ability over DBS operators, DBS might be a better opinion.

As DBS is a fast-growing, capital-intense industry, new challenges keep show up. The descriptive statistics of BS and DBS are changing quickly, which means the above empirical study cannot fully cover the present development of DBS. By the time this thesis is writing, Mobike is purchased by Meituan and Ofo is on the edge of bankrupt due to financial problems. Therefore, scholars are, on one side, well-advised to closely follow the changing developing conditions of DBS; on the other side, to target the inherent characteristic of DBS and link it with the policy environment and look it in a long-term way.

This chapter provides up-to-date information of BS and DBS development in China. In a macro level, the empirical study of BS/DBS impact on mass transit is discussed. Users preference towards BS/DBS is revealed in this chapter as well. These inspire us to further dig integration study between BS and mass transit systems in Chapter 5 and 6.

CHAPTER 5: A DATA-DRIVEN METHODOLOGY TO STUDY THE IMPACT OF A NEW MASS TRANSIT ON AN EXISTING BIKE-SHARE SYSTEM



5.1 Overview

The understanding of how BS and DBS develop in recent years (Chapter 3 and 4) formed the base of the integration study between BS (DBS) and mass transit systems (Chapter 5 and 6). One of the main functions of BS is to enhance public transport by offering "last-mile" or "first-mile" service. Since public transport services as mass transit systems could largely change the transport environment in a city-scale and require huge financial investment (Li et al. 2015). Ancillary transport facilities, such as BS, need to be prepared and deployed accordingly. In Chapter 4, BS and DBS are proven to promote mass transit systems in some places from a macro point of view. In this chapter, the author would like to dig at a micro and quantitative level, to understand the impact of new mass transit on other transport modes (BS for instance). It is especially meaningful in developing communities like China, one that has a giant BS market, where new mass transit systems keep growing (Bao 2018; Dong et al. 2018).

Moreover, insight on this impact could further the understanding of BS's role as an interchanging mode of metros. Normally, BS are considered useful in "first and last mile" to interchange mass transit systems, in which "first-mile" indicates trips from origins (for instance, home in morning peak) to the metro stations while the "last-mile" indicates trips from metro stations to destinations (for instance, working place in morning peak). Although these two trips are always discussed in the same context, limited research focuses on identifying the difference between these two. However, due to the difference in land use, cycling facilities' demand and supply, and difficult to find the available bikes and docks, the "first-mile" and "last-mile" might occur independently and require different management. By identifying the renting and returning numbers in one BS station near a metro station in continuous time (namely, the temporal trip-pattern in station-level), "first-mile" or "last-mile" could be distinguished. For instance, when returning bikes largely outnumber renting ones in the morning, it could be interpreted that more users are cycling shared bikes towards metro stations rather than away from metro stations. In another word, BS serves as "first-mile" in this case. By studying this, we could know how metros trigger the change of BS and whether BS act as a "first-mile" or "last-mile" function, so that more work could be done to motivate cycling and promote interchange between BS and public transit.

In this chapter, a before-and-after study is firstly presented using city-scale BS trip-dataset covering the period a new metro system was introduced in Suzhou, China. Unlike research focusing on BS's impact on mass transit, this study focuses on the changes, if any, caused by a new metro to existing BS in a developing community-context. In the hypothesis, if the relationship between Metro line 4 (M4) and BS are complementary as expected, an immediate and more significant increase of BS ridership within M4 catchment (the treatment group) could be observed after M4 opened, compared to BS ridership beyond M4 catchment (the control group). Due to the data limit, in this chapter, the author mainly focus on metros' immediate impact on BS in two dimensions – change of BS trip-count (the number of renting and returning bikes) in the macro city-level and change of BS trip-pattern (the difference between renting and returning in different times) in the station-level. By answering "how" BS and mass transit systems interact mutually, this chapter formed the base of "why" this interact happens, which is the main content in the next chapter. The research gap and objective are described in Table 4-1.

Table 5-1 Research gap and objective of Chapter 5

Research topic	Research gaps	Research objective
A study of the impact of new mass transit on an existing bike-share system	➢ The study of before-and-after change caused by the impact of a new metro on BS is few, especially in a China-context. ➢ No existing methodology to create control and treatment groups exists in a before-and-after change study. ➢ No investigation has been done in studying the difference between "first-mile" and "last-mile".	Establishing a data-driven framework to investigate how BS trip-counts and trip-patterns change after a new mass transit is introduced.

The chapter includes the following paper:

Gu, Tianqi, *Kim, I. *, & Currie, G. (2019). Measuring immediate impacts of a new mass transit system on an existing bike-share system in China. Transportation Research Part A: Policy and Practice, 124, 20-39. (SCI, IF: 3.693)*

5.2 Paper 2: Measuring immediate impacts of a new mass transit system on an existing bike-share system in China

The following paper studies how a new metro system impact on an existing bike-share system (BS) and aim to understand how they interact to ensure they inter-enhance rather than inter-replace each other. By using trip-pattern and land use to create control and treatment groups based on trip data from Suzhou Public Bicycle System (SPBS), a ''before-and-after'' study is initiated to measure changes of an existing BS during a period when a new metro system (Here, Metro line 4: M4) opened. Normalized bike flow data (NF) is introduced to cluster and indicate trip-pattern in this study. The result indicates that most SPBS ridership and users within the metro's catchment (the treatment group) have largely increased since the introduction of the M4, while non-commuting cycling increased more than commuting cycling. The exception happens in the metros' hub, where SPBS ridership slightly decreased after M4. As for SPBS trip-pattern, before M4 was introduced, trip-pattern in CBD areas in Gusu District is found to be partially imbalanced (high returning in the morning and high renting in the evening), while balanced pattern (similar returning and renting in morning and evening) is more often seen in other areas. After M4 was introduced, a general trip-pattern change from the balanced to the imbalanced is observed regardless of land use, except for educational land use existing in Wuzhong District. This further indicates that after new metros were introduced, SPBS tends to serve "first-mile" interchange (origins to metros) rather than "last-mile" interchange (metros to destinations) in the morning and vice versa in the evening regardless of the land use type. This unique pattern could lead to different policies and management in enhancing interchanging service between BS and mass transit. This component of research answers "How" BS and mass transit systems interact. In Chapter 6, potential influential factors of this integration are investigated.

The published version could be seen on https://doi.org/10.1016/j.tra.2019.03.003.

Transportation Research Part A 124 (2019) 20–39

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Measuring immediate impacts of a new mass transit system on an existing bike-share system in China

Tianqi Gu, Inhi Kim*, Graham Currie

Institute of Transport Studies, Dept. of Civil Engineering, Monash University, Clayton, VIC 3800, Australia

ARTICLE INFO

Keywords:
Bike-share
Metro
First-mile
Last-mile
Trip-count
Trip-pattern
Land use

ABSTRACT

Mass transit systems as metros thrive nowadays in China – the largest bike-share market all over the world. Hence, it is meaningful to study how a new metro system impact on an existing bike-share system (BS) and understand how they interact to ensure they inter-enhance rather than inter-replace each other. By using trip-pattern and land use to create control and treatment groups based on trip data from Suzhou Public Bicycle System (SPBS), a "before-and-after" study is initiated to measure changes of an existing BS during a period when a new metro system (Here, Metro line 4: M4) opened. Normalized bike flow data (NF) is introduced to cluster and indicate trip-pattern in this study. The result indicates that most SPBS ridership and users within the metro's catchment (the treatment group) have largely increased since the introduction of the M4, while non-commuting cycling increased more than commuting cycling. The exception happens in metros' hub, where SPBS ridership slightly decreased after M4. As for SPBS trip-pattern, before M4 was introduced, trip-pattern in CBD areas in Gusu District is found to be partially imbalanced (high returning in the morning and high renting in the evening), while balanced pattern (similar returning and renting in morning and evening) is more often seen in other areas. After M4 was introduced, a general trip-pattern change from the balanced to the imbalanced is observed regardless of land use, except for educational land use existing in Wuzhong District. This further indicates that after new metros was introduced, SPBS tends to serve "first-mile" interchange (origins to metros) rather than "last-mile" interchange (metros to destinations) in the morning and vice versa in the evening regardless of land use type. This unique pattern could lead to different policy and management in enhancing interchanging service between BS and mass transit.

1. Introduction

Bike-share systems (BS) have been considered a sustainable and healthy transport mode since their first appearance in Amsterdam in the 1960s (Parkes et al., 2013). From 2010 to 2017, BS increased from 101 to 1286 worldwide, although the majority existed in China (DeMaio and Meddin, 2017). One of the main functions of BS is to enhance public transport by offering "last-mile" or "first-mile" service to mass transit systems which normally largely change the transport environment in a city-scale and require huge financial investment (Li et al., 2015). Therefore, it is essential to understand its impact on other transport modes (BS for instance) and make proper preparation in policy, management and operation for the new metro, especially in the largest BS market China where new mass transit systems keep growing (Bao, 2018; Dong et al., 2018).

* Corresponding author.
E-mail addresses: tianqi.gu@monash.edu (T. Gu), inhi.kim@monash.edu (I. Kim), graham.currie@monash.edu (G. Currie).

https://doi.org/10.1016/j.tra.2019.03.003
Received 13 May 2018; Received in revised form 7 February 2019; Accepted 8 March 2019
0965-8564/

Moreover, insight on this impact could further the understanding of BS's role as an interchanging mode of metros. Normally, BS are considered useful in "first and last mile" to interchange mass transit systems, in which "first-mile" indicates trips from origins (for instance, home in morning peak) to the metro stations while the "last-mile" indicates trips from metro stations to destinations (for instance, working place in morning peak). Although these two trips are always discussed in the same context, limited research focuses on identifying the difference from these two. However, due to the difference in land use, cycling facilities' demand and supply, and difficulty to find the available bikes and docks, the "first-mile" and "last-mile" might occur independently and require different management. By identifying the renting and returning numbers in one BS station near a metro station in continuous time (namely, the temporal trip-pattern in station-level), "first-mile" or "last-mile" could be distinguished. For instance, when returning bikes largely outnumber renting ones in the morning, it could be interpreted that more users are cycling shared bikes towards metro stations rather than away from metro stations. In another word, BS serves as "first-mile" in this case. By studying this, we could know how metros trigger the change of BS and whether BS act as a "first-mile" or "last-mile" function, so that more work could be done to motivate cycling and promote interchange between BS and public transit.

In this research, a before-and-after study is presented using city-scale BS trip-dataset covering the period a new metro system was introduced in Suzhou, China. Unlike research focusing on BS's impact on mass transit, this study focuses on the changes, if any, caused by a new metro to existing BS. If the relationship between Metro line 4 (M4) and BS are complementary as expected, an immediate and more significant increase of BS ridership within M4 catchment (the treatment group) could be observed after M4 opened, compared to BS ridership beyond M4 catchment (the control group). Future research will expand time coverage of data to mitigate new mass transit's ramp up effect and dig the reasons behind this impact. However, in this paper, we mainly focus on metros' immediate impact on BS in two dimensions – change of BS trip-count (the number of renting and returning bikes) in the macro city-level and change of BS trip-pattern (the difference between renting and returning in different times) in the station-level.

Main contributions of this paper are listed as follow:

a. The change of BS trip-count before and after a new metro is presented, which was not studied before.
b. It develops a quantitative method to describe BS trip-pattern. To quantify and visually measure the impact caused by a new metro system. Normalized bike flow data (NF) is introduced to cluster and indicate BS station's pattern shift.
c. Methodology to create the control group is presented. Clustering based on trip-pattern and land use are used to in a two-step process to find out corresponding control group once the treatment group is determined.
d. The change of BS trip-pattern before-and-after a new metro is presented. The difference in "first-mile" and "last-mile" trips could be identified based on this trip-pattern change.

The paper begins with a review of the related literature (Section 2), followed by an introduction of data sources (Section 3). A before and after comparison results of SPBS is discussed in Section 4, and then discussion, implication, and conclusion are in the following sections.

2. Literature review

The literature presented in this sector includes BS development, studies of influential factors of BS ridership, studies of the relationship between public transit and BS.

2.1. Development of BS

It is widely accepted that the development of BS could be divided into 4 generations: (1) White Bikes (or Free Bike Systems) that firstly appeared in Amsterdam in 1965; (2) Coin-Deposit Systems that firstly appeared in Copenhagen in 1995; (3) IT-based Systems; and (4) Demand-Responsive, Multi-Modal Systems (Bachand-Marleau et al., 2012; Shaheen et al., 2010b). Most current BS are third generation products where bikes are normally returned and rented by smart cards or credit cards while the terminal centers record the time, location as well as the users' personal information (Ricci, 2015). According to the Bikesharingmap (2017), cities and places deployed BS increased from 101 to 1286 at an annual rate of 152.8% from 2010 to 2016. By the end of 2016, China had already become the largest BS market, with 1.9 million bikes and 430 cities and places deployed BS while the total number of shared bikes world-wide were 2.29 million in the same time.

Fourth generation BS (also known as a dockless bike-share system, namely DBS) is a highly flexible dockless system comprising GPS and personal smart phone, easier to be installed (Parkes et al., 2013; Shaheen et al., 2010a). The prevalence of DBS (normally considered as the fourth generation) worldwide has been a relatively new trend, especially in China. According to Mr. Liu Xiaoming, vice minister of the Ministry of Transportation of China, by February 2018, 23 million DBS bikes had been deployed in China – ten times larger than regular BS. Mobike and Ofo are two leading fourth generation DBS operators that rapidly grow nowadays. Since DBS is not limited by a rental station, equipped with GPS devices, the renting and returning of bikes are normally less effected by manual rebalance than regular BS which means renting and returning of DBS could reflect more accurate demand and supply.

2.2. Weather and calendar's impact on BS

Overall, a large number of studies have indicated that weather and temperature have a significant influence on cycling. Miranda-Moreno and Nosal (2011) found temperature, rainfall and humidity had an immediate and large impact on cyclists. Ding (2016) studied the impact of the built environment and weather on Seattle's BS-Proto and found annual members and non-members behaved differently in different weather conditions. By studying Brisbane's 'CityCycle', Jonathan Corcoran et al. (2014) found strong winds and rainfall could significantly reduce BS trips. Although some studies focused on air pollution and cycling (Hatzopoulou et al., 2013; Jarjour et al., 2013; MacNaughton et al., 2014), most of them focused on health impacts while no previous research considered air pollution's impact on BS usage.

As for calendar events, Kim (2018) found that heat and non-working days differently affect the demand for public bikes. Corcoran et al. (2014) concluded that calendar events (in particular public holidays) did exert some subtle variations in the spatial distribution of trips. Borgnat et al. (2009) predicted the number of bicycles hired per hour in Lyon's community bicycle program by introducing explanatory factors such as the number of subscribed users, the time of the week, the occurrence of holidays or strikes, and weather parameters.

2.3. Relationship between BS and mass transit

Overall, research related to BS-public transit integration tended to focus on BS's impact on transport mode substitution areas (e.g., how much public transport and walking are substituted by BS) (Fishman, 2016). A number of studies have indicated that BS had a conditional positive impact on increasing public transit trips. Recently, in a survey taken near metro stations in Nanjing, Ji et al. (2017) found commuting BS users were more likely to interchange to the metro. A study conducted by Nair et al. (2013) on usage patterns of Paris' Velib' stations near transit stops revealed that coupling of BS and transit stops can lead to higher public bicycle use. By comparing BIXI (a BS in Montreal, Canada) cyclists with private bike users, Bachand-Marleau et al. (2011) found that regular BIXI users were more inclined to integrate cycling with public transport. While these studies tended to support a positive effect of BS on public transit, Martin and Shaheen (2014) compared the two American cities of Washington DC and Minneapolis. He found introducing a BS may cause diverse results since BS might cause a shift away from public transit in core urban environments with high population density. On the other hand, studies of how mass transit system influence BS are very rare.

2.4. Before-and-after change and impact analysis

One of the essences of establishing a successful interchanging system between bike-share and transits is to understand how they affect each other. A direct way to study this effect is so-called "before-and-after" studies, or "quasi-experiments," which are not seldom used in the domain of transport research (Lathia et al., 2012). It is useful and accurate when studying a large-scale transport environment's change, by observing and comparing two complete datasets created by splitting one observation into pre- and post-invention period.

In an early study of London, UK's underground's strike's impact on its BS (the 'Boris bikes') usage, Fuller et al. (2012) concluded that limiting transportation options (even it is unintended) may have a potential to increase population levels of physical activity by promoting the use of cycling. Based on survey and the modeling, Martin and Shaheen (2014) studied how public transit in Washington DC and Minneapolis reacted after new BS systems were introduced by asking whether the survey participants used more public transit after new BS was introduced.

Wang and Zhou (2017) examined whether the launch of BSSs can reduce citywide congestion. In this before-and-after change study, the authors employed a difference-in-differences model with two-way fixed-effects panel regression and concluded that the introduction of BSSs shows a significant mixed impact on congestion in general. This difference-in-difference method is frequently used in evaluating transport policy problems (Billings, 2011; Hurst and West, 2014; Li et al., 2012). The idea of building treatment and control groups at different times inspired this research.

Moreover, when comparing the BS usage pattern (as the station-based temporal distribution of trips), clustering is widely used. In very recent research conducted Shenzhen, China (Wu et al., 2018), applied time series analysis in two districts' comparison study (similar to a before-and-after change study) and used NAB (Normalization Available Bicycles) as an index to cluster BS stations in different districts. A hierarchical cluster method was applied to indicate a relationship between public bicycle usage daily changing patterns and underlying spatial and cultural characteristics. Similarly, the same clustering methods (as k-means or hierarchical cluster), are used by Wang et al. (2016) in his study in Taipei's BS system, Kim (2018) in his study in Daejeon, Korea. Overall, clustering is widely used in impact analysis, especially in indicating significant BS usage pattern.

2.5. BS usage analysis techniques and key index

Traditionally, sampling surveys and expert interviews have been widely deployed in BS research especially in issues as transport mode shift and measuring BS's impact on other transport modes.

In a recent study of Taipei's public bike rental system (YouBike), Jenhung Wang et al. (2016) built a spatial-temporal analysis model of the YouBike rental system. They collected a real-time number of available bikes per station (NAB) at each rental station and categorized YouBike rental stations into the following five categories from No bikes/Lacking bikes to No bike racks/Lacking-bike racks. Faghih-Imani et al. (2014) studied BIXI in Montreal to investigate how bicycle infrastructure and land use impact BS flow, in which NAB in station-level was used directly to transfer to the value of renting and returning. In this process, the author commented that "by using available bikes, it is not possible to directly distinguish whether or not the addition (removal) of bikes is due to customers or operators". Similarly, Lathia et al. (2012) used a data-centric approach combined with GIS-based analysis to cluster 66 London bike-share stations. They recorded NAB and detected how BS stations changed before and after a system-scale bike-sharing policy was released.

In general, some gaps exist in the BS research:

a. Study of before-and-after change caused by the impact of a new metro on BS is few, especially in a China-context (the biggest shared bike market now). However, as more local governments of China are planning and constructing mass transits (mainly metros), it is meaningful to measure this impact and set up sound policy and management.
b. No existing methodology to create control and treatment groups exists in a before-and-after change study.
c. No investigation has been done in studying the difference of "first-mile" and "last-mile", most studies did not distinguish renting and returning, while this difference, if any, could lead to different policy and management.
d. Most of the shared bike research relied on the survey or using real-time number of the available bike (NAB) since BS interfaces with NAB dataset are normally easy to access. However, by NAB, it is hard to reflect the changing of both renting and returning bikes over a continuous time since NAB is collected in a discrete duration. In addition, NAB could mask the effects of rebalancing as well since it cannot tell the number-change is caused by operators or users. Besides, the methodology based on NAB cannot be used in dockless bike-share (DBS) since there are no stations or docks of DBS while renting or returning data of DBS are usually accessible and accurate. Therefore, continuous real-time renting and returning trip data with rebalancing data excluded is much more needed not only for accurate research of regular BS but also for DBS.

3. Research context and data collection

3.1. The bike-share system and metro system in Suzhou

Suzhou is a major city located in the southeastern Jiangsu Province of East China, about 100 km (62 mi) northwest of Shanghai, east to Lake Tai, as can be seen in Fig. 1. Its urban area is 2743 km^2 (1059 mi^2) with 10.68 million populations by the end of 2017. According to Suzhou Statistical Bureau (2018), in 2017, city GDP of Suzhou was 1.7 trillion RMB or 268 billion USD (at an exchanging rate of May 2018), listed in 7th among all the cities in China (Shanghai, Beijing, and Shenzhen were top 3). According to the national and local statistical yearbook, in 2017, average per capita disposable income of Suzhou residents was 50.6 thousand RMB (7.29 thousand USD), compared to a provincial level of 35.0 thousand RMB (5.04 thousand USD) and a national level of 26.0 thousand RMB (3.79 thousand USD). It is a relatively rich city with strong finance. Its motor vehicle ownership was 3.43 million by the end of 2017 (0.32 vehicle/person). Three metro lines (M1, M2, and M4 which can be seen in Fig. 1) have already been in

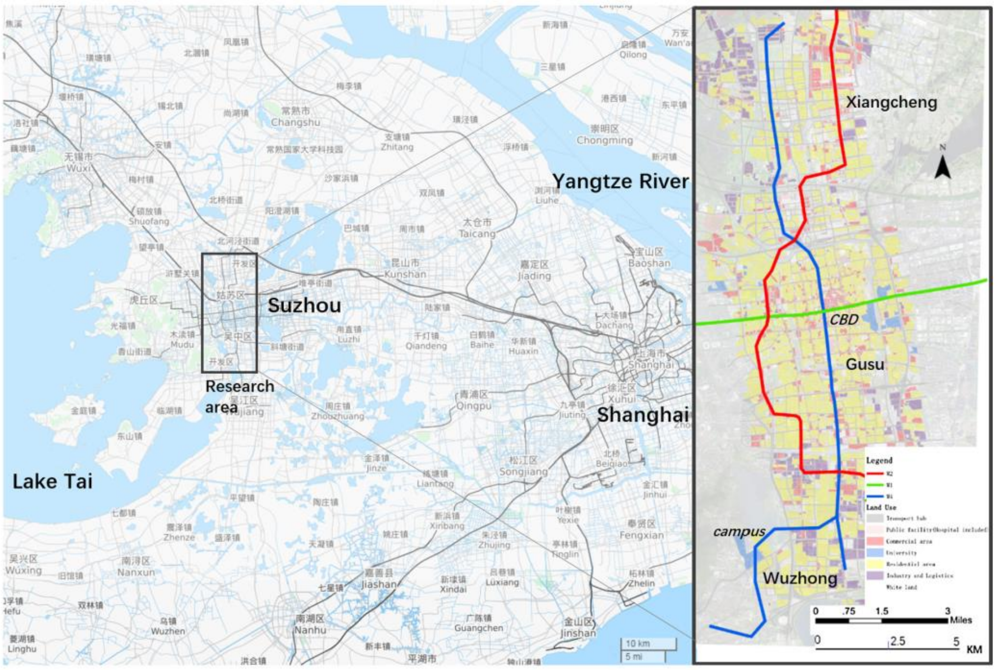


Fig. 1. Location of Suzhou, Layout of 3 metro lines (M4 is the blue one) and land use. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

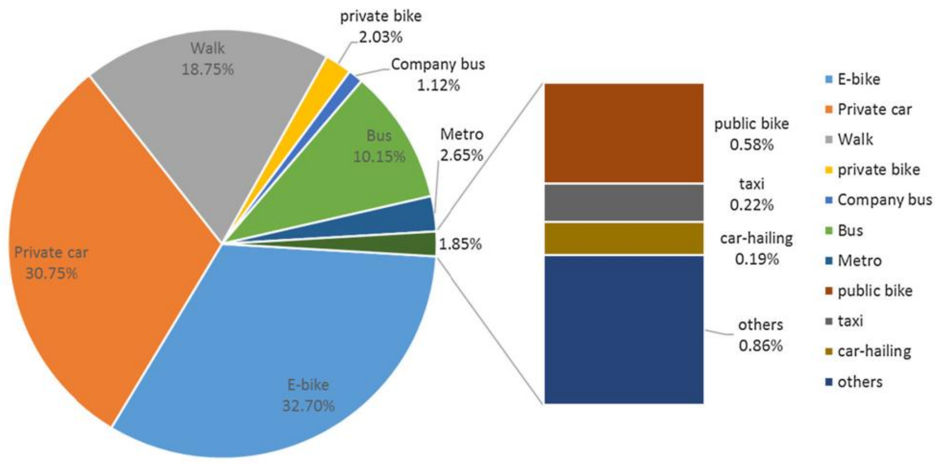


Fig. 2. Traffic mode split rate of Suzhou in 2017.
Source: Suzhou Annual Transport Report 2017.

operation with three more lines under construction. Total passenger flow of three metro lines was 246 million in 2017 with daily-flow at 0.67 million, in which M1 accounted for 41.3%, M2 34.5% and M4 24.2% (at 56 million).

3.1.1. Metro Line 4 (M4) and land use alongside M4

Metro Line 4 (known as the M4, the blue line in Fig. 1) is the third metro line deployed in Suzhou, opened on 15th April 2017 (even before metro line 3). It runs from the north (Xiangcheng District) to the south (Wuzhong District) crossing through the central area (Gusu District) as shown in Fig. 1.

Its 31 stations cover areas of various land use types (see Fig. 1). For instance, Gusu District is the old town of Suzhou where residential, commercial and business land use density is relatively high and mixed, and a central commercial and business center district (CBD) locates in the very central area where M1 and M4 crossed (pink and red areas near intersection of green and blue line in Fig. 1). In contrast, areas in the northern Xiangcheng District and southern Wuzhong District along the M4 are peripheral urban areas with solo land use type (mainly residential), and lower population density. An international educational center with many institutes and universities (southwest of the map, colored in blue in Fig. 1) locates in the southwest of the Wuzhong District.

3.1.2. Suzhou's Public Bike bike-share system

Suzhou Public Bicycle System (SPBS) is a third-generation bike share system located in Suzhou which is operated by a private BS company - Youon and supervised by Suzhou Urban Management Bureau (SUMB) - a local bike-share administration authority. This public-owned, privately operated system was firstly launched on August 30, 2010, with only 11 stations and 200 bikes (2 years before the first metro line was opened). Currently, over 2200 SPBS stations and 45,600 bikes are distributed in Suzhou. The average daily ridership of SPBS was around 0.22 million in 2017, which meant every SPBS bike has been used around 4.8 times/day. According to Suzhou Planning Bureau (2018), SPBS contributed to 0.58% of the overall transport modes in 2017 (see Fig. 2).

The deposit is 200 RMB (around 30 USD) for card registrations and free for Alipay APP (a Chinese payment APP) users with high credits. The first hour's ride is always free, followed by 1 RMB/h (0.15 USD/h) in the following time. No extra subscription fees or membership fees are needed. The financial threshold to SPBS is low since BS are encouraged and subsided by the government.

In order to enhance the interchange between local metro systems and SPBS, the Suzhou government has produced several broad guidelines (Suzhou Planning Bureau, 2018):

A. For each metro station, at least one SPBS station should be set up within 50 m of this metro station's entrance before the metro opens.
B. The coverage radius of BS station is 300–500 m in urban core areas and 500–900 m in peripheral urban areas.
C. The SPBS stations are normally deployed in pedestrian's sidewalk. The minimum width requirement of the sidewalk is 3.5 m.
D. Each SPBS station normally contains 15–40 docks with 20 docks to be the most popular index.
E. SPBS stations are normally deployed near the entrances of public buildings, big residential communities, schools, hospitals, and commercial buildings. Citizens could apply online to SUMB to ask for adding new stations.

However, the preparation of SPBS to welcome a new metro line still mainly rely on the operator's experience. Rebalancing efficiency of bikes, for instance, for a long time after M4 opened, remained the same as it used to be before M4. "Unavailable bikes and unavailable docks" near metro stations were listed as the most complaining issues in a city-scale survey in 2017 initiated by

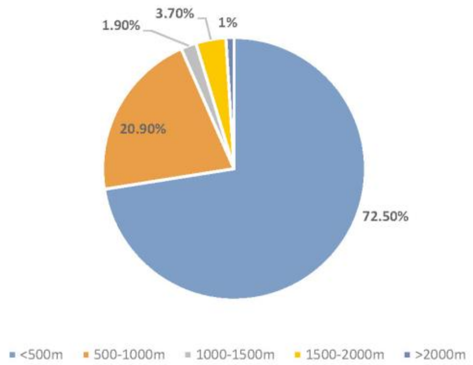


Fig. 3. Acceptable walking distance when using SPBS.
Source: Suzhou Annual Transport Report 2017.

Suzhou Planning Bureau. The reason behind this might be inconsistent operation mechanism and supervision mechanism. SPBS is operated by Youon, a private operator who runs many public bike programs in China. And the metro system in Suzhou is operated by Suzhou Rail Transit company, a local state-owned company. Moreover, the SPBS is supervised by Urban Management Bureau while the metro system is supervised by Urban Transport Bureau. We assume that different operators and supervising bureaus make the interaction between the new metro and existing SPBS relatively lagging.

3.2. Data preparation

The original dataset is provided by SUMB which contained 30 million usage records. It contains one-year trip records of all 2256 stations in Suzhou from June 1, 2016 to May 31, 2017. Since M4 opened on April 14, 2017, the dataset offers time windows to measure changes in SPBS before and after M4 opened. Every record represents an SPBS trip. The dataset includes fields such as users' name, citizen ID (containing age and gender information), bike ID, renting time and station/dock ID as well as returning time and station/dock ID. Particularly, a field named "card type" is given so that normal users and operators (for rebalancing) could be distinguished, so that rebalancing effect could be detected and eliminated unlike studies relying on a number of the available bike (NAB) which cannot tell the difference of normal usage and rebalance.

In order to observe how M4 influenced SPBS, SPBS stations within M4's catchment are firstly selected. Acceptable walking distance is usually used to identify metros' catchment (Guerra et al., 2012) varying from 500 to 900 m based on local walking condition and travelers' habit (Hu et al., 2018). In Suzhou's case, a 500-m catchment is used. According to Suzhou Annual Transport Report 2017, the majority (72.5%) of the SPBS users took 500 m as an acceptable walking distance as could be seen in Fig. 3. Moreover, the average distance between two metro stations is 1 km and made 500 m a suitable coverage for walking.

Through a GIS-based technique, 84 SPBS stations are found to be located within 500 m of the M4 stations. By checking station ID in operator's database, the of construction and operation information of these 84 stations could be identified. 6 out of 84 were constructed and operated in 2011 – before any metro line was operated in Suzhou. 9 out of 84 were constructed during 2012 and 2013 – after the first metro line (M1) opened yet before the second metro line (M2). 39 out of 84 were constructed during 2014 and 2016 when M4 was still under construction. The rest, about 30 stations were operated in 2017, most of which opened two or three months before M4 opened in April 2017. Only two stations operated the same time M4 opened. In another word, some stations were built to meet the requirement of interchange of M4, yet most of which were already be there for a long time. Therefore, the total 82 stations are selected to proceed the before and after analysis. In a classic difference-in-difference analysis, they are categorized as the treatment group, which means we need to create a control group to initiate a comparison (Wang and Zhou, 2017).

Since this is an immediate impact measurement, we select two equal time durations to compare this before- and after- change. The period is limited deliberately to offset weather influences and the effects caused by SPBS's growth. As indicated in the literature, weather and calendar's events are considered as significant effects on BS demand. Trip data in extreme weather and holidays are removed – days with extremely high temperatures (less than 5 °C or more than 35 °C), and medium to heavy precipitation are excluded. National holidays (not weekends) are removed to ensure SPBS users engage in their regular trip-pattern (Jonathan Corcoran et al., 2014).

Two datasets are produced in this step. The "post-M4" dataset is from April 17, 2017 to May 31, 2017 - the last day of data we had so far. And the "pre-M4" dataset is from March 6, 2017 to April 14, 2017. Each dataset contains 36 valid days, with 28 weekdays and eight weekends.

4. Results of spatial-temporal change using a before-and-after analysis

Since both values and patterns have changed after M4, it is hard to directly compare SPBS stations near the M4 in two different

T. Gu, et al. Transportation Research Part A 124 (2019) 20–39

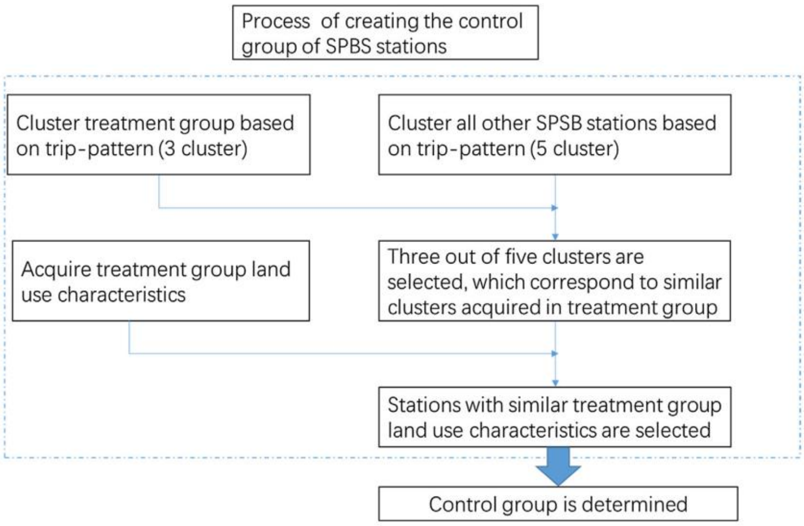


Fig. 4. Process of creating the control group.

times. In this section, a change of station-level trip-count is firstly analyzed and discussed, followed by trip-pattern.

4.1. Macro-level temporal analysis of trip-count

Since the treatment group is already created in the last section, a control group is created in this step to compare the before-and-after change of trip-count. Trip-pattern and land use are used in this two-step process as shown in Fig. 4.

4.1.1. Index explanation and clustering preparation

A clustering algorithm is prepared firstly to analyze trip-pattern within the metro's catchment (the treatment group) on weekdays. We use normalized bike flow data (NF) as an index in the clustering process. For each trip record, it includes a renting station ID and a returning station ID. Two indices are then introduced to indicate trip-pattern in one BS station: normalized flow-in/hour (*FI*) and normalized flow-out/hour (*FO*). For each station, the count of returning is aggregated and averaged on an hourly basis as *FI*, as the count of renting is defined as *FO*. Then for a station *m*, *FI* is a 24-h time-sequence vector:

$$FI_m = [fi_{m,0},\ \ fi_{m,1}, fi_{m,2},\ \ \cdots, fi_{m123}] \tag{1}$$

where $fi_{m,t} = \frac{1}{k}\sum_{1}^{k=28} fi_{m,t,k}$,

m indicates the counts of SPBS station within M4, $1 \le m \le 82$
k indicates valid weekdays since there are 28 valid weekdays, $1 \le k \le 28$;
t indicates 24-h time-sequence, $0 \le t \le 23$;

It is a time vector containing 24 values which could be understood as the counts of bikes returning to a particular station in a continuous 24-h period.

Similarly, for a particular station *m, FO* could be used to indicate the temporal change of the counts of rented bikes m as:

$$FO_m = [fo_{m,0}, fo_{m,1}, fo_{m,2}, \cdots, fo_{m,23}] \tag{2}$$

This is a time vector containing 24 values which could be understood as the counts of bikes rented from a particular station in one hour.

To mix them so that stations could be clustered, F_m is used to represent a station's temporal counts change.

$$F_m = [fi_{m,0},\ \ fi_{m,0},\ \ fi_{m,1},\ \ fi_{m,1},\ \ fi_{m.2},\ \ fo_{m,2}, \cdots, fi_{m,23}, fo_{m,23}] \tag{3}$$

This is a time vector contains 24 pairs of counts (48 counts). And for each pair of counts in an hour, the number of returning and rented bikes in that hour is indicated.

Since the change of trip-count has been discussed in Section 4.1, we focus on the change of trip-patter in this section. Therefore, to avoid the fluctuation of trip-count impact clustering results, we introduce a normalizing process to eliminate this impact.

Provided for each station *m*, there is a f_{max} (highest trip-count in vector F_m), the normalized bike flow NF_m is defined as:

$$NF_m = [fi_{m,0}/f_{max}, fo_{m,0}/f_{max}, fi_{m,1}/f_{max}, fo_{m,1}/f_{max}, \cdots, fi_{m,23}/f_{max}, fo_{m,23}/f_{max}] \quad (4)$$

Similar to F_m, NF_m is a time vector contains 24 pairs of normalized counts (48 counts) with its count value limited to (0, 1). NF_m is used in clustering process so that trip-pattern could still be observed without the impact of absolute trip-count.

A k-means clustering algorithm is used to cluster these 82 SPBS stations alongside the M4. K-means clustering is a method of vector quantization, originally from signal processing that is widely used for cluster analysis in data-mining (Rokach and Maimon, 2005).

To determine the appropriate number of clusters, the different number of clusters, k from 2 to 15 (as we thought any number above 15 is too much for a total 82 stations) were tested. The results of clustering were evaluated using the silhouette coefficient (Kim, 2018). The silhouette coefficient is a measure of how similar an object is to its own cluster (cohesion) compared to other clusters (separation).

The silhouette coefficient is defined as

$$s(i) = \frac{b(i) - a(i)}{\max\{a(i), b(i)\}} \quad (5)$$

where $a(i)$ indicates the average dissimilarity of i to all other objects in a cluster A, and $b(i)$ indicates as $b(i) = \min C \neq A d(i,C)$ where $d(i,C)$ is the average dissimilarity of i to all objects in a cluster, C.

which can be also written as:

$$s(i) = \begin{cases} 1 - \frac{a(i)}{b(i)}, & if \quad a(i) < b(i) \\ 0, & if \quad a(i) = b(i) \\ \frac{b(i)}{a(i)} - 1, & if \quad a(i) > b(i) \end{cases} \quad (6)$$

From the above, it is clear that the silhouette coefficient ranges from -1 to $+1$, where a high value indicates that the object is well matched to its own cluster and poorly matched to neighboring clusters (Rousseeuw, 1987).

Fig. 5 indicates the silhouette coefficients vary with the number of clusters. The silhouette coefficient is highest (0.289) when k = 3, which means 3 is determined as the cluster number in this study.

4.1.2. Cluster results of pre-M4 treatment group

By using NF_m to cluster, both "amount"—trip-count and "direction"—flow-in(returning) and out (renting) are used as two characters to determine the clustering results.

Fig. 19 shows the clustering results of the pre-dataset, containing the centroid patterns and the spatial distribution on a city map. Each circle represents an SPBS station selected within the M4 catchment with its color representing the cluster to which it belongs. The value of the Y-axis represents F_m - the returning and renting number that appear alternately.

The trip-pattern of three pre-M4 clusters described in the following figures. The value of X-axis represents 24 h in one day.

Cluster 1 – balanced and double peaks pattern: This is a pattern with two obvious peak values during peak hours (see Fig. 6). 69 stations (red circles in Fig. 19) belong to this cluster. Obvious peak is observed in the morning (7 am–9 am) and the evening (5 pm–6 pm). The difference between returning (flow-in) and renting (flow-out) values is relatively insignificant **(this pattern is defined as balanced)**. Changes in the morning are greater than during the rest of the day. They appear in most areas, especially in Xiangcheng and Wuzhong Districts.

Cluster 2 – imbalanced (more returning in the morning) and double peaks pattern: This pattern has more returning ("arrivals" of SPBS trips) in the morning and more renting ("departure" of SPBS trips) in the evening, with a single peak value in the evening rush hour (see Fig. 7). 12 stations (blue circles in Fig. 19) belong to this cluster. The morning peak is more aggregated than the evening peak for stations in Cluster 2. They mostly appear in central business commercial district areas (CBD) in Gusu District and show great attractions in the morning.

Cluster 3 – outlier with only one peak in the evening: Only 1 station (yellow circle in the southwest in Fig. 19) belong to this

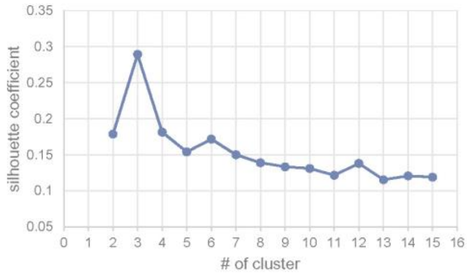


Fig. 5. The silhouette coefficients varying with the number of clusters.

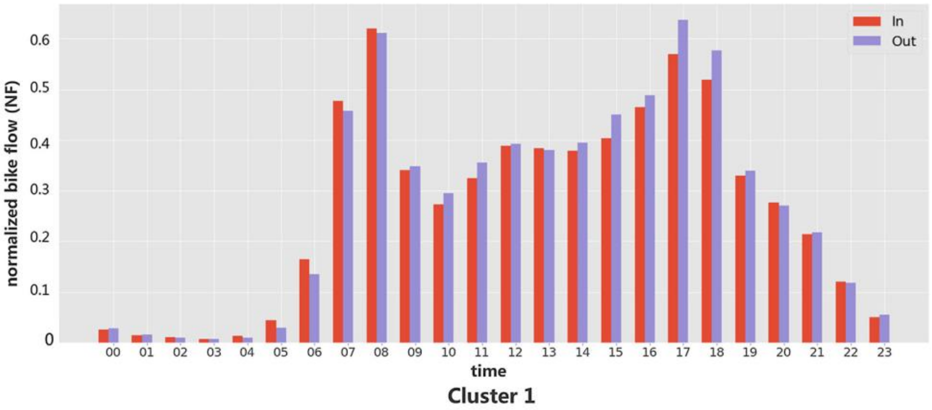


Fig. 6. Normalized bike flow of Cluster 1.

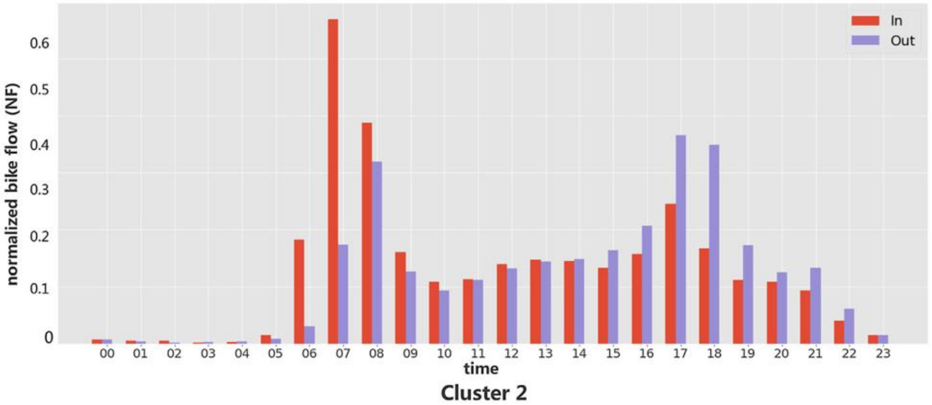


Fig. 7. Normalized bike flow of Cluster 2.

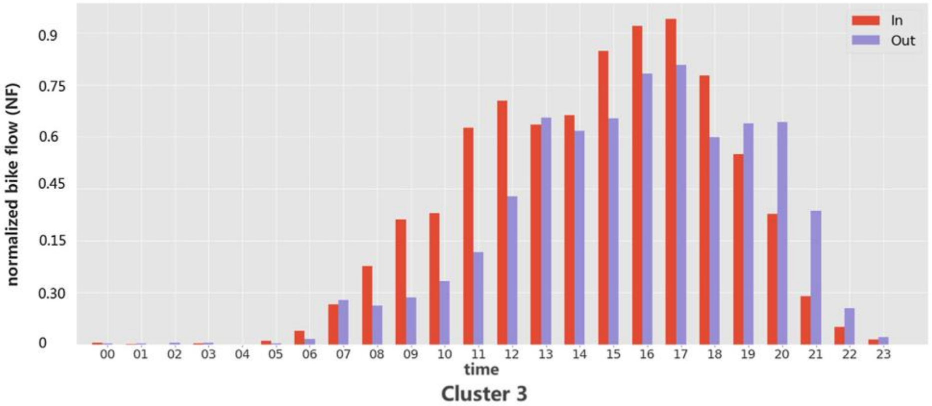


Fig. 8. Normalized bike flow of Cluster 3.

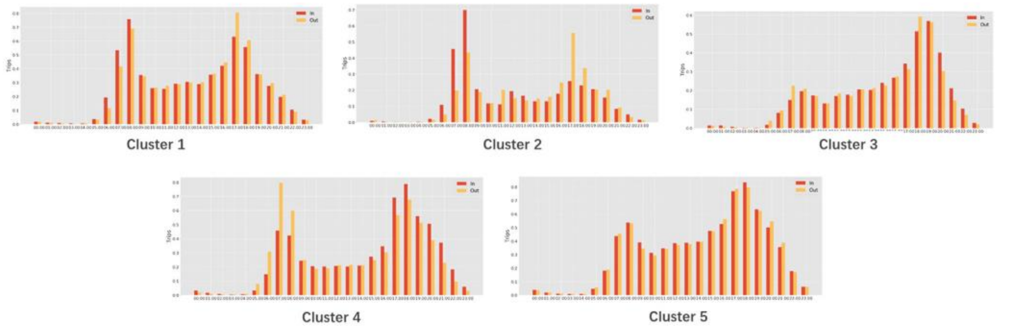


Fig. 9. Five clusters of the other SPBS stations. Note that the first three clusters are similar to the treatment group.

cluster. It is an outlier in an educational area in the southwest of the city. No peak is observed until evening peak – Its trip-count remains increasing to a single peak in the evening (see Fig. 8). For most of the time, returning number of bikes (flow-in) outnumbers the renting numbers (flow-out). However, from 6 pm, more renting activities are observed.

Overall, in the pre-M4 stage, most BS stations belong to Cluster 1 with balanced trip-pattern. And Cluster 2 appears in the CBD areas near the hub of M1 and M4.

4.1.3. Constructing the control group

5 clusters are acquired among over 2000 SPBS stations all over the city with the treatment group excluded as could be seen in Fig. 9. We selected the three clusters (from Cluster 1 to Cluster 3, corresponding to the treatment group) that sharing the same three trip-patterns as the treatment group. 661 SPBS stations are selected in this step. Two other clusters are "imbalanced (more renting in the morning) and double peaks pattern" and "balanced and even pattern" as the last two in Fig. 9.

In the next step. We analyzed three clusters' land use structure in the treatment group. Land use structure could be further divided into categories as "Industrial", "Public service", "Residential", "higher-educational" and "Commercial". For each cluster, category percentage is calculated and evaluated by using the land use information provided by Suzhou Urban Planning Bureau. So that main land use structure within 500 m in SPBS stations in the treatment group could be extracted. For Cluster 1 (balanced/double peaks) in the treatment group, over 75% of the land use is residential. Cluster 2 mainly locates in mixed land use areas while Cluster 3 mainly locates in higher-educational areas. According to these three land use structures, stations after clustering (661 stations left) are further filtered. 193 out of 661 SPBS stations corresponding to each cluster that matching the land use structure are finally selected. They are determined as the control group. This two-step filtering process is shown in Table 1.

Spatial distribution of the control group could be seen in Fig. 10. It covers mainly residential, commercial and educational areas.

4.1.4. Trend analysis in one whole year between treatment and control groups

Daily temporal distribution of ridership and cycling distance is indicated in this sector. From Jun. 2016 to May. 2017, a whole year's trip-count distribution is divided into two groups – Blue group indicates the treatment group (n = 82), and the orange group represents for the control group (n = 280). We normalized trip-count as average trips per station per day and average trip times in Fig. 11.

In Fig. 11, Y-axis value represents for average trips per station per day. The vertical blue dash line means the opening time of M4 (April 15, 2017). Apart from M4's operation, no city-level transport condition or policy changed during this time. It is clear before M4 opened, no big difference could be seen in these two groups - they follow the same trend. Especially, all trip-count fluctuate in different seasons with the lowest trip numbers observed in winter (January and February), which happens to be the same time the biggest national holiday - spring festival.

However, after M4 opened, a sharp increase in the treatment group could be seen while the control group remains still - the treatment group begins to experience an independent trend. Since no other condition or policy changed, this independent trend is highly likely triggered by new M4 and make normalized trips within M4 outnumber those beyond M4, as can be seen in Fig. 11.

As for the average trip length and time, it seems to be irrelevant to the opening of M4. The distribution of trip time recorded in the dataset is shown in Fig. 12. No significant difference could be seen from these two groups. In a year, normalized trips of these two groups are relatively the same even after M4 opened as can be seen in Fig. 12. Note that the large variance of normalized trip length is

Table 1
Filtering process to create the control group.

Filtering rounds to correspond to the treatment group	Cluster 1	Cluster 2	Cluster 3	Total
1. Clustering	252	239	170	661
2. Evaluating land use structure	136	49	8	193

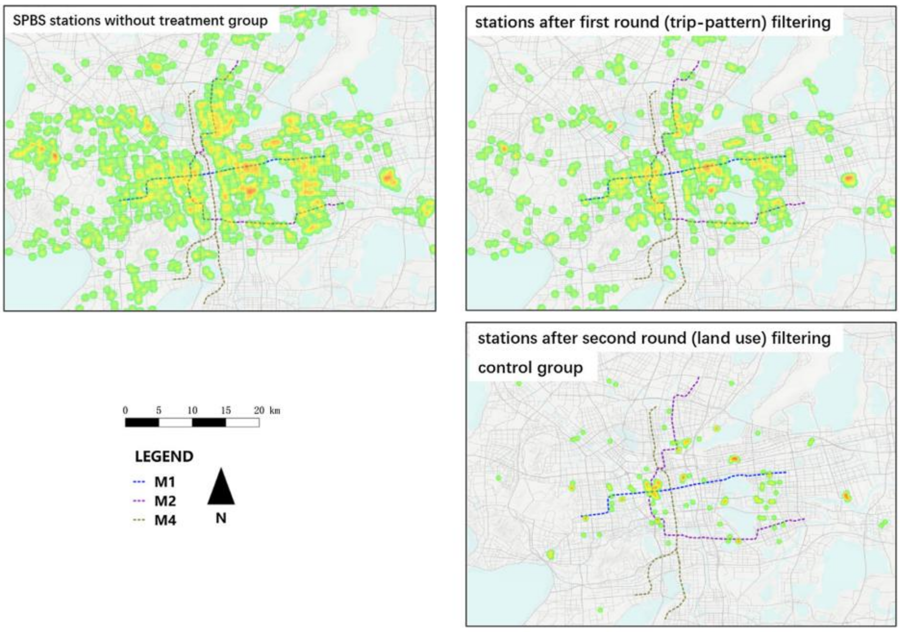


Fig. 10. Clockwise, distribution of SPBS stations without the treatment group, distribution of stations after first round filtering, distribution of stations after second round distribution (the control group).

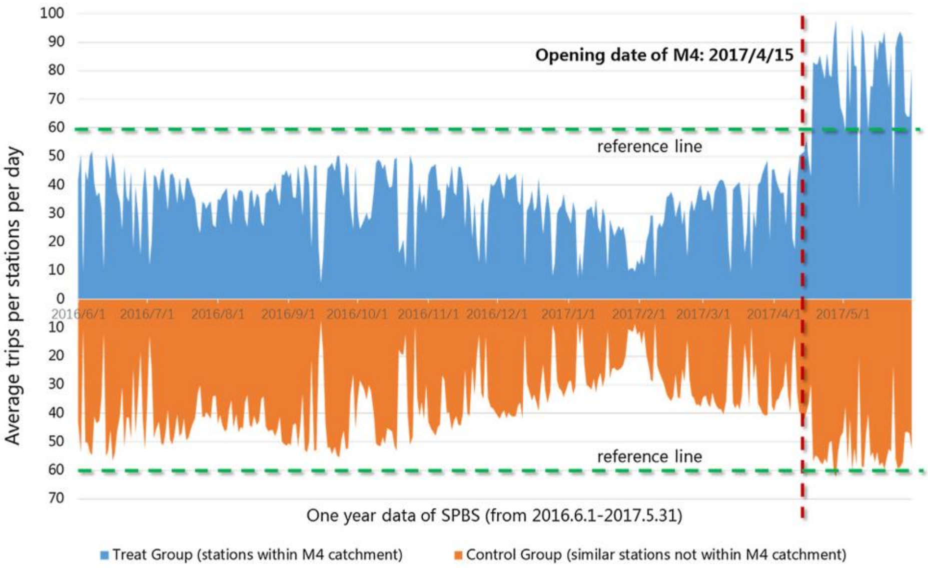


Fig. 11. A comparison between treatment and control groups in term of trip-count's annual distribution.

due to weather conditions as precipitation, which will be discussed in another paper.

According to Mobike's White Book of shared bike's development, the average speed of shared bike was 9.22 km/h in 2017 in China. Based on that, average trips lengths in different groups before and after M4 are around 2.4–2.7 km with a slight difference.

A summary table with the normalized operation index of the above figures is shown in Table 2. Which indicates that while

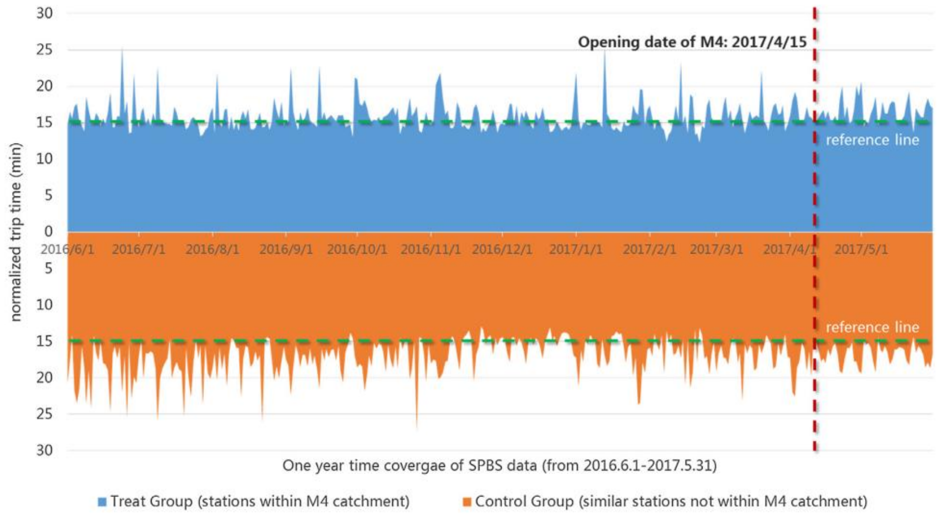


Fig. 12. A comparison between treatment and control groups in term of trip-time's annual distribution.

Table 2
Operation index before and after M4.

Status	Station groups	Number	Average trip-counts per station per day	Average trip's time (min)	Average trip's length (km)
Before M4	Treatment group	82	68	15.87	2.44
	Control group	193	72	17.11	2.63
After M4	Treatment group	82	157	17.03	2.62
	Control group	193	104	16.76	2.58

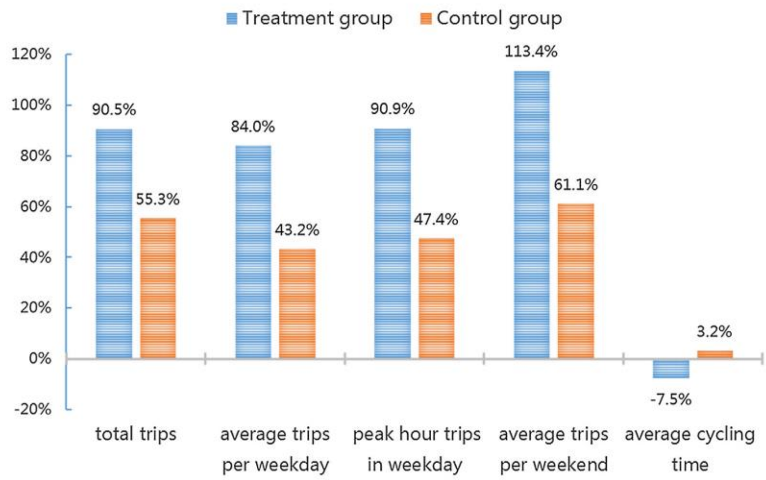


Fig. 13. Increasing rate of trips caused by M4.

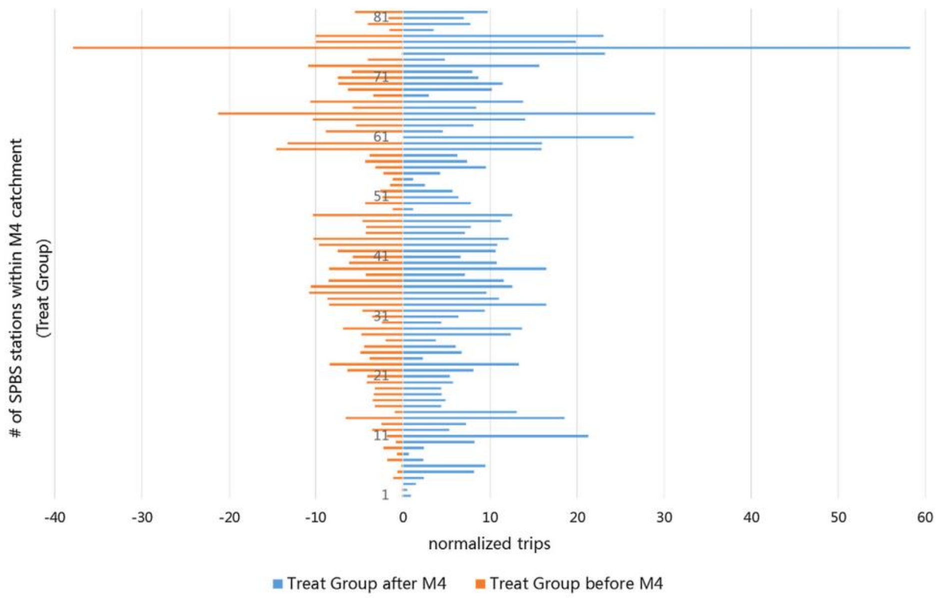


Fig. 14. Normalized trips before-and-after M4.

ridership increased significantly, trip's length and time remained stable. This means the turnover rate of bikes increased substantially, and the SPBS operator should increase rebalancing frequency as well as deploy new stations along with new metros.

4.1.5. Before-and-after analysis of trip-count in the same time duration

By analyzing pre- and post M4 datasets in a selected time duration in a city-level (orange bars in Fig. 13), trips are found to increase greatly after the M4 was introduced. The total SPBS ridership increase from 1.8 million to 2.67 million at a rate of 148.1% from March to May. Trips generated on weekdays and weekends increase 42.4% and 52.2% respectively, with weekend trips always exceeding those of working days. In other words, after the introduction of the M4, people used SPBS more on weekends to have leisure activities.

Furthermore, when focusing on the treatment group (blue bars in Fig. 13), more significant change could be seen compared to the control group. All-day trips and commuting trips on weekdays increase about 90% directly after M4 (morning peak is from 7:00 to 9:00 while evening peak from 16:30 to 18:30 based on local Annual Transport Report). And people use SPBS even more frequently at weekends - average trips per weekend is 8850 (after M4) vs. 4150 (before M4). Weekend trips grow 113.4% while weekday trips grow 84.0%. The larger increase in weekend trips compared to weekday trips at both city-level and selected stations means the new metro may trigger more non-commuting cycling than commuting cycling. The average cycle traveling time remains relatively still during this time.

Furthermore, we normalized weekday trips in the treatment group as average daily trips per station per dock before and after M4. The results are shown in Fig. 14. Blue group indicates normalized trips before M4 while orange means normalized trips after M4. Since most of the stations have a higher trip-count after M4, blue colors are mostly overlapped by orange and become brown. Normalized trips grow from 5.5 to 9.7. Most of the stations (79 out of 82) have witnessed increased normalized trips, only 3 out of 82 stations are found to have decreased trips (purple points in Fig. 15).

Interestingly, 2 out of 3 stations with decreased trip-count are both located in hubs between M4 and another metro line. In addition, the third one with decreasing trip is located near the Wuzhong government. It might be explained that more convenient metro services in central areas could attract former SPBS users, as Martin and Shaheen (2014) stated when they found new BS substituted metros in core urban areas while supported metro in marginal urban areas.

4.1.6. Before-and-after analysis of users' number in the same time duration

Since trip records in the original dataset also contain users' information, it could be used to investigate the users' change.

In general, users of the control group increased slightly from 54,221 to 60,353 over the 72 days before and after M4 opened (pre- and post-M4 dataset contains 36 days each). In particular, the number of active users, most of which are commuting users, grows significantly from 5879 to 7742 during the same time. See Table 3.

An active user is defined according to his or her travel frequency. In N valid days, if users have more than or equal to N/2 times trip records, they are active SPBS users. Otherwise, they are casual users.

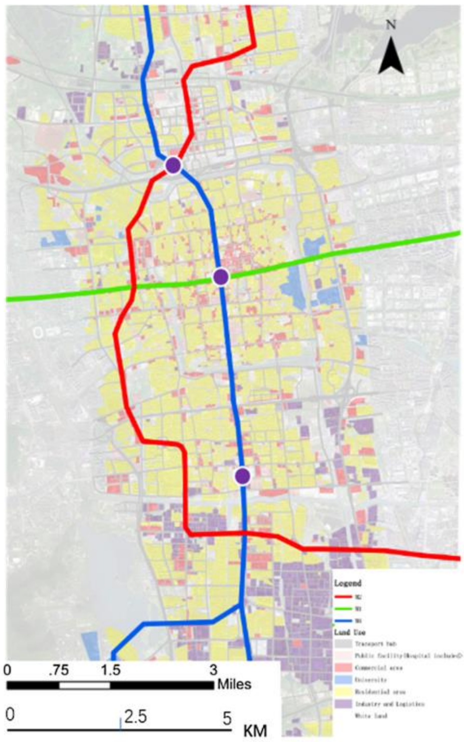


Fig. 15. Three SPBS station with decreased trip-count (purple points in the map).

Table 3
Change in users over the 72 days (36 days before M4 and 36 days after M4).

Control group (n = 193, unit: 100)			
Time	Users	Active users	Share of active users
Before_M4	542.2	58.8	10.8%
After_M4	603.4	77.4	12.8%
Rate of change	111.31%	131.70%	118.32%
Treatment group (n = 82, unit: 100)			
Time	Users	Active users	Share of active users
Before_M4	257.1	12.7	4.94%
After_M4	345.1	22.2	6.43%
Rate of change	134.21%	174.78%	130.23%

For the treatment group, new users and new active users increase at a substantial rate of 34.21% and 74.78% respectively. As expected, the growth of users and active users in the treatment group is faster than growth in the control group. This difference of growth rate of (active) users in an equivalent time interval between treatment and control groups indicates that the new metro triggered more SPBS users, especially new active users.

To sum up, several distinguished features could be found after M4 was introduced. As expected, after M4 began operation, it significantly triggers both ridership and user numbers, especially for SPBS stations in the treatment group compared to the control group, except for stations located in metro-hub. Moreover, while the M4 triggers an increase in both weekday and weekend trips, it encourages more cycling at weekends. It shows that a combination of transit and SPBS might create more non-commuting cycling than commute cycling. As for average cycling time, little difference is observed after M4 opened.

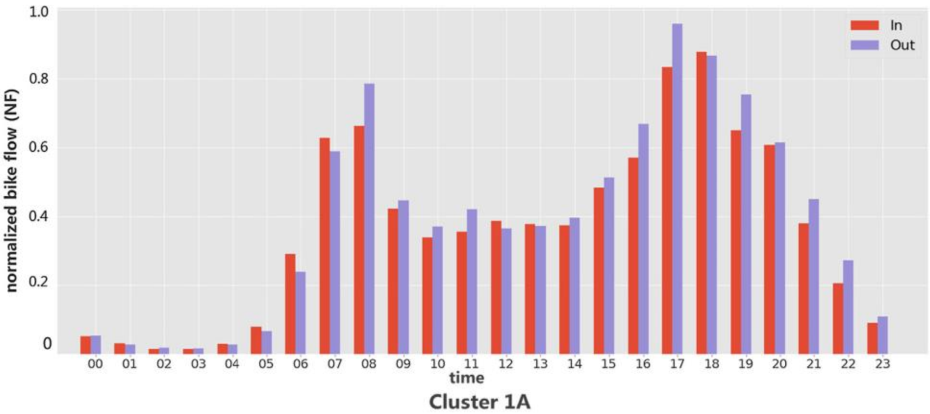


Fig. 16. Normalized bike flow of Cluster 1A.

4.2. Station-level change of trip-pattern

In this part, trip-pattern within the metro's catchment on weekdays is analyzed after M4 is introduced. Using the similar clustering process, post-M4 stations in the treatment group could be further clustered as three similar clusters. The cluster number is determined as 3 as it has the highest silhouette coefficient and could be compared with pre-M4 treatment group.

4.2.1. Cluster results of post-M4 treatment group

In post-M4 stage, most SPBS stations in CBD areas turn into imbalanced from the balanced pattern. Stations in the peripheral urban areas begin to show an imbalanced pattern as well. Still, three clusters could be determined as follow:

Cluster 1A – two peaks and balanced (similar to Cluster 1 in Fig. 6): 27 stations belong to this cluster as shown in Fig. 20 (red circles). They have a relatively balanced trip-pattern with two peak values (see Fig. 16). They mostly show in marginal residential areas in Xiangcheng and Wuzhong Districts.

Cluster 2A – two peaks and imbalanced with medium value (similar to Cluster 2 in Fig. 7): 54 stations belong to this cluster as shown in Fig. 20 (blue circles). There are two peak values, with more returned bikes in the morning and more rented bikes in the evening (see Fig. 17). They appear in most areas, not only in CBD area in Gusu District but also begin to show in Xiangcheng and Wuzhong Districts.

Cluster 3A – outlier with only one peak in the evening (similar to Cluster 3 in Fig. 8): Only 1 station belong to this cluster (yellow circle in Fig. 20). It is an outlier similar to Cluster 3 in the pre-M4 treatment group. It has an increasing trip trend to a single peak in the evening. More returning records occur during the daytime, while more renting activities occur after 6 pm (see Fig. 18). It is the same SPBS station located in an educational area in southwest Wuzhong District as in pre-M4 groups.

As for the only outlier (Cluster 3A) remains in educational areas in the southwest before and after M4, it is easy to explain based

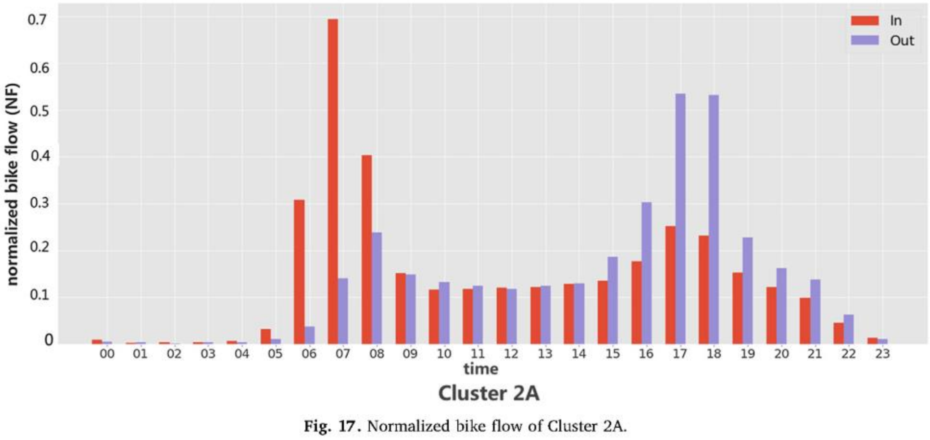


Fig. 17. Normalized bike flow of Cluster 2A.

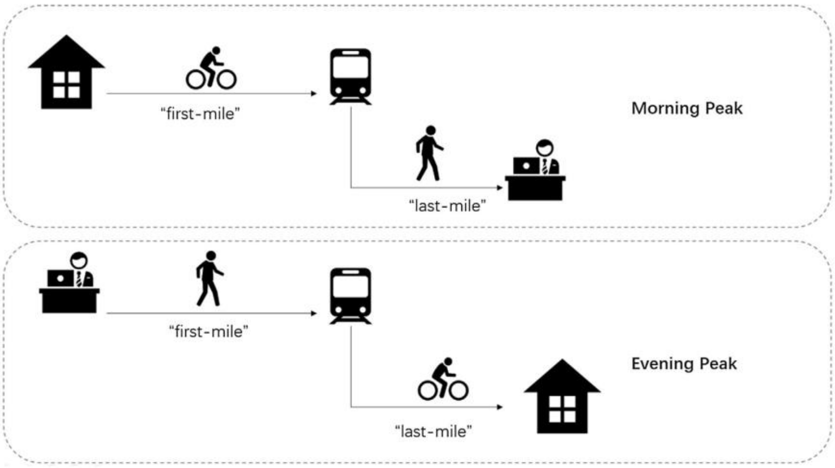


Fig. 21. SPBS serve"first-mile" in the morning and "last-mile" in the evening.

1 or Cluster 1A) to imbalanced (Cluster 2 or Cluster 2A) along with increasing trips could be seen. It is understandable in residential areas since people tend to cycle to "arrive" (shown as high returning) at metro stations near residential areas. However, this also occurs in metro stations near working areas and CBDs, where it was assumed people would "departed" (shown as high renting) from metro stations near working areas. The reasons are discussed in the following section.

4.3. The difference between "first-mile" and "last-mile"

The result of post-M4 clustering analysis suggests that higher SPBS arrivals (returning) happen near metros stations in commercial areas within core urban areas, where it was once assumed people would have used shared bikes to "depart" from metro stations to their workplaces and resulted in high renting (departure).

This might be interpreted as more people cycled to the metro stations to interchange M4 from their homes rather than cycling to workplaces from the metro stations in the morning and vice versa in the evening, as seen in Fig. 21. In other words, the SPBS mainly serves as "first-mile" in the morning and "last-mile" in the evening on working days. Until further information is collected and analyzed, it is uncertain why this happened after the M4 began operation. Abundant, convenient interchanges services to M4 other than SPBS (like bus, uber and other metro lines) in core urban areas might be one of the reasons.

Another reason might be the density of population, and relative low-efficient rebalance – the CBD areas, office areas normally have a relatively high density, which means it is more difficult to rent or return a bike in metro-stations in office areas. For example, in the morning, when a traveler departs from a metro station and has to walk a long time to rent a shared bike, he has to take the risk that the SPBS station might be empty, and he has to walk further to reach another station. Thus, it may take more time and physical effort to walk rather than cycle, as can be seen in Fig. 22.

Moreover, we monitor the SPBS stations in business areas in Gusu District (representative as popular trip destinations). Most of the stations are located next to offices and working places. It is found that normally these stations had higher NAB (normalized available bike) in the morning peak hour and lower NAB in the night peak hour before M4, which means users are hard to find

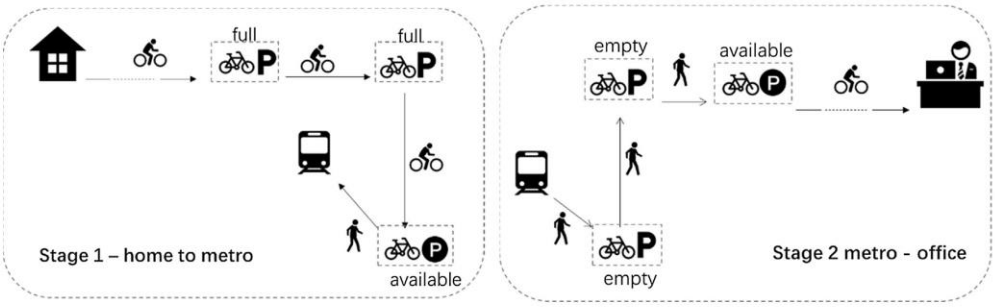


Fig. 22. Possible reasons behind "first-mile" over "last-mile" bike use.

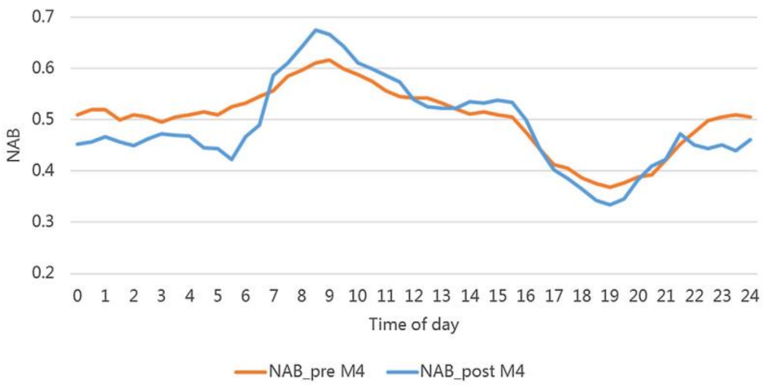


Fig. 23. NAB of stations in business areas before and after M4.

available bikes when they finish their work in the evening. This situation kept the same or even worsened after M4. Due to the increasing BS demands triggered by M4, the difference of NAB between morning and evening became more obvious. NAB kept lower in night peak hour (see Fig. 23). Since rebalancing efficiency improved not much as we discussed in Section 3.1, the users might still find bikes in nearby stations in low supply to cycle to M4 stations. In that case, they might walk to M4 as shown in Fig. 23.

5. Discussion and implication

5.1. Suggestions for local governments, urban planners and operators

With the background that more cities in China are introducing metros while they already had mature BS system (Bao, 2018; Dong et al., 2018), this research could be meaningful in many ways.

As for local governments, some suggestions are made so that interchange between BS and mass transit could function well. Since BS and metros are operated by different operators, a consistent operation mechanism between BS and mass transit should be built and led by local governments. This mechanism could bridge different operators, so that complains as lagging BS rebalance will not happen after new metros are introduced. Also, necessary planning and studies (like estimated BS ridership and trip-pattern) should be initiated by local governments in advance. Necessary ridership and trip-pattern estimation should be made by urban planners, based on which BS operators could do rebalancing schemes. In particular, since land use is found to correspond to BS trip-pattern change, a broad guide about how trip-count and trip-pattern might change after new metros open should be released from urban planners to BS and metros' operators. Universities, commercial areas, and residential areas have different demands and temporal distribution patterns so that they should be considered separately. How many new BS stations are required, and how to deploy them considering land use supplies should also be answered by urban planners since BS operators normally lack the impulse and capability to do such research.

Furthermore, for urban planners and policymakers, one of their tasks is to make a good preparation for a huge transport change, such as the prevalence of dockless bike-share (DBS). Since index in this study is based on continuous renting and returning trip data (just as DBS), rather than a discrete number of available bikes (which does not exist in DBS), it could be further used in DBS's before-and-after study. The inter relationship between DBS and metros could be further analyzed and improved based on our research contribution. This is very important for cities which have not equipped with dockless bike-share (like Suzhou). Take Suzhou as an example, although it banned DBS for now, as a mainstream encouraged by the central government, it is highly likely that DBS will flood in as it did in mega cities like Beijing, Shanghai, and Guangzhou. A before-and-after change study would be practical in making policies and operation schemes to deal with the impact of DBS.

As for BS operators, they are advised to follow local governments and urban planners' guides. Pre-arranged operation scheme should be made based on them so that BS rebalancing will not lag after new metros are introduced. When a new metro opens, normally BS demands to increase substantially along the new metro line (in our case, an 85%-115% ridership increase in weekday and weekend was observed). Thus, new BS stations are encouraged to deploy in advance, and higher frequency of rebalancing is required along with new metros. For instance, operation schemes in weekends and weekdays should be different. More rebalancing work is required in weekends according to our study. As for daily rebalance and maintenance, as trip-pattern normally changes after new metro, new rebalancing route scheme should be made to achieve a cost-effective aim and satisfy cyclists' needs. According to our research, trip demands in commercial areas in PM peaks needs to be met so that more commuters could use shared bikes from office to metros to finish "last-mile" interchange. The concerns about empty stations or fully-occupied stations could decrease.

5.2. Limitations and future research

Even if steps are taken to eliminate or at least mitigate bias, the SPBS growth, the prevailing season and weather, and the disorder resulting from a transitional period might still have a minor influence on the accuracy of research outcome. Moreover, although the rebalancing trips are already eliminated, once an SPBS station is full of parked bikes or empty, and no operator is available to rebalance it manually, it would cease to operate, and therefore the demand of renting cannot be fully revealed.

Still, due to data limitations, we are unable to track the long-term impact of mass transit on BS for now. Future research will expand time coverage of data to mitigate new mass transit's ramp up impact.

In this study, we focus on immediate impact rather than the reasons behind. In the further study, survey and questionnaires will initiate to investigate demographic factors that might affect this impact.

6. Conclusion

This study investigates the impact of a new metro on existing BS in terms of both trip-count and pattern considering land use. As expected, overall SPBS trips and users have increased at most stations since the introduction of the M4, especially for SPBS stations alongside M4 (the treatment group). SPBS and M4 inter-enhance rather than inter-replace each other in our case, even in CBD areas where these two modes were expected to conflict each other. However, two SPBS stations located in metro-hub are observed with decreasing trip-count. Future study will investigate the reason behind.

Different land use contexts tend to have distinct SPBS trip-pattern before M4 is introduced – trip-pattern in most areas is balanced, except for CBD areas. After M4 opened, for SPBS stations within M4's catchment (the treatment group), a general transfer from balanced to imbalanced is observed in all districts, regardless of land use except for the educational area in Wuzhong District. This result indicates that the SPBS served as "first-mile" interchanges (origin to metro) rather than "last-mile" (metro to destination) in the morning, and vice versa in the evening.

SPBS users, especially active users in the treatment group increased more after M4 opened. Evidence shows that a combination of M4 and SPBS creates more non-commuting cycling than commuting cycling while cycling time of SPBS remains still before and after M4.

A new index is developed in this study to indicate how trip-pattern change at a spatial level. The methodology employed in this study mainly relies on continuous real-time renting (flow-out) and returning (flow-in) number of bikes combining with location data, which could be further used in DBS. Because DBS have more accurate GIS data (DBS are generally equipped with GPS devices) with more accurate renting/returning number (DBS are normally less influenced by manual rebalance). Some research gaps (limitation caused by NAB, the difference in first-mile and last-mile, and before-and-after impact by new metros on BS) is filled.

In conclusion, the research results provide pragmatic implication not only to researchers but also to BS operators, government authorities and urban planners.

Acknowledgments

This work was supported by Jiangsu Industrial Technology Research Institute and CCDI Suzhou, China.

References

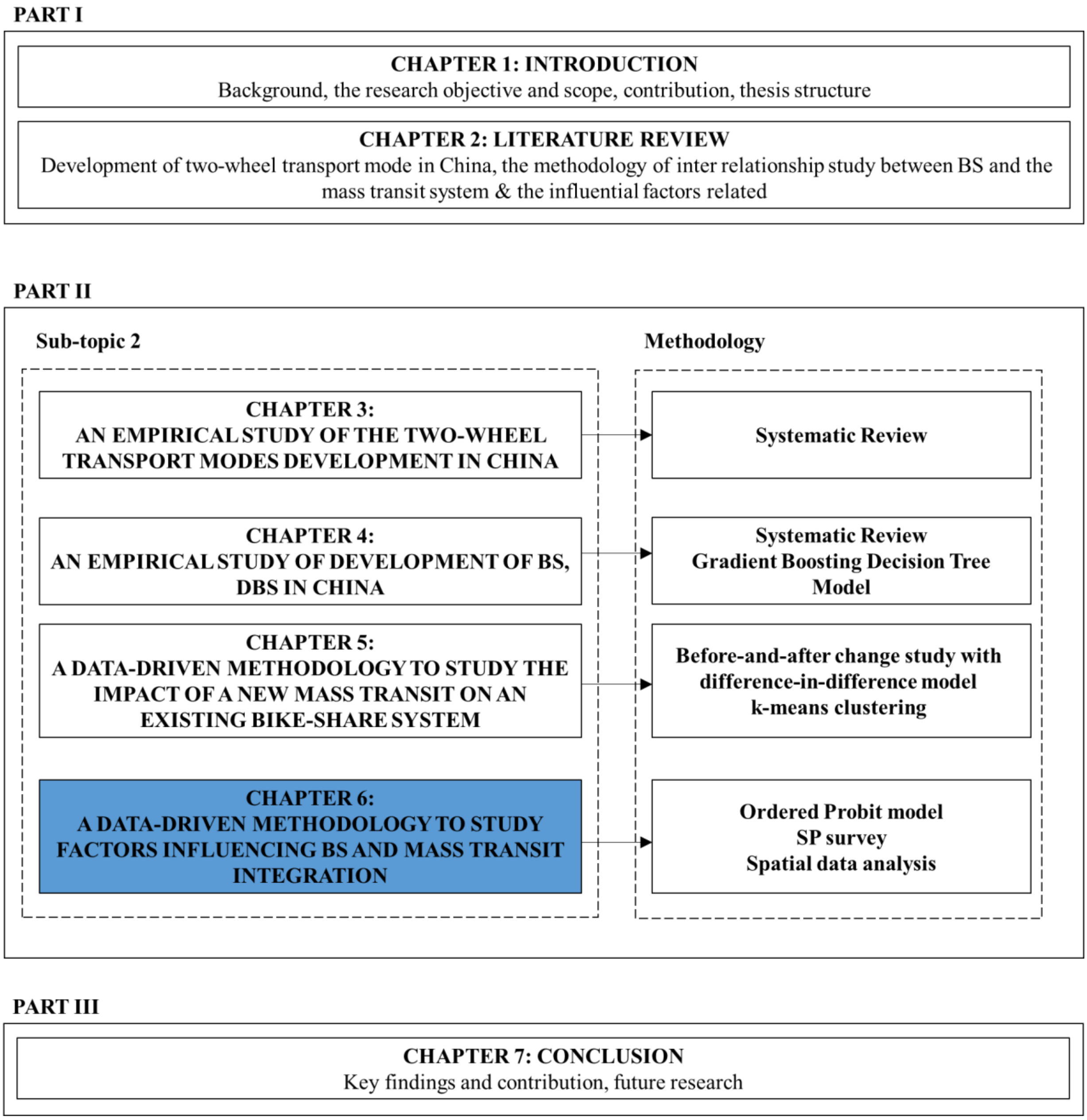
Bachand-Marleau, J., Larsen, J., El-Geneidy, A.M., 2011. Much-anticipated marriage of cycling and transit: how will it work? Transp. Res. Rec. 109–117.
Bachand-Marleau, Julie, Lee, Brian, El-Geneidy, Ahmed, 2012. Better understanding of factors influencing likelihood of using shared bicycle systems and frequency of use. Transport. Res. Rec.: J. Transport. Res. Board 2314, 66–71.
Bao, Xuding, 2018. Urban rail transit present situation and future development trends in China: overall analysis based on national policies and strategic plans in 2016–2020. Urban Rail Transit 4 (1), 1–12. https://doi.org/10.1007/s40864-018-0078-4.
Billings, Stephen B., 2011. Estimating the value of a new transit option. Reg. Sci. Urban Econ. 41 (6), 525–536.
Borgnat, Pierre, Abry, Patrice, Flandrin, Patrick, Rouquier, Jean-Baptiste, 2009. Studying Lyon's VéloV: a statistical cyclic model. Paper Presented at the ECCS'09, Warwick, United Kingdom. (2009-09-21).
Corcoran, Jonathan, Li, Tiebei, Rohde, David, Charles-Edwards, Elin, Mateo-Babiano, Derlie, 2014. Spatio-temporal patterns of a Public Bicycle Sharing Program: the effect of weather and calendar events. J. Transp. Geogr. 41, 292–305.
DeMaio, Paul, Meddin, Russell, 2017. The Bike-sharing World Map. Retrieved from www.bikesharingmap.com.
Ding, Wei, 2016. The relationship of built environment and weather with bike share–evidence from the pronto bike share system in Seattle.
Dong, Dan, Duan, Huabo, Mao, Ruichang, Song, Qingbin, Zuo, Jian, Zhu, Jiasong, Wang, Gang, Hu, Mingwei, Dong, Biqin, Liu, Gang, 2018. Towards a low carbon transition of urban public transport in megacities: a case study of Shenzhen, China. Resour. Conserv. Recycl. 134, 149–155. https://doi.org/10.1016/j.resconrec.2018.03.011.
Faghih-Imani, Ahmadreza, Eluru, Naveen, El-Geneidy, Ahmed M, Rabbat, Michael, Haq, Usama, 2014. How land-use and urban form impact bicycle flows: evidence from the bicycle-sharing system (BIXI) in Montreal. J. Transp. Geogr. 41, 306–314.
Fishman, Elliot, 2016. Bikeshare: a review of recent literature. Transp. Rev. 36 (1), 92–113.
Fuller, Daniel, Sahlqvist, Shannon, Cummins, Steven, Ogilvie, David, 2012. The impact of public transportation strikes on use of a bicycle share program in London: interrupted time series design. Prev. Med. 54 (1), 74–76.
Guerra, E., Cervero, R., Tischler, D., 2012. Half-mile circle. Transport. Res. Rec. 101–109.
Hatzopoulou, Marianne, Weichenthal, Scott, Dugum, Hussam, Pickett, Graeme, Miranda-Moreno, Luis, Kulka, Ryan, Andersen, Ross, Goldberg, Mark, 2013. The impact of traffic volume, composition, and road geometry on personal air pollution exposures among cyclists in Montreal, Canada. J. Eposure Sci. Environ. Epidemiol. 23 (1), 46–51.
Hu, Hong, Xu, Jiangang, Shen, Qing, Shi, Fei, Chen, Yangjin, 2018. Travel mode choices in small cities of China: a case study of Changting. Transport. Res. Part D: Transp. Environ. 59, 361–374. https://doi.org/10.1016/j.trd.2018.01.013.
Hurst, Needham B., West, Sarah E., 2014. Public transit and urban redevelopment: the effect of light rail transit on land use in Minneapolis, Minnesota. Reg. Sci. Urban

Econ. 46, 57–72.
Jarjour, Sarah, Jerrett, Michael, Westerdahl, Dane, de Nazelle, Audrey, Hanning, Cooper, Daly, Laura, Lipsitt, Jonah, Balmes, John, 2013. Cyclist route choice, traffic-related air pollution, and lung function: a scripted exposure study. Environ. Health 12 (1), 14.
Ji, Y., Fan, Y., Ermagun, A., Cao, X., Wang, W., Das, K., 2017. Public bicycle as a feeder mode to rail transit in China: the role of gender, age, income, trip purpose, and bicycle theft experience. Int. J. Sustain. Transport. 11 (4), 308–317. https://doi.org/10.1080/15568318.2016.1253802.
Kim, Kyoungok, 2018. Investigation on the effects of weather and calendar events on bike-sharing according to the trip patterns of bike rentals of stations. J. Transp. Geogr. 66, 309–320. https://doi.org/10.1016/j.jtrangeo.2018.01.001.
Lathia, N., Ahmed, S., Capra, L., 2012. Measuring the impact of opening the London shared bicycle scheme to casual users. Transport. Res. Part C: Emerg. Technol. 22, 88–102. https://doi.org/10.1016/j.trc.2011.12.004.
Li, Haojie, Graham, Daniel J, Majumdar, Arnab, 2012. The effects of congestion charging on road traffic casualties: a causal analysis using difference-in-difference estimation. Accid. Anal. Prev. 49, 366–377.
Li, Zhi-Chun, Yao, Ming-Zhu, Lam, WilliamH.K., Sumalee, Agachai, Choi, Keechoo, 2015. Modeling the effects of public bicycle schemes in a congested multi-modal road network. Int. J. Sustain. Transport. 9 (4), 282–297. https://doi.org/10.1080/15568318.2013.767398.
MacNaughton, Piers, Melly, Steven, Vallarino, Jose, Adamkiewicz, Gary, Spengler, John D., 2014. Impact of bicycle route type on exposure to traffic-related air pollution. Sci. Total Environ. 490, 37–43.
Martin, Elliot W., Shaheen, Susan A., 2014. Evaluating public transit modal shift dynamics in response to bikesharing: a tale of two U.S. cities. J. Transp. Geogr. 41 (Supplement C), 315–324. https://doi.org/10.1016/j.jtrangeo.2014.06.026.
Miranda-Moreno, L., Nosal, T., 2011. Weather or not to cycle: temporal trends and impact of weather on cycling in an urban environment. Transport. Res. Rec. 42–52.
Nair, Rahul, Miller-Hooks, Elise, Hampshire, Robert C., Bušić, Ana, 2013. Large-scale vehicle sharing systems: analysis of Vélib'. Int. J. Sustain. Transport. 7 (1), 85–106. https://doi.org/10.1080/15568318.2012.660115.
Parkes, Stephen D., Marsden, Greg, Shaheen, Susan A., Cohen, Adam P., 2013. Understanding the diffusion of public bikesharing systems: evidence from Europe and North America. J. Transp. Geogr. 31, 94–103.
Ricci, Miriam, 2015. Bike sharing: a review of evidence on impacts and processes of implementation and operation. Res. Transport. Bus. Management 15, 28–38.
Rokach, Lior, Maimon, Oded, 2005. Clustering methods. In: Maimon, Rokach (Eds.), Data Mining and Knowledge Discovery Handbook. Springer US, Boston, MA, pp. 321–352.
Rousseeuw, Peter J., 1987. Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. J. Comput. Appl. Math. 20, 53–65. https://doi.org/10.1016/0377-0427(87)90125-7.
Shaheen, Susan A., Guzman, Stacey, Zhang, Hua, 2010a. Bikesharing in Europe, the Americas, and Asia: past, present, and future. Transport. Res. Rec.: J. Transport. Res. Board 2143 (1316350), 159–167.
Shaheen, Susan, Guzman, Stacey, Zhang, Hua, 2010b. Bikesharing in Europe, the Americas, and Asia: past, present, and future. Transport. Res. Rec.: J. Transport. Res. Board 2143, 159–167.
Suzhou Planning Bureau, 2018. Suzhou Annual Transport Report_2017. Retrieved from http://www.szghj.gov.cn/.
Suzhou Statistical Bureau, 2018. Suzhou Annual Statistical Report_2017. Retrieved from http://www.sztjj.gov.cn/.
Wang, Jenhung, Tsai, Ching-Hui, Lin, Pei-Chun, 2016. Applying spatial-temporal analysis and retail location theory to public bikes site selection in Taipei. Transport. Res. Part A: Policy Pract. 94 (Supplement C), 45–61. https://doi.org/10.1016/j.tra.2016.08.025.
Wang, Mingshu, Zhou, Xiaolu, 2017. Bike-sharing systems and congestion: Evidence from US cities. J. Transp. Geogr. 65, 147–154. https://doi.org/10.1016/j.jtrangeo.2017.10.022.
Wu, Jiansheng, Wang, Luyi, Li, Weifeng, 2018. Usage patterns and impact factors of public bicycle systems: comparison between city center and suburban district in Shenzhen. J. Urban Plann. Dev. 144 (3), 04018027.

5.3 Chapter conclusion

Based on a data-driven methodology, this study investigates the impact of a new metro on existing BS in terms of both trip-count and pattern considering land use. As expected, overall SPBS trips and users have increased at most stations since the introduction of the M4, especially for SPBS stations alongside M4 (the treatment group). SPBS and M4 inter-enhance rather than inter-replace each other in our case, even in CBD areas where these two modes were expected to conflict each other. However, two SPBS stations located in metro-hub are observed with decreasing trip-count. Future study will investigate the reason behind. Different land use contexts tend to have distinct SPBS trip-pattern before M4 is introduced – trip-pattern in most areas is balanced, except for CBD areas. After M4 opened, for SPBS stations within M4's catchment (the treatment group), a general transfer from balanced to imbalanced is observed in all districts, regardless of land use except for the educational area in Wuzhong District. This result indicates that the SPBS served as "first-mile" interchanges (origin to metro) rather than "last-mile" (metro to destination) in the morning, and vice versa in the evening. SPBS users, especially active users in the treatment group increased more after M4 opened. Evidence shows that a combination of M4 and SPBS creates more non-commuting cycling than commuting cycling while cycling time of SPBS remains still before and after M4. A new index is developed in this study to indicate how trip-pattern change at a spatial level. The methodology employed in this study mainly relies on continuous real-time renting (flow-out) and returning (flow-in) number of bikes combining with location data, which could be further used in DBS. Because DBS have more accurate GIS data (DBS are generally equipped with GPS devices) with more accurate renting/returning number (DBS are normally less influenced by manual rebalance). Some research gaps (limitation caused by NAB, the difference in first-mile and last-mile, and before-and-after impact by new metros on BS) is filled. This chapter introduced how BS and mass transit systems interacts. Then in Chapter 6, the influential factors are investigated.

CHAPTER 6: A DATA-DRIVEN METHODOLOGY TO STUDY FACTORS INFLUENCING BS AND MASS TRANSIT INTEGRATION



6.1 Overview

In Chapter 5, the author investigated how bike-share usage behaviour (trip-count and trip-pattern) changed before-and-after a new metro was opened by a difference-in-difference methodology. In this chapter, reasons for this change is investigated.

Factors as users' demographics, land use, weather, POI, infrastructure are widely studied and accepted as influential factors in the interrelationship between metros and BS (Campbell et al. 2016; Zhang et al. 2017). However, research gaps still exist. Since most of the former factors are investigated based on case studies conducted in developed or car-oriented communities. In the places experiencing transforming periods and confronting conflicts caused by booming cars and cycling tradition, unique factors might exist.

To promote cycling (BS cycling included), a common understanding is to build a cycling-friendly infrastructure, which usually means exclusive and safe cycling lanes (Abolhassani, Afghari, and Borzadaran 2019; Chen, Liu, and Sun 2018). Meanwhile, seldom does research investigate if physical road separations as fences or green belts have any adverse effect on cycling. As a matter of fact, in many developing communities in East Asia, as China, a mode share of non-motor vehicles could be with substantial proportion as over 50% (Gu, Kim, and Currie 2019). Urban planners or road designers are used to deploying multiple columns of separations in one road out of the concerns of safety – to protect the "vulnerable road user". By using this term "vulnerable road user", it is implicitly suggested that there are others on the road who have the right to cause vulnerability. However, when the number of cyclists (E-bikes included) outnumbers the car drivers, cycling's advantage of flexibility should be given priority. Then the concern is – separations, while they are supposed to protect cyclists, might bring inconvenience for cyclists since they could impede the cyclists from reach the other side of the road (see Figure 6-1). This is also confirmed by the research outcome in Chapter 3. Since BS stations and metros stations are normally deployed in a single side of the segment or corners of the intersection, BS and metros users are required more detouring or crossing street activities to rent/return the shared bicycles. Besides, since multiple road separations are normally designed in the arterial road, it could be inferred that arterial road, rather than small alleys, might be unfriendly to BS users and metros' users. Therefore, the author investigate if road separations have any effect on the integration between BS and metros.

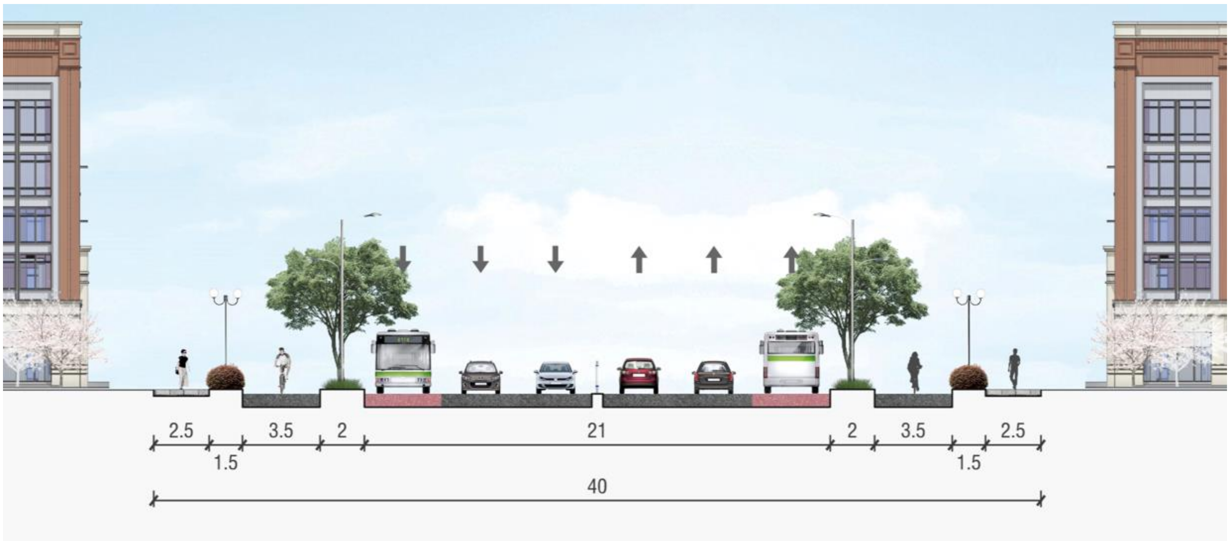


Figure 6-1 A typical main road cross-section design.

Source: Huifen (2018). Note there are five physical separations (one fence, four green belts). If a cyclist wants to reach the other side of the road, he has to cross four separations.

Moreover, as mobilization goes intensified and traffic congestion grows, car drivers sometimes turn to BS and metros. This is also confirmed in surveys in Chapter 1 and 2. Therefore, in this component of research, traffic congestion and parking fee are also studied to see if these motor-vehicle-related factors feedback the usage of BS and metros. Although the combination between BS and metros is considered to mitigate traffic congestion (Hamilton and Wichman 2018; Yang et al. 2018), barely any study focused on private motor vehicle's impact on BS. For instance, the metros' lines and stations, as well as BS stations could scheme in the most congested network topology. It could also promote BS and metros' usage by adjusting the parking fee in particular areas. For BS and metro operators, their operation scheme, charging policies could be set up based on information as traffic congestion, as in places with heavy traffic congestions, more frequent BS and metros rebalancing work are needed.

As for methodology, a data-driven one needs two major groups of datasets. Firstly, various spatial variables need to be collected, including new variables (infrastructure, congestion condition, road separation). Besides, a survey is designed and conducted to not only achieve demographic attributes but acquire BS usage change options to build the model. The possible infrastructure factors are inspired by the contents of Chapter 3 and 4, then confirmed in our survey and local transport reports. A changing idea of infrastructure design (represented by road separation), traffic congestion, and parking fee are identified in a developing community-context. Then by building an ordinal probit model, significant impact factors could be determined.

The research gap and objective are described in Table 6-1.

Table 6-1 Research gap and objective of Chapter 5

Research topic	Research gaps	Research objective
An study of factors influencing BS and mass transit integration	➢ The limited studies of the potential influential factors as traffic condition and road design, considering developing communities' fast transforming background	Building models to identify significant factors influencing inter-relationship between BS and mass transit based on a data-driven methodology, which are unique and inspiring for developing commutes.

6.2 A case study

The case study follows Chapter 5. After investigating what happens when a new metro line opened in Suzhou, China, influential factors are studied in this chapter.

6.2.1 The survey of mode shift

An interrupt survey was initiated along with M4 stations to identify the factors that might influence the integration of the new metro and an existing BS. The survey is designed to investigate metro users' travel mode shift after the new metro opened. Preference. An interrupted survey is arranged along the newly opened M4, while 1336 participants were involved in this survey, 1062 valid responds were acquired finally.

The survey was conducted from 10th May 2018 (Thursday) to 13th May (Sunday), 2018 - one year after M4 opened. One year is long enough to avoid a ramp-up effect, yet not too long to forget the user's habits before M4 opened. In these consecutive four days, the weather was good, and no national holidays occurred. Surveying locations were the entrance of M4 stations, where SPBS stations were not far away (generally within 50 meters of metro entrances). The survey covered peak hours (7:00-9:00 am, 5:00-7:00 pm) both in the morning and afternoon. Participants were metros' users, and they were asked to answer questions about their personal information, trip's information (goals, loading and unloading stations), the frequency of metros' usage, and SPBS's usage. They were required to answer the question, "After M4 opened, how did you change your frequency of using SPBS?" The options contained "increased a lot", "increased a little", "no change", "decrease a little", and "decrease a lot". A total of 1336 participants were involved in this survey, and 1062 valid responds were acquired finally. A statistic of the participants is presented in Table 6-2. It turns out that the participants are almost gender equal. Most of them (over 65%) are young men (age < 30) with a higher educational background (bachelor's degree or above). Family income distribution is relatively even. Most of the participants (around 75%) have a family income of less than 240 thousand RMB (35.6 thousand US dollars). The most popular occupation are company employees and students. Also, the author list the trip purposes, most of the users (nearly 60%) used metros as a commuting mode.

Table 6-2 Participants' personal information

Item	Subgroup	Freq.	Proportion	Cum.
Gender	male	557	52.45%	52.45%
	female	505	47.55%	100%
Age	<16	57	5.37%	5.37%
	16~25	464	43.69%	49.06%
	26~30	246	23.16%	72.22%
	31~40	203	19.11%	91.33%
	41~50	52	4.90%	96.23%
	51~60	32	3.01%	99.24%
	>60	8	0.76%	100.00%
Educational background	middle school or low	104	9.79%	9.79%
	high school	257	24.20%	33.99%
	bachelor	539	50.75%	84.74%
	master or above	162	15.26%	100.00%
Occupation	company employee	420	42.09%	42.09%
	government officer	165	16.10%	58.19%
	student	369	30.60%	88.79%
	retired	28	3.67%	92.46%
	others	80	7.54%	100.00%
Family Income (unit: thousand RMB)	<60	129	12.15%	12.15%
	60-90	169	15.91%	28.06%
	90-150	303	28.53%	56.59%
	150-240	224	21.09%	77.68%
	240-360	140	13.18%	90.87%
	360-500	68	6.40%	97.27%
	>500	29	2.73%	100.00%
Trip purpose of using M4 in the usual time	go to work	417	19.04%	19.04%
	go to school	222	10.14%	29.18%
	recreation	451	20.59%	49.77%
	tour	187	8.54%	58.31%
	business	220	10.05%	68.36%
	go home	636	29.04%	97.40%
	others	57	2.60%	100.00%

The author listed some general multi-choice questions about the reasons why participants use BS or not use BS. Each participant was asked to choose three reasons at most. The top 7 reasons to promote/suppress BS use were listed in Figure 6-2 and Figure 6-3. The most popular reasons were the cheap fee, and meeting trip demands to interchange metros. Wellbeing, free from the concern of theft, was also chosen widely. Interestingly, for many car owners, they also chose BS plus metros since they are unhappy with the traffic congestion and high parking fee, which inspired us. Similar to the annual transport report, "no bicycle or dock available" and "long walking distance to rent a bicycle" were top two reasons why people DO NOT use BS. Apart from that, the concern to detour to cross the street by road separations was also a big reason, which is considered into impact factors' data preparation.

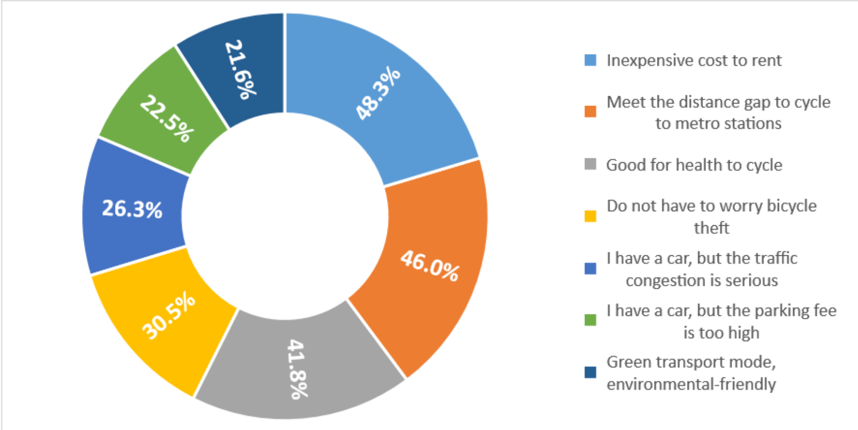


Figure 6-2 Top reasons why survey participants use BS.

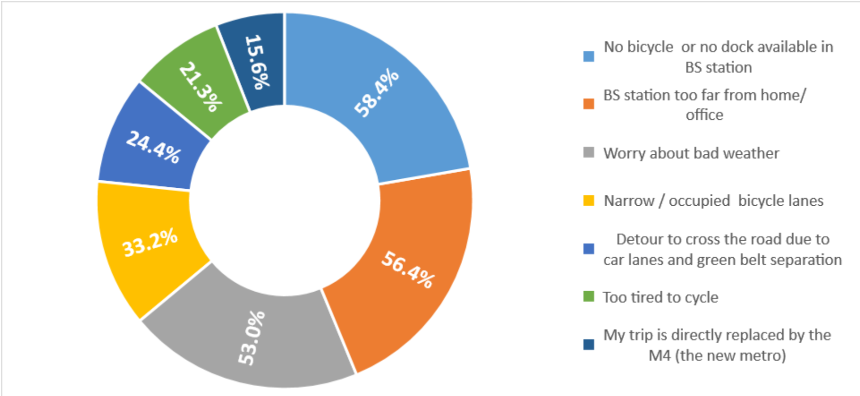


Figure 6-3 Top reasons why survey participants DO NOT use BS.

6.2.2 Variable preparation

For each participant, the personal attributes were acquired directly from the survey. Other variables as traffic congestion and road separation, were acquired based on survey areas. Therefore, the first step of data preparation is to define an area that covers the necessary variables. To achieve a precise service area, a cyclable network considering Thiessen Polygon is introduced.

In this study, since the survey was conducted along M4, service areas around these metro stations are determined through Thiessen Polygons, network distance, and distance-decay weighting.

According to the local BS planning, for each metro station, 2-3 BS stations are deployed within 50 meters of the metros' entrances. These BS stations are directly functioned as Interchanging BS Stations (IBS). In corresponding to these IBS, there are origin BS stations (OBS) from residential areas or commercial areas. When people use BS to interchange M4, a pair of IBS and OBS could be interpreted as OD of the BS cycling route. The max cycling distance is seen as the service area as shown in Figure 6-4. The service area is not the walking distance, but cycling distance from IBS to OBS.

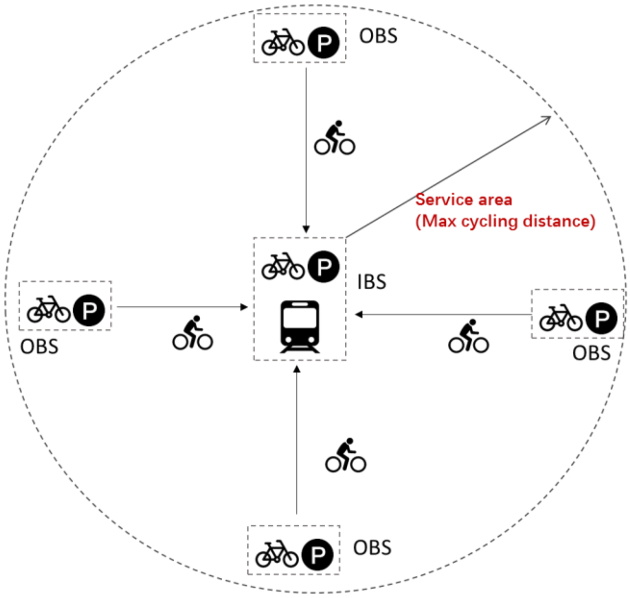


Figure 6-4 The concept of the service area.

Some steps are taken to create the service areas along M4. Firstly, normalized BS trip time around surveyed metro stations is calculated based on trip data. Then an all-or-nothing straight-line distance service area is set up while the radius is the corresponding normalized BS trip distance considering decay function. This decay function is defined as:

$f_i = 1/d_i^2$,

where *di* is the distance between the metro station and any point in the all-or-nothing straight-line distance service area (Gutiérrez, Cardozo, and García-Palomares 2011; Noland, Smart, and Guo 2016).

Since BS trip distance could not be acquired directly from the dataset. Firstly, normalized BS trip time is derived from statistical trip time, as shown in Figure 6-5 as follows. Normalized BS trip distance is then converted from normalized BS trip time by multiplying average cycling speed.

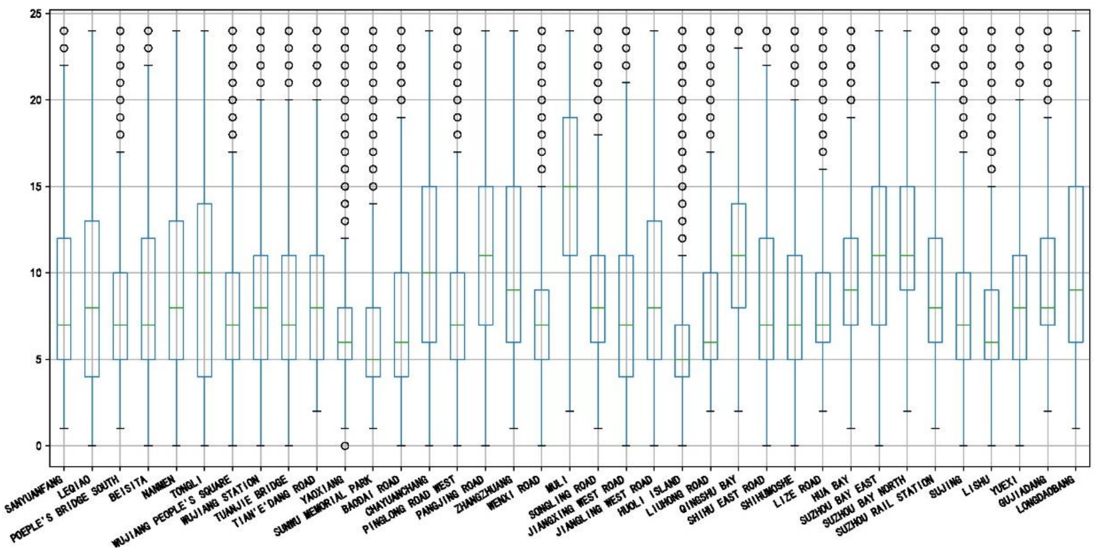


Figure 6-5 Normalized cycling time near each metro station (unit: min)

In the next step, a cycling network is built by information acquired from Gaode cycling Navigation function - a mainstream navigation APP in China (similar to Google navigation) (García-Albertos et al.

2018). Finally, having the hypothesis that BS cyclists only interchange the nearest metro stations, Thiessen Polygons of each metros' station are created and overlapped with a series of network distance service areas considering distance-decay. Take one of the stations "Beisita Station" as an example; the above process of creating service areas could be seen in Figure 6-6. Firstly, an all-or-nothing straight-line distance service area considering distance decay is established. Then in phase two, by adding the real cyclable network (some alleys included that cannot allow cars to enter), the cyclable network is optimized. In the third phase, the Thiessen Polygon of Beisita Station is created. The overlapping part of phase two and three is the service area used in the model afterward. The service areas along M4 is shown in Figure 6-7.

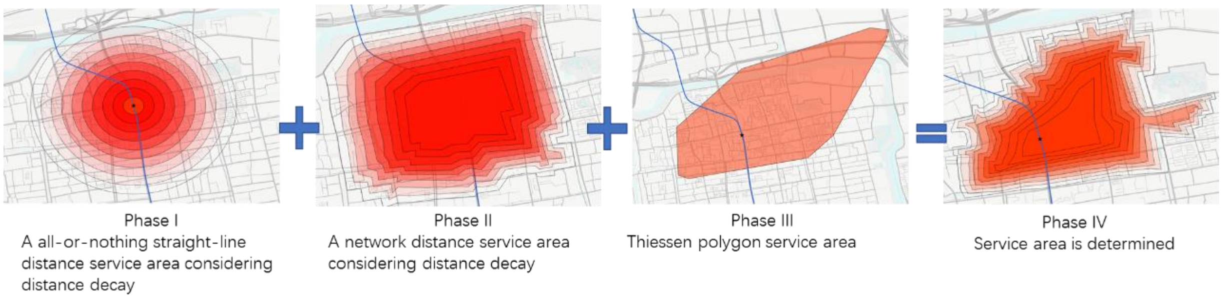


Figure 6-6 Process of building up a service area, take Beisita station as an example

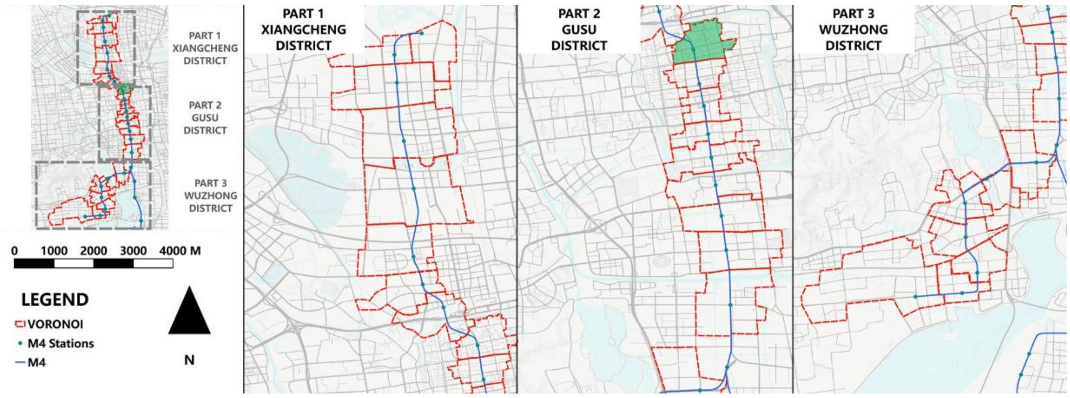


Figure 6-7 Service areas alone M4

Note that the green shadow indicates Beisita station's service area.

As discussed in the previous section, standard variables as participants' demographics, infrastructure as a bus route, cyclable network density are listed here as possible impact factors. Newly inspired variables as traffic congestion, parking fee, and road separation are also considered. Related data (road network, transit route, number of road separation, and parking fee) are provided by the local planning bureau. In the preparation process, the author calculated and normalized these variables (apart from demographics, other variables are listed in Table 6-3). For instance, for network density (ND), for each metro station along M4, the ND is defined as:

$ND_i = L_i\,(f_i) / A_i,$

where *i* indicates metro station *i*'s service area,

L_i indicates road network length.

f_i is a decay function.

As for the traffic congestion, in a very recent study conducted in Madrid, García-Albertos et al. (2018) calculated travel times between transport zones using the Google Maps API and constructed origin and destination (OD) travel matrices. It inspired us to turn to a local Navigation Map's API to acquire the congestion index (since congestion could be indicated as velocity or travel time). The congestion is defined as:

$C_i = (\,T_{i,p} - T_{i,f}\,) / T_{i,p}$

where *i* indicates the participant's ID;

$T_{i,f}$ indicates driving time in midnight for participant *i* 's OD metro stations, derived from Gaode API;

$T_{i,p}$ indicates driving time in afternoon peak hour (5 pm to 7 pm) for participant *i* 's OD metro stations, derived from Gaode API.

Table 6-3 Variables in data preparation

Variables	Definition	Data source
Normalized network density (ND)	Road network length considering decay function over the area in a particular metro station's service area	Urban Planning Bureau
Normalized cyclable network density (CND)	Cyclable network length (some alleys included that cannot pass cars) considering decay function over the area in a particular metro station's service area	
Normalized number of physical road separation (PRS)	Average road separations number considering decay function in a particular metro station's service area	
metro's hub (HUB)	Whether or not this particular metro station is a metro hub	
Normalized bus routes' density (BRD)	Number of bus routes considering decay function over the area in a particular metro station's service area	
Normalized parking price (PR)	Average parking price considering decay function in a particular metro station's service area	Urban Administration Bureau
Congestion (C)	Peak hour driving time minus free driving time over Peak hour driving time for participant's metro trip	Gaode Navigation APP

To organize these variables, the author plotted them based on service areas along M4. For instance, information of the cyclable network density (Figure 6-8), road separation (Figure 6-9), transit network (Figure 6-10) as well as parking fee (Figure 6-11) are processed in a normalized way. It is obvious from Figure 6-8 that Gusu District (the centre district) has relatively high cyclable network density, low separation number, and a high park fee. For instance, Beisita Station (located in the Gusu District) has smaller cyclable alleys compared to Huoli Island Station (located in the northern Xiangcheng District), as can be seen in Figure 6-12.

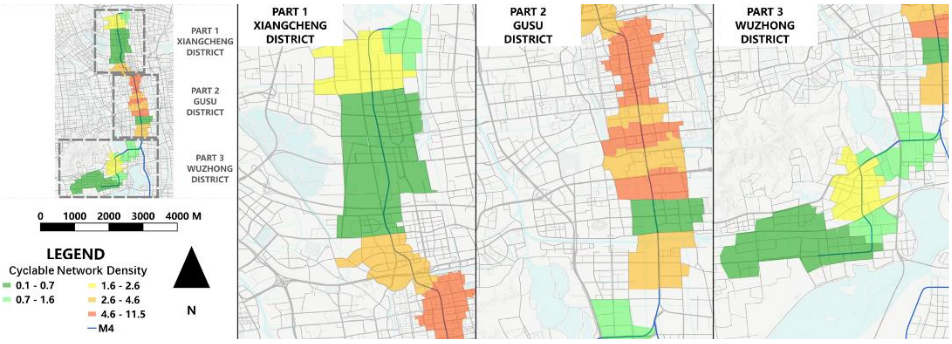


Figure 6-8 Cyclable network density in service areas along M4

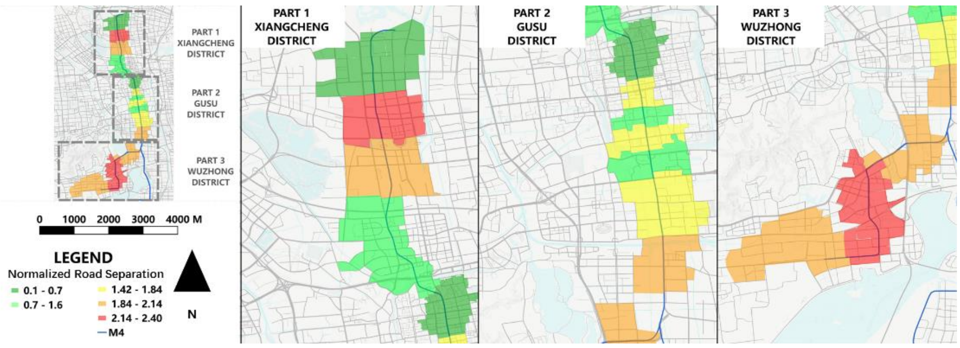


Figure 6-9 Normalized road separation number in service areas along M4

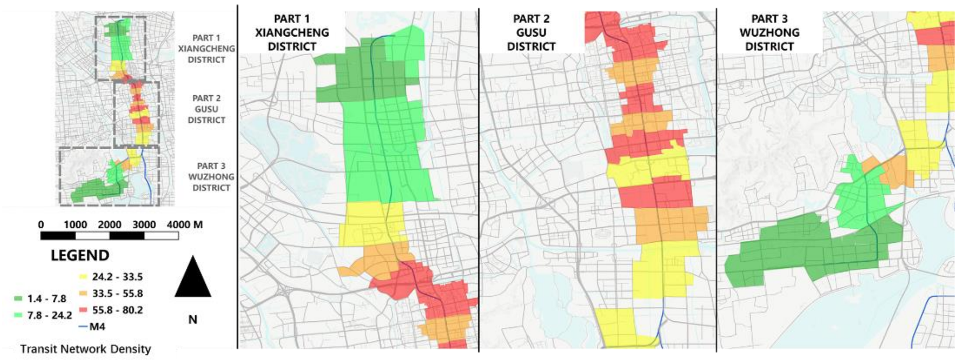


Figure 6-10 Transit network density in service areas along M4

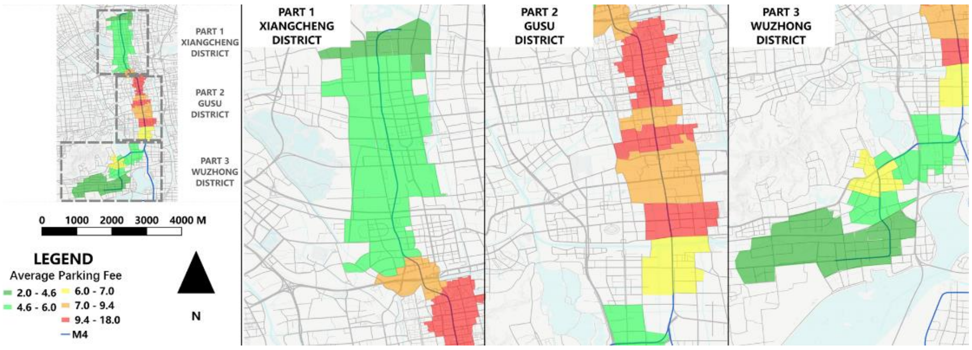


Figure 6-11 Average parking fee in service areas along M4

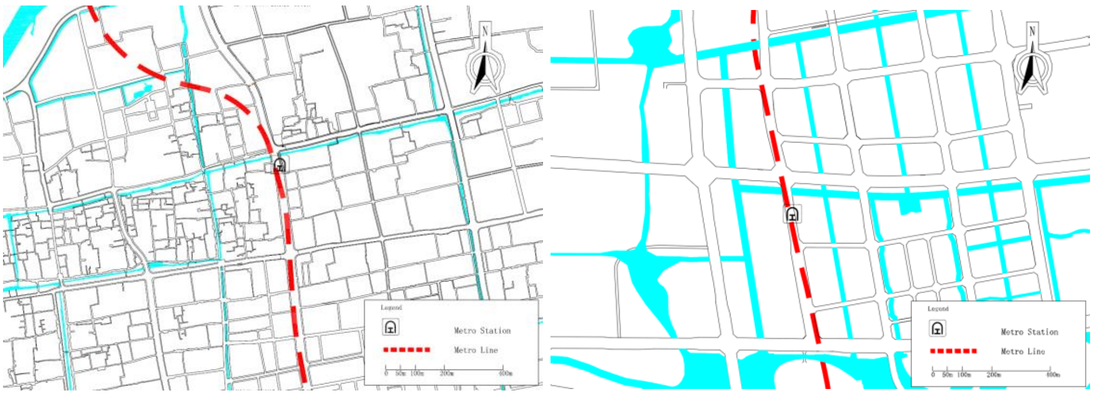


Figure 6-12 A comparison between Beisita Station and Huoli Island Station in terms of the cyclable network.

Note that these two figures are on the same scale.

6.3 Results

6.3.1 BS usage change of survey respondents

As for the question "How did you change the frequency of SPBS usage after the new M4 opened?", participants are required to answer the question in two scenarios – on weekdays and weekends.

Table 6-4 Statistical description of the choice change question

Day of the week	Answers	Frequency	Proportion (%)	Cum.
weekday	greatly increase	195	18.36%	18.36%
	increase	223	21.00%	39.36%

	not change	351	33.05%	72.41%
	decrease	201	18.93%	91.34%
	greatly decrease	92	8.66%	100.00%
weekend	greatly increase	270	25.42%	25.42%
	increase	301	28.34%	53.77%
	not change	258	24.29%	78.06%
	decrease	126	11.86%	89.92%
	greatly decrease	107	10.08%	100.00%

As seen in Table 6-4, on weekdays, nearly 40% of the metro users increased their SPBS usage frequency ("increase" and "greatly increase"), and one-third of the users remained the same usage frequency. As for weekends, over 50% of participants increased SPBS usage. The overall trend is that after M4 opened, more people turned into SPBS, which was more evident at the weekend.

6.3.2 Modelling results

Ordered probit is a generalization of the widely used probit analysis to the case of more than two outcomes of an ordinal dependent variable (a dependent variable for which the potential values have a natural ordering, as in poor, fair, good, excellent). Since participants are asked to answer their change of frequency in an ordered level, the ordered probit model is used in this study. In our case, the survey participants were asked if they "greatly increase" /" increase" /" maintain" /" decrease" /" greatly decrease" their BS usage after a new metro was introduced. Similar to studies conducted by Martin and Shaheen 2014, as these options are non-numerical while it could be seen in a structured order, an ordered probit model is then established to investigate if explaining variables as personal information, traffic conditions, cyclable infrastructure are significant influential factors in mode shift. Participants are randomly selected in 7 stations along M4, covering various land-use situations – core areas with dense and mixed land-use and good cyclable condition as well as marginal areas with the car-oriented road network and single land-use. To further mitigate the potential redundant correlation caused by environmental factors, the survey time covered not only commuting peak hours but the whole day as well.

Ordered probit modelling results are shown in Table 6-5, considering the difference between weekdays and weekends. Demographic variables as gender, age, family income, education level (4 levels), and job (5 types) are included. The ways to access to SPBS is also determined as a variable. Two ways exist in renting the bikes. The traditional way is to deposit 200 RMB in a membership card. Users use that card to rent the SPBS bikes. The other way is to use a smartphone and a popular online payment APP to rent the bikes. The author also include the variable whether the private bikes' stolen experience would affect as other research did (Ji et al. 2017). Apart from that, the traffic conditions (congestions, parking fee) and cycling infrastructure conditions discussed before (cyclable network density, road network density, road separation number, bus routes' density) are included as well.

Table 6-5 Ordered probit regression on the mode shift (with some lines about education and job omitted)

VARIABLES	**(weekday) y1**	**(weekend) y2**
gender	-0.0562	-0.0558
(male=1, female=0)	(0.0746)	(0.0758)
age	0.0190***	-0.0685
	(0.0052)	(0.0459)
family income	-0.0177	0.00607
	(0.0268)	(0.0271)
edu_2	0.182	0.185
	(0.160)	(0.162)
Job_5	0.123	0.144
	(0.150)	(0.152)

method of using SPBS	-0.0630**	-0.0858
(card =0, smart phone=1)	(0.0287)	(0.100)
bicycle stolen experience	0.0414	0.0169
(yes=1, no=0)	(0.0790)	(0.0804)
network density	0.0752	0.0488
	(0.127)	(0.133)
cyclable network density	-0.139***	-0.0732***
	(0.035)	(0.0140)
number of columns of physical road separation	0.273**	0.250**
	(0.107)	(0.109)
metro's hub	0.135**	0.399***
(yes=1, no=0)	(0.0611)	(0.115)
bus routes' density	-0.00306	-0.00214
	(0.00419)	(0.00426)
parking price	-0.0171*	-0.0892***
	(0.0092)	(0.0170)
congestion	-0.514**	-0.284
	(0.255)	(0.164)
observations	1,009	1,009
Pseudo R^2	0.2023	0.1516
LR chi^2 (28)	368.52***	222.14***

Note that ***，**，* indicate significant at 0.01，0.05，0.1 separately. Figures in brackets are a standard error.

The modelling results could be seen in Table 6-5. The proposed weekdays' model is tested by Pseudo R2 (20.23%). LR chi2 equals 368.52 (significant at 0.01), which means the overall model is significant at a high confidence interval. Age has a positive correlation with the SPBS choice shift (the shift is from an increase to decrease) at $P<0.01$ level, which means that younger the participants, the high possibility they increase SPBS usage after M4. The method of using SPBS includes a traditional way of swiping cards as well as scanning QR code by smartphone. It has a negative correlation with the SPBS choice shift at $P<0.05$ level, which indicates that participants using smartphones to rent SPBS are inclined to increase SPBS after M4, which is reasonable since young people are more likely to use smartphones. As for traffic and infrastructure conditions, some road separations ($P<0.05$), proximity to metros' hub ($P<0.05$), and cyclable network density ($P<0.01$) are seen to have a negative correlation with the SPBS choice shift. In other words, in a particular service area, if a road has too many columns of separations, higher cyclable allies' density, and is close to a metro's hub, the metros' users are more likely to decrease SPBS usage after new metro is introduced. The parking fee ($P<0.1$) and congestion level ($P<0.05$) are positively correlated with the SPBS choice shift, which indicates that higher parking fees and congestion levels promote more cycling for metros' users. The other impact factors, including some demographic characteristics, bus routes' density, and road network density, show no significance in the model. As for the bus route density, it might be because most of the bus routes remain the same after M4 opened.

In the weekends' model, Pseudo R2 is 15.16%, while LR χ^2 equals 222.14 ($P< 0.01$). The majority of the variables remain the same as in weekdays' model. However, the age, method of using SPBS, congestion level lose significance in the weekends' model. Many aged metros' users also turn to SPBS at weekends, which makes the variable "age" less significant, so as the method of using SPBS. Since people care less about trip-time (no need to rush in peak hours), the change of congestion level (from significant to insignificant) becomes understandable.

6.4 Discussion and suggestions

From the result, proximity to a metros' hub (the new metro line and an old metro line's intersection) plays an adverse role in using BS to interchange to metros. It is assumed that as a new metro opens, the new hub attracts some former cyclists because they could directly interchange from different metros' lines without leaving metros' stations to rent bikes. Also, this result is consistent with what the trip-count analysis shows us – among all the BS stations within M4 catchment, only three BS stations witnessed a decreased BS trip-count, in which two of the three locates just next to metros' hubs.

More road separation brings inconvenience for cyclists. Although exclusive bicycle lanes are beneficial to promote cycling in some studies, the situation in Suzhou is quite different. As a city with cycling tradition and high dense cyclable network, SPBS cyclists tend to cycle in small roads with few separations. Small roads typically have fewer motor vehicles and slow vehicle speed limits, which make the safety of cycling within an acceptable level. According to this finding, when planning and design roads, urban planners should be well advised to treat road separations cautiously. The separation design should consider the balance between safety and convenience. For road designers, they are highly recommended to reconsider before implementing multiple road separations before construction – at least in areas where metros' stations and BS stations are located.

Congestion and parking fee levels have active feedback on SPBS's integration with metros. From the survey, after M4 opened, some long-distance trips used to be completed by cars were replaced with the combination of metros and SPBS. As BS and metros are considered to mitigate traffic congestion, the congestion itself in return reacts to promote BS usage with metros. Therefore, policymakers and urban planners could make more effective low-carbon policies and practice them - by evaluating traffic conditions and scheming the metros and BS deployment according to the level of traffic congestions. For BS operators, it is a good strategy to deploy more BS fleets in congested areas since the cycling demands to the metros are higher. A more frequent rebalancing service is also needed in these areas.

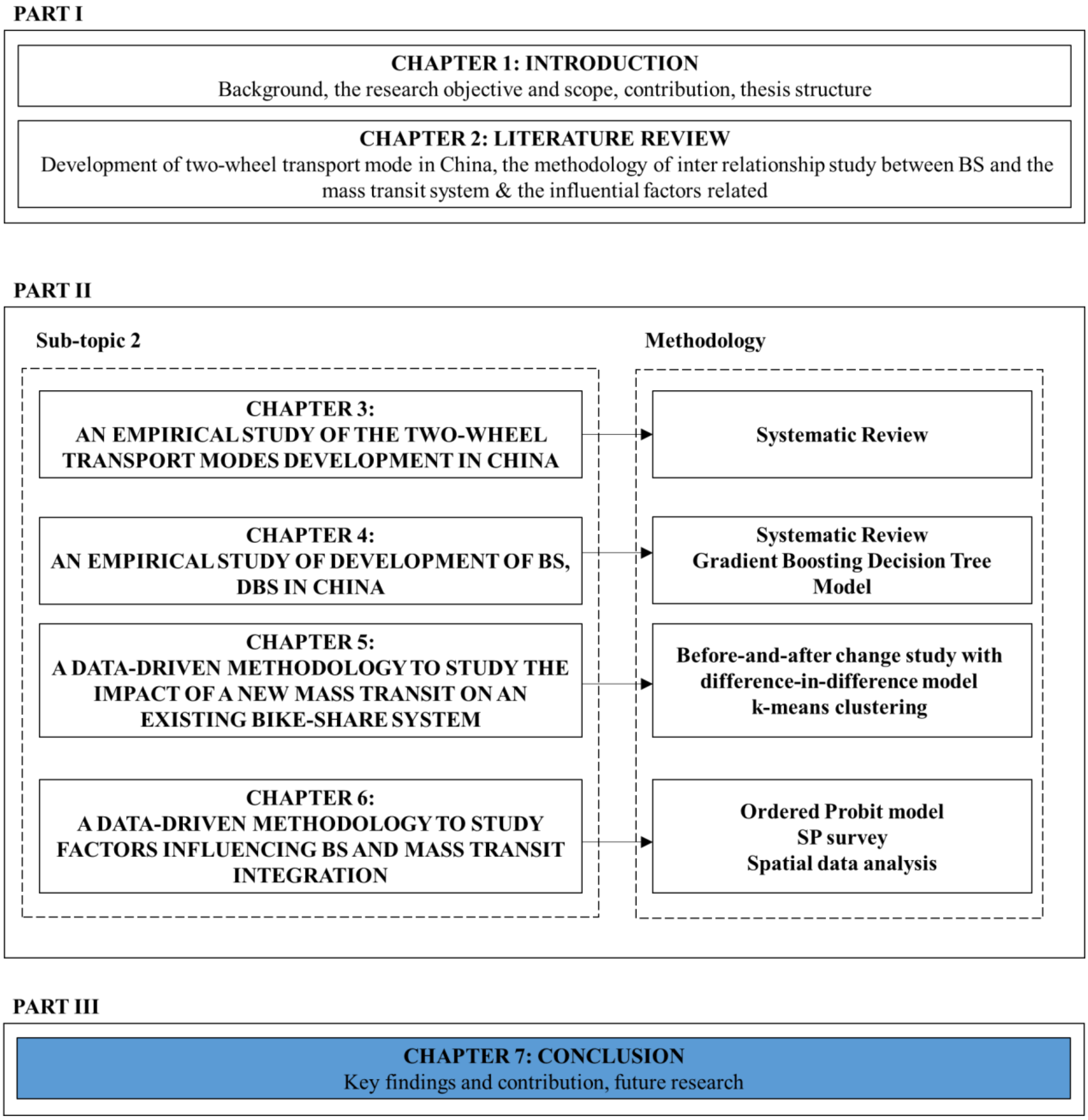
6.5 Chapter conclusion

In this chapter, novel impact factors influencing BS and metros' integration are analysed, based on a data-driven methodology and a survey conducted in Suzhou, China. It is a city with long cycling tradition and suffering from rapid car booming and congestion. Local government builds mass transit and enhances BS as countermeasures, which is very representative as a developing community. However, research of influential factors is mainly conducted in developed communities' context. Therefore, research gap exists. According to our survey, road separations sometimes are complained by cyclists since they need to detour to reach their destinations (as BS stations and metro stations). Severe traffic congestion is also listed as one of the reasons why car drivers turn to metros and BS. Information on traffic congestion and road separations are collected and analysed before and after a new metro was introduced to find out whether these factors could influence the integration between BS and metros. Spatial variables and analysis consider network distance decay and Thiessen polygon to make the results accurate. An ordered probit model considering the difference between weekdays and weekends is established to investigate these potential impact factors, based on a SP survey the author conducted.

It is found that young people, who get familiar with using smartphones to rent BS, are more inclined to increase their BS usage towards metros on weekdays rather than weekends. Traffic congestion caused by increasing motor vehicles also feedbacks on the integration between BS and metros. The higher congestion level promotes more cycling towards metros (on weekdays especially), the same as the parking fee level. Still, as expected, higher cyclable network density is positively correlated with higher mode shifts toward BS and metros. However, too many road separations and proximity to metros' hubs are to impede cyclists' passion towards metros. A convenient cycling environment (high density of cyclable allies and fewer road separations) and adverse motor vehicle traffic conditions (high congestion and parking fee) would promote a better combination between BS and metros.

Overall, new factors that seldom considered in developed community-oriented studies, are proven to affect BS and metros usage. Unfavourable motor vehicle traffic conditions (high congestion and parking fee) have a positive feedback on the combination between BS and metros. Besides, road separations that considered as safe and facilities in developed communities, is found to impede the flexibility of cycling. Proximity to metros' hub also impairs the usage of BS. These findings are instructive for urban planners, road designers as well as operators of BS and metros.

CHAPTER 7: CONCLUSION



7.1 Overview
In this chapter, the key findings, implications are reviewed in this thesis and propose some future extensions.

7.2 Key findings and implications
The study in Chapter 3 (sub-topic 1) aims to investigate the development of two-wheeled transport, especially human-powered bicycle transport in China from 1985 to 2019. The overall development trend of two-wheel transport in China is divergent based on the particular type. Bicycle transport continues to increase due to the changing attitudes from all levels of government and the increasing concern about the environment. Moreover, as more people realize that fast mobilization brings congestion as well as pollution means that bicycle transport will continue to exist. However, challenges within DBS contribute to the latest revival of human-powered cycling. DBS's prevalence is mainly caused by large and direct investment rather than fees collected from users. There is no guarantee of sustainable profit in the future which makes the DBS industry fragile and unstable. Stricter policies and attitudes towards DBS might add to the risk unless more effective technology is used to prevent streets from "bicycle-congestion". As the regulations and technical standards become clearer and pragmatic and drivers' awareness grows, it is believed safety issues will decrease. Moreover, as new eco-friendly techniques are introduced, government attitude may become even more favorable. Motorbikes and mopeds have lost their attraction to users and have been gradually replaced by E-bikes and automobiles, as can be seen from the usage rates. The inherent character of gasoline makes it eco-unfriendly and it is unwelcomed by governments particularly in large cities. Therefore, although there is still a small proportion of motorbike usage in remote rural areas, the position of motorbikes and mopeds will continue to be minimal.

The development of two-wheeled human-powered bicycles, along with E-bikes and motorbikes, is following a zigzag track. The most significant influence on urban transport development is the power exerted by the strong central government. Five phases could be seen in the development of human-powered bicycle transport in China from 1985 to 2019, where policies towards human-powered cycling changed from "encouraged", "discouraged", "converted and re-recognized" to "encouraged again" due to environmental concerns along with rapid mobilization. Human-powered cycling use continued to fall during this period until DBS emerged in 2016. Due to its enormous scale and capacity to attract users, DBS has helped to revive the overall human-powered cycling rate in China. It is found that public transport and the idea of infrastructure design have a conditional effect on bicycle transport development, which inspired us to dig the inter-relationship between bicycles (BS) and public transport in Chapter 5 (sub-topic 3), and find related, novel influential factors in Chapter 6 (sub-topic 4).

E-bikes and motorbikes witnessed an independent growth trend like human-powered bicycles. Following their popularity in the 1990s, the number of motorbikes has gradually decreased, and they are now largely banned due to their lack of safety as well as environmental and transport efficiency concerns, while E-bikes have been diversely treated in different cities. A clear regional difference in the E-bike policy was seen in southern cities of the Pearl River Delta, who hold a negative attitude towards E-bikes while cities in the Yangtze River delta hold a positive attitude towards them. The rapid growth of E-bikes is found to be demand-driven rather than supply-pushed.

After discussing the change of the influential factors in the following years, the author concluded that the future of human-powered bicycles and E-bikes is promising while motorbikes will become a thing of the past.

The study in Chapter 4 (sub-topic 2) aims to investigate the bike-share system development in China, especially the new-born innovative DBS programs. By comparing classic city bikeshare in China with its overseas counterparts, it is found that a government-oriented operator model plus a low financial threshold to users are the keys to the success of city BS. As for DBS, this innovative, flexible, shared cycling mode is a highly capital-driven, privately-operated business mode, largely deployed in cities with urban railway systems and has achieved high penetration in mega cites. Three growth phases have been identified based on government policy and DBS's development, namely the "free growth" phase, the "regulated" phase and the "limited" phase. DBS systems are found to have penetration advantages such as easy access by smart-phone, the convenience of pick and park, and low cost. These merits successfully attract its main users, who are found to be young, highly educated and almost equally male and female. The trips are mainly short, highly frequent and for commuting purposes. To understand the reasons behind the burgeoning of DBS systems, three factors have emerged: (1) those promoting user demands, (2) those winning partial support of the government, and (3) those promoting operators' supply are analysed. It is found that this rapid growth is mainly supply-driven by the operator rather than by user demand or triggered by government policy. Financial sustainability, vandalism and the threat of DBS to the bicycle industry are the three main challenges that require investigation in the future.

By a general comparison between BS and DBS, it is concluded that BS and DBS have their own merits and demerits. For instance, in megacities with abundant transport choices and good cycling facilities, if local governments have strong supervision and control ability over DBS operators, DBS might be a better opinion. Since most of the cities build-up urban BS to feed urban mass transit systems, an interesting question is how these two really perform together, especially in a developing community like China (answered in the next chapter).

The study in Chapter 5 (sub-topic 3) aims to investigate the impact of a new metro on existing BS in terms of both trip-count and pattern considering land use. A "before-and-after" study is firstly adopted based on the difference-in-difference model in this research topic. A new index is developed in this study to indicate how trip-pattern changes at a spatial level. Continuous real-time renting (flow-out) and returning (flow-in) number of bikes combining with location data is analyzed to indicate the impact, which could be further used in DBS studies. The results show that after a new metro opened, for BS stations within the metro's catchment (the treatment group), most BS ridership and users within the metro's catchment (the treatment group) have largely increased, except for BS stations in metros' hub, where BS ridership slightly decreased. For trip patterns, a general transfer from balanced to imbalanced is observed in all districts, which indicates that the BS served as "first-mile" interchanges (origin to metro) rather than "last-mile" (metro to destination) in the morning, and vice versa in the evening.

Governments and operators could be inspired in this part of the research outcome. As for local governments, some suggestions are made so that interchange between BS and mass transit could function well. Since BS and metros are operated by different operators, a consistent operation mechanism between BS and mass transit should be built and led by local governments to bridge different profit participants, so that complaints, as lagging BS rebalance will not happen after new metros are introduced. Also, necessary planning and studies should be initiated by local governments in advance. For instance, necessary ridership and trip-pattern estimation should be made by urban planners, based on which BS operators could make rebalancing schemes. In particular, since land use is found to correspond to BS trip-patterns change, a broad guide about how trip-count and trip-pattern might change after a new metro opens in different communities, should be released from urban planners to BS and metros' operators. Universities, commercial areas and residential areas have different demands and temporal distribution patterns, they should be considered separately. How many new BS stations are needed, and how to deploy them considering land use supplies should also be answered by urban planners since BS operators normally lakes the impulse and capability to do such research. Furthermore, for urban planners and city leaders, one of their tasks is to make preparation to huge transport change, as the prevalence of dockless shared bike (DBS). Since the before-and-after methodology in this study is based on continuous renting and returning trip data (just as DBS), this research could be further applied in DBS's before-and-after study as well. The inter relationship between DBS and metros could be further analyzed and improved based on our research contribution. This is very important for cities without a dockless shared bike (like Suzhou). Take Suzhou as an example, although it banned DBS for now, as a mainstream encouraged by the central government, it is highly likely that DBS will flood in as it did in Beijing, Shanghai, Guangzhou etc. A before-and-after change study would be practical in making policies and operation schemes to deal with the impact of DBS. As for BS operators, they are advised to follow local governments and urban planners' guide, pre-arrange operation scheme so that BS rebalancing will not lag after new metros are introduced. When new metro opens, normally BS demands to increase substantially along the new metro line (in our case, an 85%-115% ridership increase in weekday and weekend was observed). So new BS stations are encouraged to deployed in advance and a higher frequency of rebalancing is required along with new metros. For instance, operation schemes in weekends and weekdays should be different. More rebalancing work is needed on weekends according to our study. As for daily rebalance and maintenance, a new rebalancing route scheme should be made based on trip-pattern to achieve a balance between cost and cyclists' needs. Also, trip demands in commercial areas in PM peaks need to be met so that more commuters could use shared bikes from offices to metros to finish "last-mile" interchange. So that complains as empty stations without bikes to rent or fully-occupied stations with no docks to return could decrease.

The study in Chapter 6 (sub-topic 4) aims to investigate novel impact factors influencing BS and metros' integration, based on a data-driven methodology and an SP survey. In developing communities with long cycling tradition, influential factors are found to be quite unique and novel, compared to former research outcomes. In the ordered probit model considering the difference between weekdays and weekends is established to investigate these potential impact factors. Overall, Unfavorable motor vehicle traffic conditions (high congestion and parking fee) would feedback a better combination between BS and metros. Besides, road separations that considered as safe and facilities impede the flexibility of cycling. Proximity to metros' hub also impairs the usage of BS. For urban administration bureaus, they are well-advised that more road separation might bring inconvenience for cyclists. Although exclusive bicycle lanes are beneficial to promote cycling in some studies, the situation in Suzhou is quite different. As a city with cycling tradition and high dense cyclable network, SPBS cyclists tend to cycle in small roads with few separations. Small roads typically have fewer motor vehicles and slow vehicle speed limits, which make the safety of cycling within an acceptable level. According to this finding, when planning and design roads, urban planners should be well advised to treat road separations cautiously. The separation design should consider the balance between safety and convenience. For road designers, they are highly recommended to reconsider before implementing multiple road separations before construction – at least in areas where metros' stations and BS stations are located. +

7.3 Suggestions for future work

More works are necessary to promote the BS and mass transit systems connection in practice. Recommendations are provided based on the four main studies in this thesis, which might be valuable research topics in the future.

In Section 1 and 2, the author focus on two-wheel transport mode and BS/DBS development in China, since it is the biggest market in BS and the born-place of DBS. The empirical studies give inspirations as policies and operation modes to other countries. To make it even general, the BS/DBS development from a global point of view could be further investigated.

The study in Section 3 adopts a before-and-after change study in a short time. It is the first time this methodology used in this research topic. Several aspects still require further study. Firstly, to achieve higher accuracy, more steps are taken to eliminate or at least mitigate bias and reveal actual demand. The BS growth, the prevailing season and weather, and the disorder resulting from a transitional period might still have a minor influence on the accuracy of the research outcome. Moreover, although the rebalancing trips are already eliminated, once a BS station is full of parked bikes or empty, and no operator is available to rebalance it manually, it would cease to operate, and therefore the actual demand for renting cannot be fully revealed. Secondly, due to data limitations, it is unable to track the long-term impact of mass transit on BS for now. Future research will expand the time coverage of data to mitigate this ramp-up effect. Thirdly, a similar methodology could be adopted in DBS & metros, which is more intensely deployed nowadays in megacities.

By determining the influential factors in Chapter 6, congestion and parking fee levels are found to have active feedback on SPBS's integration with metros. Therefore, future studies could focus on how to optimize the operation and administration from policymakers and urban planners' points of view. Low-carbon policies and practice could be studied by evaluating traffic conditions and scheming the metros and BS deployment according to the level of traffic congestions. For BS operators, it is a good strategy to deploy more BS fleets in congested areas since the cycling demands to the metros are higher. A more frequent rebalancing service is also needed in these areas. Besides, although exclusive bicycle lanes are beneficial to promote cycling in some studies, the situation in case the study of this research is quite different. In cities with cycling tradition and high dense cyclable network (like Suzhou), BS cyclists might tend to cycle in small roads with few separations. Further work could focus on this threshold - the balance between safety and convenience. Besides, similar mythology could be further used to solve problems between DBS & metros.

In the end of this thesis, as John Pucher et al. (2008) stated in "Making Cycling Irresistible: lessons from The Netherlands, Denmark and Germany" - "The success of cycling does not depend on poverty, dictatorial regimes or the lack of motorized transport options to force people onto bikes". When we look back at the evolution of human mobility, cycling has always found a place. As a healthy and sustainable mode of transport, once appropriate and innovative business models are found and introduced, people will choose to cycle, and cycling will continue.

REFERENCES

Abolhassani, L., Afghari, A. P., and Borzadaran, H. M. (2019). Public preferences towards bicycle sharing system in developing countries: The case of Mashhad, Iran. *Sustainable Cities and Society* 44:763-73. doi: https://doi.org/10.1016/j.scs.2018.10.032

Ahmed, F., Rose, G., and Jacob, C. (2010). Impact of weather on commuter cyclist behaviour and implications for climate change adaptation. Paper presented at the Australasian Transport Research Forum (ATRF), 33rd, 2010, Canberra, ACT, Australia.

AllTechAsia. (2018). Can popular Chinese bike-sharing startups Mobike & Ofo replicate their success overseas? In *AllTechAsia*. https://medium.com/@actallchinatech/can-popular-chinese-bike-sharing-startups-mobike-ofo-replicate-their-success-overseas-d2ecb42bd537

Angus, M. (2018). Vandalism a bump in road for bike-sharing. In *China Daily*. http://www.chinadaily.com.cn/a/201804/17/WS5ad538c0a3105cdcf6518a09.html

Böcker, L., Dijst, M., and Prillwitz, J. (2013). Impact of everyday weather on individual daily travel behaviours in perspective: a literature review. *Transport Reviews* 33 (1):71-91.

Bachand-Marleau, J., Larsen, J., and El-Geneidy, A. M. (2011). Much-anticipated marriage of cycling and transit: How will it work? In *Transportation Research Record*, 109-17.

Bachand-Marleau, J., Lee, B., and El-Geneidy, A. (2012). Better understanding of factors influencing likelihood of using shared bicycle systems and frequency of use. *Transportation Research Record: Journal of the Transportation Research Board* (2314):66-71.

Bai, L., Liu, P., Chen, Y., et al. (2013). Comparative analysis of the safety effects of electric bikes at signalized intersections. *Transportation Research Part D: Transport and Environment* 20:48-54. doi: http://dx.doi.org/10.1016/j.trd.2013.02.001

Bao, X. (2018). Urban Rail Transit Present Situation and Future Development Trends in China: Overall Analysis Based on National Policies and Strategic Plans in 2016–2020. *Urban Rail Transit* 4 (1):1-12. doi: 10.1007/s40864-018-0078-4

Ben, B. (2017). China's bicycle-sharing boom poses hazards for manufacturers. In *Financial Times*. https://www.ft.com/content/bfba9f6e-299c-11e7-9ec8-168383da43b7?mhq5j=e3

Bernardi, S., La Paix-Puello, L., and Geurs, K. (2018). Modelling route choice of Dutch cyclists using smartphone data. *Journal of transport and land use* 11 (1).

Beroud, B., Clavel, R., and Le Vine, S. (2010). Perspectives on the Growing Market for Public Bicycles Focus on France and the United Kingdom. Paper presented at the European Transport Conference. Glasgow, Scotland. 11th October.

Bikesharingmap. (2017). The Bike-sharing World Map. In.

Billings, S. B. (2011). Estimating the value of a new transit option. *Regional Science and Urban Economics* 41 (6):525-36.

Bo, T. (2017). A Reflection on Municipal Regulations to Supervise“Bike- sharing”—— a Comparative Study of a Dozen Cities. *Journal of Jianghan University (Social Science Edition*）.

Borgnat, P., Abry, P., Flandrin, P., et al. (2009). Studying Lyon's Vélo'V: A Statistical Cyclic Model. Paper presented at the ECCS'09, Warwick, United Kingdom, 2009-09-21.

Broach, J., Dill, J., and Gliebe, J. (2012). Where do cyclists ride? A route choice model developed with revealed preference GPS data. *Transportation Research Part A: Policy and Practice* 46 (10):1730-40. doi: https://doi.org/10.1016/j.tra.2012.07.005

Buehler, R., Pucher, J., Gerike, R., et al. (2017). Reducing car dependence in the heart of Europe: lessons from Germany, Austria, and Switzerland. *Transport Reviews* 37 (1):4-28. doi: 10.1080/01441647.2016.1177799

Cai, M. (2017). Guangzhou Shared Bike has reached 8 million, new increase is officially banned. In *Sina News*. http://news.sina.com.cn/o/2017-08-03/doc-ifyitayr8906690.shtml

Campbell, A. A. (2012). Factors Influencing the Choice of Shared Bicycles and Electric Bicycles in Beijing--A Stated Preference Approach.

Campbell, A. A., Cherry, C. R., Ryerson, M. S., et al. (2016). Factors influencing the choice of shared bicycles and shared electric bikes in Beijing. *Transportation Research Part C: Emerging Technologies* 67:399-414. doi: https://doi.org/10.1016/j.trc.2016.03.004

CCTV Finance and Economics. (2018). Dockless shared bike - from madness to the rational development. In *CCTV finance and Economics*. http://op.inews.qq.com/m/20180610A1KJUA00?refer=100000355&chl_code=kb_news_hotnews&h=0

Chan, C. K., and Yao, X. (2008). Air pollution in mega cities in China. *Atmospheric Environment* 42 (1):1-42. doi: https://doi.org/10.1016/j.atmosenv.2007.09.003

Chen, P., Liu, Q., and Sun, F. (2018). Bicycle parking security and built environments. *Transportation Research Part D: Transport and Environment* 62:169-78. doi: https://doi.org/10.1016/j.trd.2018.02.020

Cherry, C. R., Weinert, J. X., and Xinmiao, Y. (2009). Comparative environmental impacts of electric bikes in China. *Transportation Research Part D: Transport and Environment* 14 (5):281-90. doi: https://doi.org/10.1016/j.trd.2008.11.003

China Academy of Transportation Science & Ofo. (2018). Cycling report of major cities in China 2017 (Q4) (in Chinese). Retrieved from http://www.motcats.com.cn/newsitem/278161930

China Information and Communication Research Institute. (2018). 2017 Economic and social impact report of shared bike. Retrieved from https://mobike.com/global/

China Urban Railway Transport Association. (2018). Annual Statistical Report of China Urban Railway Transport. Retrieved from http://www.camet.org.cn/index.php?m=content&c=index&a=lists&catid=18

City Lab. (2018). What Cities Need to Understand About Bikeshare Now. Retrieved from https://www.citylab.com/transportation/2018/04/a-complete-taxonomy-of-bikeshare-so-far/558560/

Corcoran, J., Li, T., Rohde, D., et al. (2014). Spatio-temporal patterns of a Public Bicycle Sharing Program: the effect of weather and calendar events. *Journal of Transport Geography* 41:292-305.

Daisy, N. S., Millward, H., and Liu, L. (2018). Trip chaining and tour mode choice of non-workers grouped by daily activity patterns. *Journal of Transport Geography* 69:150-62.

Demaio, P. (2009). Bike-sharing: History, Impacts, Models of Provision, and Future. *Journal* *of public transportation* 12 (4).

Demaio, P. (2017). The Bike-sharing Blog. In *The Bike-sharing World at the End of 2016*.

Demaio, P., and Russell M. (2017). The Bike-sharing World Map. Retrieved from www.bikesharingmap.com

Dierking, P. (2017). New Bike Share Apps in China Create Bike 'Revolution'. In *VOA*. https://learningenglish.voanews.com/a/new-bike-share-apps-n-china-create-bike-revolution/3894394.html

Ding, W. (2016). The Relationship of Built Environment and Weather with Bike Share–Evidence from the Pronto Bike Share System in Seattle.

Dong, D., Duan, H., Mao, R., et al. (2018). Towards a low carbon transition of urban public transport in megacities: A case study of Shenzhen, China. *Resources, Conservation and Recycling* 134:149-55. doi: https://doi.org/10.1016/j.resconrec.2018.03.011

Dowling, S. (2018). Regulation Looms In Booming, Competitive Bike-Sharing Space. In *Crunchbase News*. https://news.crunchbase.com/news/regulation-looms-booming-competitive-bike-sharing-space/?utm_source=cb_daily&utm_medium=email&utm_campaign=20180108&utm_content=intro&utm_term=content&send_email=--Email--

Du, M., and Cheng, L. (2018). Better Understanding the Characteristics and Influential Factors of Different Travel Patterns in Free-Floating Bike Sharing: Evidence from Nanjing, China. *Sustainability* 10 (4):1244.

El-Assi, W., Mahmoud, M. S., and Habib, K. N. (2017). Effects of built environment and weather on bike sharing demand: a station level analysis of commercial bike sharing in Toronto. *Transportation* 44 (3):589-613.

European Bicycle Manufacturers Association. (2018). BIKE SHARING IN CHINA - Chinese Market Situation. Retrieved from http://ebma-brussels.eu/bike-sharing-in-china/

Faghih-Imani, A., Eluru, N., El-Geneidy, A. M., et al. (2014). How land-use and urban form impact bicycle flows: evidence from the bicycle-sharing system (BIXI) in Montreal. *Journal of Transport Geography* 41:306-14.

Fehr, V. M., and Macho, A. (2018). Der Leihrad-Boom erfasst die Großstädte. In *WirtschaftsWoche*. https://www.wiwo.de/unternehmen/dienstleister/bike-sharing-der-leihrad-boom-erfasst-die-grossstaedte/20970848.html

Feng, Z., Raghuwanshi, R. P., Xu, Z., et al. (2010). Electric-bicycle-related injury: a rising traffic injury burden in China. *Injury Prevention* 16 (6):417-9. doi: 10.1136/ip.2009.024646

Fishman, E. (2014). Bikeshare: barriers, facilitators and impacts on car use. *Bicycle*.

Fishman, E. (2016). Bikeshare: A review of recent literature. *Transport Reviews* 36 (1):92-113.

Fishman, E., and Cherry, C. (2016). E-bikes in the Mainstream: Reviewing a Decade of Research. *Transport Reviews* 36 (1):72-91. doi: 10.1080/01441647.2015.1069907

Fishman, E., Washington, S., and Haworth, N. (2012). Barriers and facilitators to public bicycle scheme use: A qualitative approach. *Transportation Research Part F Traffic Psychology & Behaviour* 15 (6):686-98.

Fishman, E., Washington, S., and Haworth, N. (2014). Bike share’s impact on car use: Evidence from the United States, Great Britain, and Australia. *Transportation Research Part D: Transport and Environment*:13–20.

Fishman, E., Washington, S., Haworth, N., et al. (2014). Barriers to bikesharing: an analysis from Melbourne and Brisbane. *Journal of Transport Geography* 41:325-37.

Fishman, E., Washington, S., Haworth, N., et al. (2015). Factors influencing bike share membership: An analysis of Melbourne and Brisbane. *Transportation Research Part A: Policy and Practice* 71:17-30.

Frame, G., Ardila-Gomez, A., and Chen, Y. (2017). The kingdom of the bicycle: what Wuhan can learn from Amsterdam. *Transportation Research Procedia* 25:5040-58. doi: https://doi.org/10.1016/j.trpro.2017.05.203

Fratila, S. (2018). 2017 – the year bike sharing went crazy. In. https://www.donkey.bike/2017-bike-sharing-went-crazy/

Fuller, D., Sahlqvist, S., Cummins, S., et al. (2012). The impact of public transportation strikes on use of a bicycle share program in London: interrupted time series design. *Preventive Medicine* 54 (1):74-6.

Gao, S., Zheng, M., Yang, Z., et al. (2016). The Implementation of Planning Management to Promote Pedestrian and Bicycle Transportation System Rejuvenation —— Development Strategies for Pedestrian and Bicycle Transportation System in Wuhan (in Chinese). *Traffic and Transportation*.

García-Albertos, P., Picornell, M., Salas-Olmedo, M. H., et al. (2018). Exploring the potential of mobile phone records and online route planners for dynamic accessibility analysis. *Transportation Research Part A: Policy and Practice*.

Gauthier, A., Hughes, C., Kost, C., et al. (2013). The Bike-share Planning Guide. ITDP Report. In.

Gu, T., Kim, I., and Currie, G. (2019a). Measuring immediate impacts of a new mass transit system on an existing bike-share system in China. *Transportation Research Part A: Policy and Practice* 124:20-39. doi: https://doi.org/10.1016/j.tra.2019.03.003

Gu, T., Kim, I., and Currie, G. (2019b). To be or not to be dockless: Empirical analysis of dockless bikeshare development in China. *Transportation Research Part A: Policy and Practice* 119:122-47.

Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China). (2017a). The Development and Future Prospects of Electric Bicycles in China. Retrieved from http://www.itdp-china.org/news/?newid=74&lang=0

Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China). (2017b). The Development and Policy Recommendations for Dockless Bike Share (DBS) in China. Retrieved from http://www.itdp-china.org/dbs/index/#/getcompany/2

Guangzhou Modern BRT & Sustainable Transport Institute (ITDP-China). (2017c). Non-motor vehicle transport bluepaper. Retrieved from http://www.itdp-china.org/enpublication/?lang=0

Guangzhou Transport Institute. (2017). Report of Mobike in South China 2017. Retrieved from https://mobike.com/global/

Guerra, E., Cervero, R., and Tischler, D. (2012). Half-mile circle. In *Transportation Research Record*, 101-9.

Guodong, F., and Jun, C. (2017). Wuhan public bike service closed - due to the dockless shared bike. (in Chinese). In *Xinhua*. http://news.sina.com.cn/o/2017-11-22/doc-ifypacti6700009.shtml

Gutiérrez, J., Cardozo, O. D., and García-Palomares, J. C. (2011). Transit ridership forecasting at station level: an approach based on distance-decay weighted regression. *Journal of Transport Geography* 19 (6):1081-92. doi: https://doi.org/10.1016/j.jtrangeo.2011.05.004

Haas, B. (2017). Chinese bike share graveyard a monument to industry's 'arrogance'. In *The Guardian*. https://www.theguardian.com/uk-news/2017/nov/25/chinas-bike-share-graveyard-a-monument-to-industrys-arrogance

Haixiao, P. (2011). The evolving cycle transport policy in China and urban sustainable development. *Journal of Urban Planning*.

Hamilton, T. L., and Wichman, C. J. (2018). Bicycle infrastructure and traffic congestion: Evidence from DC's Capital Bikeshare. *Journal of Environmental Economics and Management* 87:72-93.

Han, X. (2017). Is Shenzhen a bike-friendly city? A tale from two generations of Shenzhen citizens. In *Shenzhen Economic Daily*. http://szsb.sznews.com/PC/layout/201806/04/node_A01.html

Hangzhou Comprehensive Transportation Research Center. (2018). Research Report of Hangzhou Internet Rental Bike Development (in Chinese). Retrieved from http://www.zj.gov.cn/art/2018/4/9/art_13104_2273829.html

Hangzhou Public Bicycle Service and Development CO., L. (2017). Hangzhou Public Bicycle's Development History In. http://www.ggzxc.cn/index.aspx

Hatzopoulou, M., Weichenthal, S., Dugum, H., et al. (2013). The impact of traffic volume, composition, and road geometry on personal air pollution exposures among cyclists in Montreal, Canada. *Journal of Exposure Science and Environmental Epidemiology* 23 (1):46-51.

Hong, M. (2017). Beijing gears up technical, parking rules for shared bikes. In *China Daily*. http://www.chinadaily.com.cn/china/2017-11/01/content_33969945.htm

Horwitz, J. (2017). Chinese cities are saying “enough already” to bike-sharing services run rampant. In. https://qz.com/1058438/chinese-cities-saying-enough-already-to-chaos-generated-by-bike-sharing-services-like-ofo-and-mobike/

Hu, H., Xu, J., Shen, Q., et al. (2018). Travel mode choices in small cities of China: A case study of Changting. *Transportation Research Part D: Transport and Environment* 59:361-74. doi: https://doi.org/10.1016/j.trd.2018.01.013

Huifen, Z. (2018). Urban municipal roads reconstructed to meet the demand of more cars. In, edited by Gu Tianqi.

Hurst, N. B., and West, S. E. (2014). Public transit and urban redevelopment: The effect of light rail transit on land use in Minneapolis, Minnesota. *Regional Science and Urban Economics* 46:57-72.

iiMedia Research Institute. (2017). 2017 Q1 China Shared Bike Market Research Report. Retrieved from http://www.iimedia.cn/50357.html

Institute for Transportation & Development Policy (ITDP). (2018). The Bikeshare Planning Guide (2018 edition). Retrieved from https://www.itdp.org/publication/the-bike-share-planning-guide/

Jäppinen, S., Toivonen, T., and Salonen, M. (2013). Modelling the potential effect of shared bicycles on public transport travel times in Greater Helsinki: An open data approach.

Applied Geography 43:13-24. doi: http://dx.doi.org/10.1016/j.apgeog.2013.05.010

Jao, N. (2018). Beijing rolls out electronic fences and reinforces parking guidelines for bike rentals. In *TechCrunch*. https://technode.com/2018/05/03/beijing-rolls-out-electronic-fences-and-reinforces-parking-guidelines-for-share-bikes/

Jarjour, S., Jerrett, M., Westerdahl, D., et al. (2013). Cyclist route choice, traffic-related air pollution, and lung function: a scripted exposure study. *Environmental Health* 12 (1):14.

Ji, Y., Fan, Y., Ermagun, A., et al. (2017). Public bicycle as a feeder mode to rail transit in China: The role of gender, age, income, trip purpose, and bicycle theft experience. *International Journal of Sustainable Transportation* 11 (4):308-17. doi: 10.1080/15568318.2016.1253802

Jing, S. (2017). Shanghai tries to limit shared bikes. In *China Daily*. http://www.chinadaily.com.cn/china/2017-08/22/content_30944519.htm

Josh, Y. (2017). Why China's bike-sharing boom is causing headaches, South China Morning Post. In. http://www.scmp.com/news/china/society/article/2085751/chinas-bike-sharing-boom-puts-pressure-planners

Karki, T. K., and Tao, L. (2016). How accessible and convenient are the public bicycle sharing programs in China? Experiences from Suzhou city. *Habitat International* 53:188-94. doi: https://doi.org/10.1016/j.habitatint.2015.11.007

Kim, K. (2018). Investigation on the effects of weather and calendar events on bike-sharing according to the trip patterns of bike rentals of stations. *Journal of Transport Geography* 66:309-20. doi: https://doi.org/10.1016/j.jtrangeo.2018.01.001

King, D. (2018). oBikes pulls out of Melbourne. In *THE AUSTERALIAN*. https://www.theaustralian.com.au/news/nation/obikes-pulls-out-of-melbourne/news-story/08e6de562eff56472007b68065e5c552

Lathia, N., Ahmed, S., and Capra, L. (2012). Measuring the impact of opening the London shared bicycle scheme to casual users. *Transportation Research Part C: Emerging Technologies* 22:88-102. doi: 10.1016/j.trc.2011.12.004

Li, B. (2017). Beijing welcomes its "public bike day" (in Chinese). In *Beijing Evening*. http://www.takefoto.cn/viewnews-1139837.html

Li, C., Guo, J., An, Z., et al. (2016). Urban comprehensive traffic survey development - Advices from Beijing 's fifth comprehensive traffic survey (in Chinese). *Urban Transport of China* 14 (02):29-34. doi: 10.13813/j.cn11-5141/u.2016.0205

Li, D. (2018a). Shared Bike in Chengdu has reached 1.45 million. In *Sichuan News*. http://scnews.newssc.org/system/20180314/000862403.html

Li, H., Graham, D. J., and Majumdar, A. (2012). The effects of congestion charging on road traffic casualties: A causal analysis using difference-in-difference estimation. *Accident Analysis & Prevention* 49:366-77.

Li, W., and Kamargianni, M. (2018). Providing quantified evidence to policy makers for promoting bike-sharing in heavily air-polluted cities: A mode choice model and policy simulation for Taiyuan-China. *Transportation Research Part A: Policy and Practice* 111:277-91. doi: https://doi.org/10.1016/j.tra.2018.01.019

Li, Y. (2018b). Study of Beijing shared bike policy (in Chinese). *TranspoWorld of China* (30):158-60. doi: 10.16248/j.cnki.11-3723/u.2018.30.076

Li, Z.-C., Yao, M.-Z., Lam, W. H. K., et al. (2015). Modeling the Effects of Public Bicycle Schemes in a Congested Multi-Modal Road Network. *International Journal of Sustainable Transportation* 9 (4):282-97. doi: 10.1080/15568318.2013.767398

Li, Z., Yin, Z., Liao, K., et al. (2016). Study of Beijing public bike preference survey and development policy (in Chinese). *Transport Research of China* 03 (2). doi: 10.16503/j.cnki.2095-9931.2016.03.003

Liang, X. (2017). Future of the Chengdu public bike. In *Sichuan Daily*. http://sc.sina.com.cn/news/b/2017-05-02/detail-ifyetwtf9513516.shtml

Liao, S. (2018). Mobike, Ofo End Price War at Top of China's Bike-Sharing Food Chain. In *Yicai Global*. https://www.yicaiglobal.com/news/mobike-ofo-end-price-war-top-china%E2%80%99s-bike-sharing-food-chain

Lin, W., and Di, N. (2017). Dockless shared bike is over-supplied? - Ministry of Transportation replys: local governments are authorized to manage themself and the central govenrment will not take in charge. In *China Youth Daily*. http://news.cyol.com/content/2017-05/23/content_16106571.htm

Lin, X., Wells, P., and Sovacool, B. K. (2017). Benign mobility? Electric bicycles, sustainable transport consumption behaviour and socio-technical transitions in Nanjing, China. *Transportation Research Part A: Policy and Practice* 103:223-34. doi: https://doi.org/10.1016/j.tra.2017.06.014

Lin, X., Wells, P., and Sovacool, B. K. (2018). The death of a transport regime? The future of electric bicycles and transportation pathways for sustainable mobility in China. *Technological Forecasting and Social Change* 132:255-67. doi: https://doi.org/10.1016/j.techfore.2018.02.008

Ling, Z., Cherry, C. R., Yang, H., et al. (2015). From e-bike to car: A study on factors influencing motorization of e-bike users across China. *Transportation Research Part D: Transport and Environment* 41:50-63. doi: https://doi.org/10.1016/j.trd.2015.09.012

Liu, J. C., Qian; Chen, Boquan. (2017). Public bike might get retired because of dockless shared bike? (in Chinese). In. http://shenzhen.sina.com.cn/news/s/2017-12-24/detail-ifypxrpp3634020.shtml

Liu, S., and Yang, Y. (2016). Protecting Bicycle Right-of-Way under Rapid Motorization Development in Hangzhou. *Urban Transport of China* 14.

Long, Y. (2012). Bicycle develoment in Chengdu *Sichuan Architecture* 32:14-8.

Luojun, D. (2017). How many dockless shared bikes are there in Hangzhou? In *Zhengjiang News*. https://zj.zjol.com.cn/news/585237.html

Matthew, L. (2018). Scooter startup Lime is reportedly raising $250M led by Uber investor GV (formerly Google Ventures). Retrieved from https://techcrunch.com/2018/06/05/scooter-startup-lime-is-reportedly-raising-250m-led-by-uber-investor-gv/

Médard de Chardon, C., Caruso, G., and Thomas, I. (2017). Bicycle sharing system 'success' determinants. *Transportation Research Part A: Policy and Practice* 100:202-14. doi: https://doi.org/10.1016/j.tra.2017.04.020

Ma, A. (2017). Shanghai Puts Brakes on Shared Bikes Flooding City Streets. Retrieved from http://www.caixinglobal.com/2017-03-16/101066418.html

Ma, L., Xiong, H., Wang, Z., et al. (2018). Impact of weather conditions on middle school students' commute mode choices: Empirical findings from Beijing, China. *Transportation Research Part D: Transport and Environment*.

Mackett, R. L., Pan, H., May, A. D., et al. (2011). Implementing Sustainable Urban Travel Policies in China. Paper presented at the International Transport Forum Discussion Papers.

MacNaughton, P., Melly, S., Vallarino, J., et al. (2014). Impact of bicycle route type on exposure to traffic-related air pollution. *Science of the Total Environment* 490:37-43.

Manzi, G., and Saibene, G. (2018). Are they telling the truth? Revealing hidden traits of satisfaction with a public bike-sharing service. *International Journal of Sustainable Transportation* 12 (4):253-70. doi: 10.1080/15568318.2017.1353186

Martin, E. W., and Shaheen, S. A. (2014). Evaluating public transit modal shift dynamics in response to bikesharing: a tale of two U.S. cities. *Journal of Transport Geography* 41 (Supplement C):315-24. doi: https://doi.org/10.1016/j.jtrangeo.2014.06.026

Mateo-Babiano, I. (2015). Public Bicycle Sharing in Asian Cities. *Journal of the Eastern Asia Society for Transportation Studies* 11:60-74. doi: 10.11175/easts.11.60

Midgley, P. (2011). Bicycle-Sharing Schemes: Enhancing Sustainable Mobility in Urban Areas.

Ministry of Housing and Urban-rural Development. (2014). Release of "Guidelines for planning and design of urban pedestrian and bicycle transport systems", local plannings and guidenlines are required to make before 2015. http://www.mohurd.gov.cn/zxydt/201401/t20140116_216890.html.

Ministry of Housing and Urban-Rural Development & National Development and Reform Commission. (2012). Guidance to Improve Urban Pedestrian and Bicycle Transport System Construction. Retrieved from http://www.mohurd.gov.cn/wjfb/201209/t20120917_211404.html

Ministry of Transportation, Ministry of Industry and Information Technology, National Development and Reform Commission, Propaganda Department of the Central Committee of the CPC, Ministry of Housing and Urban-Rural Development, Cyberspace Administration of China and People's Bank of China. (2017). Guidance of encouraging and regulating the development of Internet rental bicycles (dockless shared bike). http://www.gov.cn/xinwen/2017-08/03/content_5215640.htm.

Miranda-Moreno, L., and Nosal, T. (2011). Weather or not to cycle: Temporal trends and impact of weather on cycling in an urban environment. In *Transportation Research Record*, 42-52.

Mobike. Access (2017). http://mobike.com/cn/

Mobike & Wuhan Transport Institute. (2017). Report of Mobike in Wuhan 2017. Retrieved from https://mobike.com/global/

Mobike Global & Beijing Tsinghua Tongheng Planning and Design Institute. (2017). The Mobike White Paper: Bike-Share in the City. Retrieved from https://mobike.com/global/blog/post/mobike-white-paper

Moudon, A. V., Lee, C., Cheadle, A. D., et al. (2005). Cycling and the built environment, a US perspective. *Transportation Research Part D: Transport and Environment* 10 (3):245-61. doi: https://doi.org/10.1016/j.trd.2005.04.001

Murphy, E., and Usher, J. (2015). The role of bicycle-sharing in the city: Analysis of the Irish experience. *International Journal of Sustainable Transportation* 9 (2):116-25.

Nair, R., Miller-Hooks, E., Hampshire, R. C., et al. (2013). Large-Scale Vehicle Sharing Systems: Analysis of Vélib'. *International Journal of Sustainable Transportation* 7 (1):85-106. doi: 10.1080/15568318.2012.660115

Nanjing Institute of City & Transport Planning Co.,Ltd. (2017). Nanjing Transport Development Annual Report. Retrieved from http://www.nictp.com/news/1620-cn.html

Nanjing Transport Bureau. (2018a). Report of Shared Bike development assesment 2017. Retrieved from http://www.nanjing.gov.cn/hdjl/zjdc/wsdc/dcbg/201709/t20170925_360504.html

National Bureau of Statistics of China. (2018). China Statistical Yearbook (1985-2017). Retrieved from http://www.stats.gov.cn/tjsj/ndsj/

National Development and Reform Commission. (2016). The 13th Five-year Plan of New Urbanization. https://www.ndrc.gov.cn/xwdt/gdzt/tjzgczh/ghzc/201403/t20140317_1201723.html.

National People's Congress. (2011). Road traffic safety law in People's Republic of China. Retrieved from http://www.mps.gov.cn/n2255040/n4908730/n4908731/c4919076/content.html

Nikiforiadis, A., and Basbas, S. (2019). Can pedestrians and cyclists share the same space? The case of a city with low cycling levels and experience. *Sustainable Cities and Society*:101453.

Noland, R. B., Smart, M. J., and Guo, Z. (2016). Bikeshare trip generation in New York City. *Transportation Research Part A: Policy and Practice* 94:164-81. doi: https://doi.org/10.1016/j.tra.2016.08.030

Parkes, S. D., Marsden, G., Shaheen, S. A., et al. (2013a). Understanding the diffusion of public bikesharing systems: evidence from Europe and North America. *Journal of Transport Geography* 31:94-103.

Parkes, S. D., Marsden, G., Shaheen, S. A., et al. (2013b). Understanding the diffusion of public bikesharing systems: evidence from Europe and North America. *Journal of Transport Geography* 31 (7):94-103.

Pucher, J., and Buehler, R. (2008). Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. *Transport Reviews* 28 (4):495-528. doi: 10.1080/01441640701806612

Pucher, J., Peng, Z. r., Mittal, N., et al. (2007). Urban transport trends and policies in China and India: impacts of rapid economic growth. *Transport Reviews* 27 (4):379-410.

Qi, Z. Access (2017). Ministry of Communications ask for advice on the development of public bike sharing expert advice: government should do more on the development of it. http://china.cnr.cn/yaowen/20170522/t20170522_523765874.shtml

Qian, K., and ZHeng, J. (2012). Study on Shenzhen's cycling characteristic and development (in Chinese). In *Annual National Urban Transport Conference*.

Qin, H., Gao, J., Kluger, R., et al. (2018). Effects of perception on public bike-and-ride: A survey under complex, multifactor mode-choice scenarios. *Transportation Research Part F: Traffic Psychology and Behaviour* 54:264-75. doi: https://doi.org/10.1016/j.trf.2018.01.021

Qu, D., Yu, Z., and Zhuang, J. (2001). Study of Suzhou presidents' transport characteristics (in Chinese). *Journal of Southeast University (Natural Science Edition)* 31.

Reid, C. (2017). China's 3rd largest dockless firm collapses. In *bikebiz*. https://www.bikebiz.com/news/chinas-3rd-largest-dockless-firm-collapses

Reid, C. (2018). Cycle miles double in China thanks to dockless bike sharing. In *bikebiz*. https://www.bikebiz.com/news/dockless-booming-in-china

Ricci, M. (2015). Bike sharing: A review of evidence on impacts and processes of implementation and operation. *Research in Transportation Business & Management* 15:28-38.

Rokach, L., and Maimon, O. (2005). Clustering Methods. In *Data Mining and Knowledge Discovery Handbook*, edited by Oded Maimon and Lior Rokach, 321-52. Boston, MA: Springer US.

Rousseeuw, P. J. (1987). Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics* 20:53-65. doi: https://doi.org/10.1016/0377-0427(87)90125-7

Ruan, Y., Hang, C. C., and Wang, Y. M. (2014). Government's role in disruptive innovation and industry emergence: The case of the electric bike in China. *Technovation* 34 (12):785-96. doi: https://doi.org/10.1016/j.technovation.2014.09.003

Safety technical specification for electric bicycle. (2018). Safety technical specification for electric bicycle. Retrieved from http://www.miit.gov.cn/n1146290/n4388791/c6177121/content.html

Scott, C. (2017). Wait, Chinese Bike-Sharing Doesn't Make Any Sense. In *Forture*. http://fortune.com/2017/03/21/chinese-bike-sharing/

Secretariat of China Bicycle Association. (2017). Bicycle Industry Report Summaries 2016. *China Bicycle of China* (9):34-8. doi: 10.3969/j.issn.1000-999X.2017.09.006

Shaheen, S., Guzman, S., and Zhang, H. (2010a). Bikesharing in Europe, the Americas, and Asia: past, present, and future. *Transportation Research Record: Journal of the Transportation Research Board* (2143):159-67.

Shaheen, S. A. (2013). Introduction Shared-Use Vehicle Services for Sustainable Transportation: Carsharing, Bikesharing, and Personal Vehicle Sharing across the Globe. *International Journal of Sustainable Transportation* 7 (1):1-4.

Shaheen, S. A., Guzman, S., and Zhang, H. (2010b). Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future. *Transportation Research Record* 2143 (1):159-67. doi: 10.3141/2143-20

Shaheen, S. A., Guzman, S., and Zhang, H. (2010c). Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future. *Transportation Research Record Journal of the Transportation Research Board* 2143 (1316350):159-67.

Shaheen, S. A., Martin, E. W., Chan, N. D., et al. (2014). Public Bikesharing in North America during a Period of Rapid Expansion: Understanding Business Models, Industry Trends, and User Impacts. *Mineta Transportation Institute*.

Shaheen, S. A., Martin, E. W., Cohen, A. P., et al. (2012). Public Bikesharing in North America: Early Operator and User Understanding. Paper presented at the European Conference on Antennas and Propagation.

Shaheen, S. A., Zhang, H., Martin, E., et al. (2011). *China's Hangzhou Public Bicycle:*

Understanding Early Adoption and Behavioral Response to Bikesharing.

Shanghai Municipal Administration of planning and land and resources & Shanghai Municipal Transportation Committee. (2016). Shanghai Street Design Guideline. Retrieved from http://www.shgtj.gov.cn/zcfg/zhl/201610/t20161019_696909.html

Shanghai urban and rural construction and Transportation Development Research Institute. (2015). 5th Shanghai Comprehensive Transport Survey. Retrieved from CNKI:SUN:YSJT.0.2015-06-005

Shanghai Urban and Transport Research Institute. (2018). 2017 Shanghai Transport Report. Retrieved from http://www.shjjw.gov.cn/gb/node2/index.html

Shao, D. (2017). E-bike's development in Shanghai. *Traffic and Transportation*:15-22.

Shared Bike System Information In. (2017). Institution for Transportation & Development Policy.

Shen, Y., Zhang, X., and Zhao, J. (2018). Understanding the usage of dockless bike sharing in Singapore. *International Journal of Sustainable Transportation*:1-15.

Spinney, J., and Lin, W.-I. (2018). Are you being shared? Mobility, data and social relations in Shanghai's Public Bike Sharing 2.0 sector. *Applied Mobilities* 3 (1):66-83. doi: 10.1080/23800127.2018.1437656

Suzhou Planning Bureau & Jiangsu Institute of Urban Planning and Design. (2019). Non-motorized Traffic Planning of Suzhou (in Chinese).

Suzhou Planning Bureau & Suzhou Public Security Bureau. (2018). Suzhou Annual Transport Report_2017 (in Chinese). http://www.szghj.gov.cn/.

Suzhou Statistical Bureau. (2018b). Suzhou Annual Statistical Report_2017 (in Chinese). http://www.sztjj.gov.cn/.

Tang, R., Liu, W., and Pan, H. (2010). Urban policy's impact on Shanghai bicycle development and local cyclists (in Chinese). *Urban Transport of China*:66-73.

Tang, Y., Pan, H., and Fei, Y. (2017). Research on Users' Frequency of Ride in Shanghai Minhang Bike-sharing System. *Transportation Research Procedia* 25:4979-87. doi: https://doi.org/10.1016/j.trpro.2017.05.376

Tang, Y., Pan, H., and Shen, Q. (2011). Bike-sharing systems in Beijing, Shanghai, and Hangzhou and their impact on travel behavior. Paper presented at the Transportation Research Board 90th Annual Meeting.

Tao, L. (2017). The Wheels Are About to Come Off China's Shared Bike Industry. In *Sixth Tone*. http://www.sixthtone.com/news/1001219/the-wheels-are-about-to-come-off-chinas-shared-bike-industry

Tran, T. D., Ovtracht, N., and d'Arcier, B. F. (2015). Modeling bike sharing system using built environment factors. *Procedia CIRP* 30:293-8.

Transport Commission of Shenzhen Municipality. (2018). Report of preliminary assesment of Shenzhen Internet Rental Bike 2018 (in Chinese). http://www.sz.gov.cn/jw/jtzx/wycx/dccx/cxtx/201803/t20180322_11419959.htm

Wang, J., Tsai, C.-H., and Lin, P.-C. (2016). Applying spatial-temporal analysis and retail location theory to public bikes site selection in Taipei. *Transportation Research Part A: Policy and Practice* 94 (Supplement C):45-61. doi: https://doi.org/10.1016/j.tra.2016.08.025

Wang, M., and Zhou, X. (2017). Bike-sharing systems and congestion: Evidence from US cities.

Journal of Transport Geography 65:147-54. doi: https://doi.org/10.1016/j.jtrangeo.2017.10.022

Wei, W., and Wei, W. (2013). Comparative Study of Commercial Operation Mode of Public Bicycle Systems Worldwide: Based on Perspective of Institutional Economics. *Urban Planning International* 3:024.

Wells, P., and Lin, X. (2015). Spontaneous emergence versus technology management in sustainable mobility transitions: Electric bicycles in China. *Transportation Research Part A: Policy and Practice* 78:371-83. doi: https://doi.org/10.1016/j.tra.2015.05.022

Wenting, Z. (2017). Authorities move against shared bike 'congestion'. In *China Daily* http://www.chinadaily.com.cn/china/2017-11/01/content_33969945.htm

World Resources Institute. (2018). Chinese Cities Aim to Rein in Bike-Sharing Boom. Retrieved from http://www.wri.org/blog/2018/01/chinese-cities-aim-rein-bike-sharing-boom

World Resouces Institute & Mobike Global. (2018). How Cycling Changes Cities – Mobike's Second White Paper Goes Global. Retrieved from https://mobike.com/global/blog/post/cycling-changes-cities

Wu, J., Wang, L., and Li, W. (2018). Usage Patterns and Impact Factors of Public Bicycle Systems: Comparison between City Center and Suburban District in Shenzhen. *Journal of Urban Planning and Development* 144 (3):04018027.

Xiaolin, O. (2017). Shenzhen upgrade the policies of forbidding motorcycle and restricting electricity changes research. Shenzhen University.

Xiaoxi, D. Access (2016). Bike-sharing firms struggle with preventing damage, theft. http://www.globaltimes.cn/content/1020051.shtml

Yamei. (2017). China Focus: New guidelines to keep China's bike sharing on track. In *Xinhua*. http://www.xinhuanet.com/english/2017-08/03/c_136496955.htm

Yang, J., Chen, J., Zhou, M., et al. (2015). Major issues for biking revival in urban China. *Habitat International* 47:176-82. doi: https://doi.org/10.1016/j.habitatint.2015.01.022

Yang, X.-H., Cheng, Z., Chen, G., et al. (2018). The impact of a public bicycle-sharing system on urban public transport networks. *Transportation Research Part A: Policy and Practice* 107:246-56. doi: https://doi.org/10.1016/j.tra.2017.10.017

Yi, Z. (2017). Dockless shared bike in Wuhan reached its limit. In *Wuhan Evening*. http://news.hbtv.com.cn/p/623161.html

Yin, Z., Wu, H., and Hao, M. (2017). Development Status and Suggestion of China Urban Bicycle Transport. *Journal of Engineering Studies of China* 9:44-9.

Yue, L. (2018). Dockless shared bike reduced 20% in Beijing, Monitoring platform is established (in Chinese). In *IFENG*. http://finance.ifeng.com/a/20180525/16317115_0.shtml

Zhang, H., Shaheen, S. A., and Chen, X. (2014). Bicycle Evolution in China: From the 1900s to the Present. *International Journal of Sustainable Transportation* 8 (5):317-35. doi: 10.1080/15568318.2012.699999

Zhang, L., Zhang, J., Duan, Z.-y., et al. (2015). Sustainable bike-sharing systems: characteristics and commonalities across cases in urban China. *Journal of Cleaner Production* 97:124-33. doi: https://doi.org/10.1016/j.jclepro.2014.04.006

Zhang, Y., and Mi, Z. (2018). Environmental benefits of bike sharing: A big data-based analysis.

Applied Energy 220:296-301. doi: https://doi.org/10.1016/j.apenergy.2018.03.101

Zhang, Y., Thomas, T., Brussel, M., et al. (2017). Exploring the impact of built environment factors on the use of public bikes at bike stations: case study in Zhongshan, China. *Journal of Transport Geography* 58:59-70.

Zhao, C., Carstensen, T. A., Nielsen, T. A. S., et al. (2018). Bicycle-friendly infrastructure planning in Beijing and Copenhagen - between adapting design solutions and learning local planning cultures. *Journal of Transport Geography* 68:149-59. doi: https://doi.org/10.1016/j.jtrangeo.2018.03.003

Zhao, P., and Li, S. (2017). Bicycle-metro integration in a growing city: The determinants of cycling as a transfer mode in metro station areas in Beijing. *Transportation Research Part A: Policy and Practice* 99:46-60. doi: https://doi.org/10.1016/j.tra.2017.03.003

ZHao, X. (2018). 50% of dockless bikes in Beijing are left idle. In *KrASIA*. https://kr-asia.com/50-of-dockless-bikes-in-beijing-are-left-idle/

Zheng, C. (2018). Shared-bike company ordered to refund deposits, apologize. In *China Daily*. http://www.chinadaily.com.cn/a/201803/26/WS5ab8a306a3105cdcf6514531.html

Zhiying, S. (2016). Study on policy change of "ban e-bike" in Guangzhou based on policy process theory. University of Science and Technology of China.

Zhou, Y. (2018). Interview from a ofo maintenance worker - the rate of vandalism is decreasing In *Tencent Tech*. http://tech.qq.com/a/20180102/001273.htm

Zhu, M. (2017). Nanjing Public Bike and its Next Development Plan (in Chinese). *Urban Public Transport* (6):9-10.