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Social Factors Influencing the Choice of Bicycle: Difference Analysis among Private Bike, Public Bike Sharing and Free-Floating Bike Sharing in Kunming, China

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Abstract

The emergence of free-floating bike sharing (FFBS) has made essential changes in urban bicycle travel. In order to explore the differences of travel behavior among private bicycle (PB), public bicycle sharing (PBS) and FFBS, a survey was conducted in Kunming, China in 2018. Firstly, the differences of travel characteristics among these three modes were analyzed based on 522 valid questionnaires. Then, a multinomial logistic model was applied to explore the influential factors among them. The results show that: 1) PB and FFBS are more attractive for long-distance travel enthusiasts compared with PBS, PB is rarely used for transfer in suburbs while FFBS is the most desirable in connecting other travel modes. The theft problem and high maintenance costs are main obstacles for PB. 2) The elderly, high-income and non-student groups in inflexible travel activities show a preference for PBS, while the young, low-income and student groups in flexible travel demands have a tendency towards FFBS. 3) PB and PBS imped the use of FFBS to a certain extent, while PB seems to have less impact on PBS. 4) FFBS is desirable in temporary travel demand while PBS is more preferable in fixed demand. Interestingly, residents with registered permanent residence tend to use PBS while those without registered permanent residence prefer FFBS. Finally, several management strategies and policy recommendations were proposed for the government and FFBS enterprises to improve the management of bicycles.

Keywords: *travel characteristic differences, preferences, influential factors, multinomial logistic model, policy recommendations*

1. Introduction

As an effective travel tool for solving the short-distance travel and connecting "the last kilometer" in city, bicycle has numerous benefits, such as traffic congestion reduction, zero CO_2 emissions, health contribution (Shaheen *et al*., 2012). In China, the bicycle travel has gone through three stages. At the first stage, in 1978, the level of urbanization and motorization was low, private bicycles (PB) became main travel tools in the city, with about one bicycle per household. As of the mid-1980s, the share rate of PB reached over 50% and it played an important role in the daily travel of urban residents (Zhang *et al*., 2014). The second stage was started in 2008, the government of China established public bicycles sharing (PBS), a station-based bicycles sharing, system in many cities, such as Hangzhou, Beijing and Wuhan, to mitigate the problems of traffic congestion, bus connection, and environmental pollution. A customer could use the magnetic stripe card to rent a bicycle at a fixed docking location and return it to any station, and real-name registration system could track user information (Shaheen *et al*., 2014). As of 2014, PBS systems had been established in 31 provinces (totally 220 cities) (Shaheen *et al.,* 2011). The third stage was started in 2016, with the development of the Internet and mobile payment, free-floating bike sharing (FFBS), a dockless bicycles sharing, developed rapidly in China. Owing to the restrictions on fixed rental stations were eliminated, FFBS could be picked up by scanning its QR code and left at any reasonable parking area at users' convenience (Pal and Zhang, 2017). It was also equipped with Global Positioning System (GPS) to record its location in real time and the user could pay the fee by smartphone directly. More than 70 FFBS companies were operating more than 16 million bikes, and the total amount of registered users exceeded 130 million by July 2017 (Communications Institute, 2018).

However, bicycle travel has faced with unprecedented challenges in the diversified travel modes due to the limited policies and regulations. For example, in the case of PB, a number of private bicycles are set aside in China, and travellers are usually afraid of the problem of bicycle theft (Nakamura and Abe, 2014). In terms of PBS, the imbalance between supply and demand in system occurs frequently due to the phenomenon of traffic tide, especially during the traffic peak period (Alvarez-Valdes *et al*., 2016). As for FFBS, substantial enterprises introduced FFBS excessively

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and randomly in order to occupy the markets. It not only wastes public space and resources, but also affects the normal operation of other travel modes (Li *et al*., 2018). In addition, these three kinds of bicycles have essential differences: in terms of stations, PBS has fixed stations while FFBS has not. With respect to registration process, PBS users need to go to bicycle operation management department to register and pay a deposit, while FFBS users only need to register in smartphone, which greatly simplifies the process although a deposit is also needed to pay. As for the ownership, PS is privately owned while PBS and FFBS belong to shared mode. For operation mode, PBS is operated by the government, but FFBS is operated by enterprises, and dockless stations make it easier to expand compared with the other two counterparts. Furthermore, faced with the challenge and competition of FFBS, the current status of PB and PBS are inexplicit. Therefore, exploring the differences of travel behavior among PB, PBS and FFBS, understanding the decision-making mechanism of bicycles and clearing the status of three bicycles are not only the basis of planning public bicycle stations and introducing new FFBS stations, but also the basis for travel forecasting. At the same time, it will also contribute to the formulation of urban bicycle policies and guide urban residents to implement green travel.

The objective of this paper is to explore the differences of travel behavior among PB, PBS and FFBS under the context of combining the Internet and bicycles. The contributions are mainly concentrated in three aspects. Firstly, travel characteristic differences of three kinds of bicycles are compared and analyzed, residents' preferences and barriers to PB, PBS and FFBS could be better understood. Secondly, a consideration of some specific factors, such as travel demand form, registered permanent residence, coupons and some interactive variables will broaden the research framework for studies of travel mode decisions in bicycle. Lastly, providing new evidence from Kunming will compensate for the limited research in this field in China and it could provide some advices for government and enterprises to formulate policies on city bicycles.

2. Literature Review

In order to compare the differences among three types of bicycle, in our literature review, we mainly concentrated on the researches regarding the travel behaviors, influential factors and related policies of PB, PBS and FFBS.

2.1 Travel Characteristics of City Cycling

Understanding user's travel characteristics was the basis for the travel demand prediction and bike station introduction. In the case of PB, Aultmanhall *et al*. (1997) showed that bicycle commute one-way trip length in male and female users were 3.8 km and 3.6 km respectively, the average one-way trip length was about 3.7 km. Dill and Gliebe (2008) presented that the average bicycle travel distance for exercise was 14 km. Castillo-Manzano *et al*. (2016) applied propensity score matching-based model to compare the distance between PB and PBS, the results suggested mean trip distance in PB was 700–800 m, greater than those in PBS, and there was a complementarity relationship between these two bicycle modes. As for PBS, Fuller *et al*. (2011) found that the users of PBS in Montreal were mainly the group of 18–24 years old with a bachelor's degree, they usually utilized PBS stations within a 250 m road network buffer from participants' residential area. In addition, Fishman *et al*. (2014) studied the differences between users and non-users of PBS in Brisbane and Melbourne, the results showed that users were younger than non-users, and they utilized PBS at the nearest stations from home and work place, moreover, their friends or family members were usually more inclined to use PBS. By contrast, the location of domicile and workplace of non-users were more dispersed. Besides, Vogel *et al*. (2011) investigated the differences in the riding time of annual and temporary users of PBS in Lyons, and concluded that annual users mainly used PBS in weekdays, the peak periods were appeared in 8:00 a.m. and 6:00 p.m., and travel purposes were mainly for commuting. By comparison, temporary users usually utilized PBS in weekends, and the travel purposes were mainly for leisure and recreation. Also, Buck *et al*. (2011) explored the characteristics of casual users in Capital Bikeshare system based on the intercept surveys, the results showed that the casual user was a well-educated, Caucasian female aged between 25 and 34, a frequent cyclist. This group of users utilized bikes if they saw Bikeshare stations or being referred by their friends. With respect to FFBS, Ai *et al*. (2018) analyzed the travel behavior of FFBS based on the data of Ofo and Mobike in Chengdu, and presented that the travel distance concentrated in 0.8–2 km, the riding time was mainly distributed in 5–35 min, the travel peak was appeared in the morning and evening, and there were few users after 9 p.m. Shen *et al*. (2018) drew spatial distribution maps of FFBS using the data of Singapore, the results showed that the number of dockless bikes was lower in the central business district with dense mass rapid transit stations than the residential areas with high population density and last-mile travel demand to access to mass rapid transit. Du and Cheng (2018) divided travel patterns of FFBS system into three categories: origin to destination pattern, travel cycle pattern and transfer pattern and identified that: employees were more inclined to choose transfer pattern and origin to destination pattern than students, and residents in short distance travel were more likely to select travel cycle pattern and origin to destination pattern, when the travel distance reached 4 km, there was a significant transfer to transfer pattern.

2.2 Influential Factors and Preferences

Exploring influential factors and preferences of bicycles were not only helpful to evaluate the service level of system, but also helped to improve user satisfaction. In terms of PB, the problem of theft was the biggest barrier to the usage of PB (Fishman *et al*. 2014). Bachand-Marleau *et al*. (2012) studied the influential factors of bicycles in Australia and Britain and found the difficulty for parking, easy to be stolen and insufficient infrastructures were main obstacles.

With regard to PBS, station density, bikes per resident, coverage area, quality bikes, easy-to-use stations were identified as five significant elements for an effective and successful bikesharing system (Institute for Transportation and Development Policy, 2014). In the literature, the studies on the preferences mainly explored the motivations and obstacles to use this system based on the questionnaires survey. Firstly, convenience was considered to be the most important motivation to promote the use of PBS (Shaheen *et al*., 2012; Fishman *et al*., 2014; Buck and Buehler, 2012). Then, Shaheen *et al*. (2011) found that the number of stations, real-time supply of information on the number of public bicycles, the maintenance of bicycle and the extension of the operation time were also significant factors. In addition, users' environmental responsibility, public transport improvement as well as users' attention to healthy had positive impacts, while users' consciousness of environmental crisis had a negative impact (Yang and Long, 2016). Further, Campbell *et al*. (2016) explored the factors influencing the choice to switch from an existing travel mode to PBS or e-bike sharing based on a stated preference survey in Beijing. The results showed that the demand of PBS was negatively associated with travel distance, temperature, precipitation, and poor air quality. By comparison, the e-bike sharing was much more tolerant of these factors. Nair *et al*. (2013) investigated the characteristics of visibility, availability and location impact utilization as for Vélib' bicycle sharing systems in Paris, and found that an integration of public transit and bicycle sharing system can improve the utilization of bicycle. Rebecca and Laurie (2012) discussed several methods to improve the availability of bicycles in Federal lands as for three options: bike sharing programs, rentals and employee fleets. Besides, the impact of bikesharing on other models has also been focused on. Shaheen *et al*. (2013) studied the mode shift of bikesharing systems in four cities in North America. The research identified that bikesharing promoted the transportation sustainability by reducing the use of driving and taxi. The usages of bus and rail transit were reduced in three larger cities: Montreal, Toronto, and Washington D.C., while the rail usage was increased in Twin under the influence of bikesharing. In the field of FFBS, the influential factors of bicycles were mainly basic attribute of users, perception, land use, transport infrastructure facilities, meteorological factors and so on. Li *et al*. (2018) explored the influencing factors of FFBS in Jiangsu, China, and concluded that a higher educational level, a higher daily transportation cost, the convenience of picking up and parking bicycles, and the contribution to users' health had positive impacts while malfunctioning bicycles and limited regulations were major obstacles. Shen *et al*. (2018) applied spatial autoregressive models to analyze the spatiotemporal patterns of FFBS usage based on 14 million GPS records data in Singapore. The results suggested that high land use mixtures, easy access to public transportation, more supportive cycling facilities, and free-ride promotions positively impacted the usage of dockless bikes, and the negative influence of rainfall and high temperatures were also exhibited. In order to explore the factors influencing use frequency for station-based bike sharing and free-floating bike sharing system, Chen *et al*. (2018) carried on ordinal logistic regression analysis and found that education level, family car ownership, travel purpose and distance were four important factors for PBS, while gender and monthly cell phone data purchased were significant factors for FFBS.

2.3 Limited Policies on Bicycles

Effective policy was a significant factor to promote active bicycle travel. Many European countries have worked to encourage bicycle active travel including the construction of cycle lanes and parking facilities, reasonable land use planning, and promoting policies which had restrictions on car ownership (Gössling, 2013; Schulz *et al*., 2016). In particular, Denmark's Ministry of Transport had proposed a special plan to improve bicycle travel conditions, including the improvement of bicycle road signs, the establishment of expert team, the development of bicycle tourism and so on (Chen *et al*. 2017). Although there was a large number of bicycle users in China, few policies or regulations could effectively promote the use of bicycle, especially for FFBS. Until August 3rd, 2017, the Guiding Opinions on Encouraging and Regulating the Development of Internet Bike Rental was issued by the ministry of transport and other nine ministries (Ministry of Transport, 2017). The Opinion proposed that parking areas or electronic fence should be determined, the operation service of the enterprise should be regulated, users' information and capital safety supervision should be strengthened. However, the relevant policies were still in infancy, detailed policies to promote bicycle development required to be further established.

As is evident from the above review, scholars have done many works related to travel characteristics, preferences and policies about bicycles in the city, and they played important roles in the development of urban bicycles. However, on the one hand, since the emergence of FFBS, the structure and environment of urban bicycle travel have changed, which directly affects the use of PB and PBS. On the other hand, the operation mode of PB, PBS and FFBS are different, this means that the travel demands, characteristics and user preferences of these three types of bicycles are inconsistent. Therefore, in order to relocate them in the background of the Internet, it is necessary to explore the differences of travel behavior and understand the mechanism of modes choice among them, which are of great significance to the development and guidance of the green travel in the city.

3. Data and Method

3.1 City Context

Kunming, located in Yunnan province in China, is one of the most important transportation hubs in western China and the core circle of urban agglomeration in the center of Yunnan. According to "statistical communiqu of national economic and social development in Kunming in 2017", about 5.63 million permanent population and 0.486 trillion Yuan (70.727 billion dollars) of GDP were achieved as of 2017 (Kunming Statistics

Bureau, 2017). And there were 484 bus lines and 4 subway operation lines in the main urban area, and the sharing rate of public transit in motorized transportation was 57.09% (Kunming Statistics Bureau, 2017).

In terms of the operation of bicycles in Kunming, by the end of 2017, about 15 thousand public bicycles were put into operation, and 3.56 million residents were benefited. By comparison, four enterprises of FFBS, including Yongan riding, ofo, Mobike and Cool riding, introduced about 240 thousand FFBSs into the market, and registered users were over 3.8 million (Yunnan Daily, 2018; Kunming Urban Transportation Research Institute, 2018). In this place, the temperature and climate were pleasant and bicycle travels were common, the bicycle sharing rate in residents' travel exceeded 6% (Kunming Urban Transportation Research Institute, 2018). These factors could provide valid evidence for understanding travel characteristics and influencing factors of bicycles. Therefore, it was selected as the case city in this current study.

3.2 Survey Design

The travel characteristics and influential factors of three different travel modes: PB, PBS and FFBS are the focuses in this paper. In order to ensure the quality of the online survey, IP addresses of respondents were limited in Kunming and one mobile phone could complete only once. The questionnaire mainly contains three parts. 1) Basic attributes, including gender, age, educational level, occupation, monthly income, whether you have a public bike IC card, whether you have a car, whether you have a registered permanent residence, number of private bicycles and number of private electric bicycles. 2) User travel information, including travel duration, frequency, travel motivation, distance, travel time, geographic space and travel demand. 3) User's perception, including convenient to park, easy to find, easy to be stolen, personal information is easy to leak, travel time saving, high travel cost, lots of coupons, high maintenance cost and improve connectivity.

3.3 Data Source

The survey was conducted in Kunming, China, as shown in Fig. 1, using online questionnaire survey and offline questionnaire survey methods. The offline survey was mainly conducted in bus stations, metro stations, parks, shopping malls, schools and residential areas. The time lasted from June 11th, 2018 to June 20th, 2018 by the graduate students of School of Transportation, Southeast University. Online survey was conducted by social software such as WeChat and QQ, a way that has been applied by many previous researches, such as Bachand-Marleau *et al*., 2012; Chen *et al*., 2017; Du and Cheng, 2018; Li *et al*., 2018. This method was simple, efficient and respondents do not intentionally dodge privacy issues. However, there were also some imperfections. For example, some respondents might not be clear about the relevant terminology in the questionnaire, resulting in distortion of their answers. A small group of respondents lacked patience during the survey. As for above problems, some detailed explanations were added to help the respondents better understand the contents.

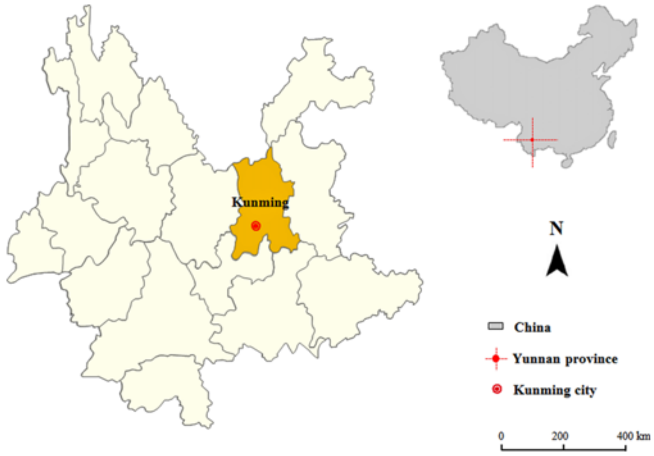

Fig. 1. Surveyed City in China

Also, in order to ensure the quality of survey results, the answer time was set to at least five minutes in the survey software, and some cash awards were provided to all respondents as incentives.

The investigation process was as follows, first, in order to identify whether the respondent was the subject of investigation, each respondent needed to answer whether he is a bicycle user. Then, the respondent filled in basic attributes, travel information, and preferences information according to the selected bicycle travel mode. A total of 556 questionnaires were sent to the respondents, in offline survey, some respondents did not provide privacy information such as income, age and occupation, in online survey, some users answered the questions in a short time. After excluding these samples with missing information and short answer time, 522 valid samples were collected, including 314 (60.15%) online samples and 208 (39.85%) field samples, and the whole recovery rate was 93.88%.

3.4 Method

Multinomial logit is a discrete choice model based on the theory of random utility (Mcfadden *et al*., 1978). It can deal with the categories and continuous variables at the same time and it is usually utilized to deal with multiple choice problems in traffic engineering (Bhatta and Larsen, 2011; Zhang, 2011). The utility consists of determination term V_{in} and random term ε_{in}:

$$U_{in} = V_{in} + \varepsilon_{in} \tag{1}$$

$$V_{in} = \theta X_{in} = \sum_{k=1}^{l} \theta_k X_{ink} \quad (i \in A_n) \tag{2}$$

where $\theta = (\theta_1, \theta_2 \cdots \theta_l)$ is an unknown parameter vector, $X_{in} = (X_{in1}, \ldots, X_{ink}, \ldots, X_{inl})$ is the influential factor (such as basic attribute, travel information and preferences) vector of traveler n in the i^{th} travel mode.

If random items $\varepsilon_{i1}, \varepsilon_{i2} \cdots \varepsilon_{in}$ are distributed independently and obey Gumbel distribution with the parameter (0, 1), the probability of the traveler n selects the transport mode i is:

$$P_{in} = e^{V_{in}} \Big/ \sum_{j \in A_n} e^{V_{jn}} \tag{3}$$

where A_n is the collection of alternative travel modes: PB, PBS and FFBS.

4. Survey Results

4.1 Respondent Attributes

A total of 522 valid samples were collected and the sample sizes and ratios of three bicycles were: PB (152, 29.12%), PBS (126, 24.12%) and FFBS (224, 46.76%). The demographic information of samples in three bicycles is shown in Table 1. As for gender, the proportion of male is more than that of women, especially in PB, which is similar to the survey results in Washington and Jiangsu (Li *et al*., 2018; Ma *et al*., 2015). With regard to age, most of users in PB and FFBS are adults while PBS customers concentrate in the group of middle-aged, maybe it is because the way of mobile payment is more suitable for young people while the way of paying by IC-card could cover different age stages, especially in groups of middle-aged and older. In terms of education and occupation, main groups in PBS are officer and employee with a relatively high educational level, which is in line with Zhang's finding (Zhang *et al*., 2015). By comparison, FFBS users focus on college and graduate students, which is consistent with the result of Du and Cheng (2018). In the case of income, PB and FFBS are mainly the groups of low-income and middle-income, while PBS users mainly located in the groups of middle and high-income.

4.2 Characteristics of Bicycles Use

4.2.1 Travel Distance

The distribution differences of travel distance in gender are shown in Table 2, the travel distance in male concentrates in 2-4 km, by contrast, that in female focuses on 1–2 km, which shows that average riding distance in male is greater than that in female (Aultmanhall *et al*., 1997), probably because men are better than women in physical strength. What's a little surprising is that some riders still utilize PB and FFBS when the travel distance is above 8 km, possibly because PB and FFBS are more suitable and attractive for long-distance exercise compared with PBS (Jäppinen *et al*., 2013). Interestingly, as for the travel distance between 4 km and 8 km in PBS, the proportion of female is higher than that of male, maybe because a portion of women who join PBS system are actually regular bicyclists and they are more inclined to pursue longer travel distance.

4.2.2 Travel Purpose

The distribution differences of travel purpose in geographical areas are shown in Table 3. As seen in the table, PB, PBS and FFBS are all used for commuting and recreation. As for PB, it is also applied for shopping activity but rarely used for transfer in suburbs. In terms of PBS, the distribution of the travel purpose in the core area is more balanced while it mainly focuses on shopping and recreation in suburbs, perhaps it is because the distribution of bicycle infrastructures in core region is more perfect than those in suburbs. It is worth noting that, in the connection with other modes of transport, FFBS is the most magnetic, especially in core area, which reflects the convenience of FFBS in the "first kilometer" and "last kilometer" in the city (Li *et al*., 2018; Fuller *et al*., 2011).

4.2.3 Analysis of Preference Characteristics

In this current paper, the users' perceptions for bicycles express in acceptance degree and are divided into five levels, which are strongly disagree (the value is 1), relatively disagree (2), not sure (3), relatively agree (4), strongly agree (5). The acceptance

Table 1. Demographic Information of the Sample

Items	Description	PB (%)	PBS (%)	FFBS (%)
Gender	Male	61.8	58.7	55.8
	Female	38.2	41.3	44.2
Age	Teenagers (<=18)	19.7	17.4	11.6
	Adults (19–40)	60.5	17.5	71.9
	Middle-aged (41–65)	10.6	55.6	9.8
	Older (>65)	9.2	9.5	6.7
Education level	<=Middle school	6.6	4.8	3.1
	High school	46.1	22.2	15.6
	Undergraduate	27.6	28.6	54.1
	Masters and higher	19.7	44.4	27.2
Occupation	Student	51.3	6.3	36.6
	Teacher	11.8	11.1	4.9
	Officer	7.9	27.0	17.9
	Employee	10.6	28.7	31.7
	Retired	3.9	19.0	0.4
	Others	14.5	7.9	8.5
Income level (CNY/month)	<3,000	57.9	11.1	54.9
	3,000–6,000	30.3	19.0	28.6
	6,001–10,000	9.2	27.0	13.8
	>10,000	2.6	42.9	2.7

Table 2. Distance Distribution Differences in Gender

Proportion	Male			Female		
	PB (%)	PBS (%)	FFBS (%)	PB (%)	PBS (%)	FFBS (%)
<1 km	13	8	11	24	18	15
1–2 km	21	34	33	31	37	43
2–4 km	38	50	41	28	27	29
4–8 km	19	8	13	7	18	9
>8 km	9	0	2	10	0	4

Table 3. Motivation Distribution Differences in Geographical Area

Proportion	Core area			Suburbs		
	PB (%)	PBS (%)	FFBS (%)	PB (%)	PBS (%)	FFBS (%)
Commute	13	25	20	24	18	15
Attending school	17	17	9	10	9	10
Shopping	6	16	4	21	27	10
Business	2	8	7	4	0	3
Recreation	51	17	31	41	37	43
Transfer	11	17	29	0	9	19

degrees of various perceptions among PB, PBS and FFBS are shown in Fig. 2. As seen in the results, FFBS has a unique advantage in the convenience of picking up and parking a bike. It is probably because stations of FFBS are relatively more dispersed, and the design of dockless stations makes it easier to return bicycles (3). In the connection with other modes of transportation, FFBS and PBS are more attractive than PB, maybe it is because FFBS and PBS are more located near bus and subway stations, which is consistent with the conclusion of

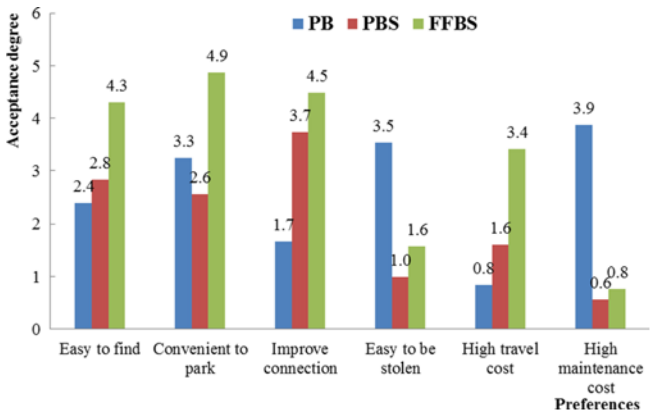

Fig. 2. Acceptance Degrees of Various Perceptions

Jäppinen (Jäppinen *et al.*, 2013): PBS and FFBS could enhance the accessibility to public transportation systems by improving last-mile connectivity. In addition, compared with PB, the real-name registration system and the design of docking stations in PBS make the problem of theft infrequency, which is the main reason why lots of residents use PBS (Fuller *et al.*, 2011; Faghih-Imani and Eluru, 2015). And FFBS could utilize embedded GPS positioning devices to achieve real-time positioning to prevent theft. Besides, as for travel costs, PB just pay for the purchase cost, while the government subsidy in PBS is greater than the other two counterparts, generally it is free within 1 hour (Du and Cheng, 2018). For FFBS, the cost (generally 1CNY per half hour) is more expensive than the other two travel modes from a long-term perspective, although some teachers and students could enjoy it for half price. Finally, PBS and FFBS are not necessary to maintain by users, the maintenance costs are significantly lower than those in PB.

5. Model Results and Discussion

5.1 Model Results

The influential factors of different bicycle travel modes are different. The dependent variables of PB, PBS and FFBS are calibrated by 2, 1 and 0 respectively. The main factors influencing

Table 4. Calibration and Definition of Variables

Items	Variable	Definition and notes
Basic attributes	Gender	Male=1 Female=0
	Age	Teenagers (<=18)=0 Adult (19–40)=1 Middle-aged (41–65) =2 Older (>=66) =3
	Educational level	< Junior middle school=0 High school=1 Undergraduate=2 >= Master=3
	Occupation	Student=1 Officer=2 Employee=3 Teacher=4 Retired=5 Others=0
	Monthly income (CNY)	<3,000=03,000~6,000=1 6,001–10,000=2 >10,000=3
	Whether you have a public bike IC card	Yes=1 No=0
	Whether you have a car	Yes=1 No=0
	Whether you have a registered permanent residence	Yes=1 No=0
	Number of private bicycles	0=1 1=2 2=3 >=3=0
	Number of private electric bicycles	0=1 1=2 2=3 >=3=0
Travel information	Travel duration (min)	<5=0 5–10=1 10–20=2 >=20=3
	Travel frequency in a week	<1=0 1–2=1 3–5=2 >5=3
	Travel motivation	Commute=1 Attending school=2 Shopping=3 Business=4 Recreation=5 Transfer=0
	Travel distance (km)	<1=0 1–2=1 2–4=2 4–8=3 >8=4
	Travel time	6:00–9:00=1 9:01–11:00=2 11:01–13:00=3 13:01–17:00=4 17:01–19:00=5 >19:00 =0
	Geographic space	Urban core area=1 Suburbs=0
	Travel demand	Temporary demand=1 Cyclical demand=0
Preferences	Convenient to park	Strongly agree=1 Relatively agree=2 Not sure=3 Relatively disagree=4 Strongly disagree=0
	Easy to find	Strongly agree=1 Relatively agree=2 Not sure=3 Relatively disagree=4 Strongly disagree=0
	Easy to be stolen	Strongly agree=1 Relatively agree=2 Not sure=3 Relatively disagree=4 Strongly disagree=0
	Personal information is easy to leak	Strongly agree=1 Relatively agree=2 Not sure=3 Relatively disagree=4 Strongly disagree=0
	Save travel time	Strongly agree=1 Relatively agree=2 Not sure=3 Relatively disagree=4 Strongly disagree=0
	High travel cost	Strongly agree=1 Relatively agree=2 Not sure=3 Relatively disagree=4 Strongly disagree=0
	Lots of coupons	Strongly agree=1 Relatively agree=2 Not sure=3 Relatively disagree=4 Strongly disagree=0
	High maintenance cost	Strongly agree=1 Relatively agree=2 Not sure=3 Relatively disagree=4 Strongly disagree=0
	Improve the connectivity	Strongly agree=1 Relatively agree=2 Not sure=3 Relatively disagree=4 Strongly disagree=0

the travel behavior choice can be divided into basic attribute, travel information, and preferences. Before establishing the MNL model, each variable is needed to be calibrated, and the results are shown in Table 4.

In the established MNL (multinomial logit) model, calibrated independent variables and dependent variables with the value of 0 are set as reference items. All the independent variables are selected with an introducing probability of 0.05 and rejecting probability of 0.1. The independent variables and results of significance tests are listed in Table 5. The Nagelkerke R Square is 0.567, Chi-square is 171.617, McFadden coefficient is 0.362 (more than 0.2), and Cox and Snell is 0.467, these are all within an acceptable range, thus proving that the model is preferable.

5.2 Discussion

The results of the model show that age, monthly income, public bike IC-card, registered permanent residence and travel motivation * occupation have significant impacts on the use of PBS. As comparison, age, the number of private bicycles, registered permanent residence, travel motivation * occupation, travel demand and coupons significantly impact the usage of FFBS.

Table 5. Estimation Results of Multinomial Logit Model

Variable	PBS			FFBS		
	B	Sig.	Exp (B)	B	Sig.	Exp (B)
Age						
Older (>=66)	.341	.841	1.406	-	-	-
Middle-aged (41–65)	3.906	.014	49.687	1.026	.417	2.789
Adult (19–40)	.670	.572	1.954	1.525	.002	4.596
Monthly income (CNY)						
>10,000	2.721	.054	15.193	–.335	.772	.715
6,001–10,000	1.987	.025	7.294	.071	.910	1.073
3,001–6,000	1.552	.120	4.719	.096	.838	1.101
Number of private bicycles						
>=3	–2.047	.659	.129	–2.762	.000	.063
2	–1.639	.572	.194	–2.683	.001	.068
1	–.536	.034	.585	–2.171	.000	.114
Whether you have a public bike IC card						
Yes	1.401	.006	4.059	–.078	.830	.925
Whether you have a registered permanent residence						
Yes	.780	.001	2.181	–.372	.002	.689
Travel motivation * Occupation						
Flexible travel * Student	–2.105	.016	.122	1.228	.002	3.414
Flexible travel * Non-student	–.377	.085	.686	.748	.053	2.113
Fixity travel * Student	–1.545	.070	.213	.567	.043	1.763
Fixity travel * Non-student	-	-	-	-	-	-
Travel demand						
Temporary demand	–.011	.988	.989	1.178	.006	3.249
Lots of coupons						
Strongly agree	.149	.872	1.160	2.260	.000	9.582
Relatively agree	–.845	.518	.430	2.047	.003	7.742
Not sure	.277	.749	1.319	1.251	.041	3.493
Relatively disagree	–1.493	.160	.225	1.219	.078	3.384
Constant	–1.579	.375	-	–.174	.857	-
Cox and Snell	.467		Nagelkerke	.567		
McFadden	.362		Chi-square	171.617		

In the case of age, the utility of PBS in the group of middle-aged is significantly positive, by comparison, the utility of FFBS in the group of adult is the most significant. It implies that compared with PB, PBS is more preferable by the middle-aged while FFBS is more attractive among young people. Probably because the middle-aged who rarely used new functions of mobile phones already used to utilizing and trusting PBS before the introduction of FFBS, under the effect of habit, there is less information to be considered when residents select which mode to travel, and it is also not easy to change this habit (Verplanken *et al*., 1997). However, young people are more inclined to accept new things such as FFBS.

As for monthly income, compared with FFBS, the impact of PBS is more significant, and with the increase of income, the utility increases. In contrast, FFBS presents an opposite trend. This shows that the high-income group prefers PBS, consistent with the findings of Fishman (Fishman *et al*., 2015) and Woodcock (Woodcock *et al*., 2014). By comparison, FFBS is more appealing among middle and low-income groups. Maybe it is because FFBS users are mainly young people, they have relatively low income and could not purchase cars in the short term. However, the advantages of flexibility, convenience and the characteristic of providing door to door service in FFBS can better satisfy their travel demands.

In terms of the number of private bicycles, the coefficient of FFBS is negative and significant, and with the increase of the number of private bicycles, the coefficient of FFBS reduced. For public bike IC card, the coefficient of PBS is positively significant while the coefficient of FFBS is negative and not significant. It indicates that PB and PBS will restrain the usage of FFBS to a certain extent. Maybe it is because these three bicycle travel modes are more similar in function and have competitive relationships among them. However, with the increase of the number of private bicycles, the coefficient of PBS is not significant. This suggests that PB has less impact on PBS, probably because PBS is more advantageous than PB in terms of travel quality, such as safety, convenience and so on (Tang *et al*., 2011).

With regard to the variable of registered permanent residence, the impact of PBS is positively significant while FFBS is negatively significant. It implies that residents with registered permanent residence are more inclined to use PBS while those without registered permanent residence show a preference for FFBS. Perhaps it is because residents with registered permanent residence can clearly understand the distribution of available PBS stations around a given period of time according to their daily experience of borrowing and returning public bicycles. This certainty of a bike station with multiple bikes and docks in one fixed location would increase people's trust in PBS. On the contrary, residents without registered permanent residence are not familiar with the PBS stations around them, therefore, scattered stations in FFBS system could increase the probability of success in finding a bike and reduce the walking distance from the starting position, and make FFBS more appealing in these groups. It also indicates that PBS and FFBS have their own service groups, and the user's trust in bicycle system and the reliability of the system would affect the choice.

In order to explore the impact of the distribution of different travel purposes in different groups on the choice of three bicycle travel modes, this paper divides travel purposes into flexible purpose and fixity purpose, and divides the occupations into students and non-students. For FFBS, the coefficient of each interactive variable is positive and significant, and the coefficient of student group in flexible travel is the largest. For PBS, the coefficient of non-student group in fixity travel is the largest. It indicates that non-student group in fixity travel activities tend to utilize PBS, coincides with the result of Shaheen (Shaheen *et al*., 2012): PBS is mainly used for commuting while student group in flexible travel activities show an inclination to FFBS.

As for the travel demand variables, FFBS is positively significant while PBS is not significant. It shows that FFBS is preferred in temporary demand compared with PB, and PBS is more suitable for fixed demand, which suggests that FFBS could induce residents' new travel to a certain extent, and the randomness of this travel is larger. This may be associated with the characteristics of stations: more dispersed and unfixed stations in FFBS while stations in PBS are fixed (Pal and Zhang, 2017).

In the case of coupons, the utility of FFBS is significantly positive, and with the increase of coupons, the utility gradually increases. It indicates that residents will show a preference for FFBS with the increase of the discount rate. While the impact on PBS is not significant, this implies that the effect of economic intervention on PBS is ineffective, to a certain extent, maybe it is related to the higher income of PBS users (Woodcock *et al*., 2014).

6. Conclusions

The main objective of this paper is to explore the factors influencing the modes choice among PB, PBS and FFBS. Firstly, the distribution of the travel distance in gender, the distribution of travel purpose in geographic space and bicycle users' preferences are analyzed. In particular, the travel distances of male and female concentrate in 2–4 km and 1–2 km respectively. PB and FFBS are more favored by long-distance exercise compared with PBS, and the female prefers PBS than male when the travel distance is between 4 km and 8 km. In addition, PB, PBS and FFBS are mainly used for commuting and recreation although the distribution of travel purpose in PBS in the core area is more balanced. Besides, FFBS has a great advantage in the convenience of picking up and returning a bike. PB is rarely used for transfer in suburbs while FFBS is the most appealing in transfer compared with the other two bicycle modes. The theft problem and high maintenance costs are main obstacles for PB. Secondly, the behavior choice of PB, PBS and FFBS is analyzed by a MNL model. The results show that the elderly, high-income and non-student groups in inflexible travel activities have a tendency towards PBS, while the young, low-income and student groups in flexible travel demands show a preference for FFBS. In addition, PB and PBS restrict the usage of FFBS while PB has less impact on PBS. Besides, to some extent, FFBS could induce residents' temporary travel demands, while PBS is more used for fixed demand. Interestingly, residents with registered permanent residence are more inclined to utilize PBS, and those without registered permanent residence prefer FFBS, due to the difference of the user's trust in bicycle system.

Several management strategies and policy recommendations are discussed from operators and governments respectively, to improve the usage of bicycles.

As for operators, four management actions can be considered: 1) Ticket price strategy. As the result indicates, FFBS is the most desirable bicycle mode in transfer. In order to better promote residents to utilize green travel mode, FFBS enterprises could cooperate with public transit companies. The embedded GPS device in FFBS could be fully utilized to locate users' origin and destination positions, further, transfer users could be identified according to the location information, and then transfer discount can be provided to them. This approach may achieve simultaneous increase of the usage of bicycle and public transit. 2) Demand management strategy. As the model indicates, PB will restrict the using of FFBS to a certain extent. At present, the number of private bicycles in China is large but most of them are set aside, therefore, private bicycles could be encouraged to join the FFBS platform after modification according to the standard of FFBS, which can not only alleviate the travel demand of urban bicycles, but also promote the utilization of bicycle resources. 3) Utilization of the influence of registered permanent residence in mode choice. As the model implies, FFBS was more appealing among residents without registered permanent residence. Therefore, maybe in some tourist spots or tourist cities, FFBS could be introduced in appropriate amount by the operators to benefit tourists who come from other places. 4) The introduction form of bike stations. As shown by the model, FFBS is preferable in temporary and flexible travel demand while PBS is more desirable in fixed and inflexible demand. Therefore, in order to use a bicycle in a reasonable way, PBS could be introduced “concentratedly” in fixed demand places such as public transport stations, subway stations, offices infrastructure and schools. FFBS could be introduced “dispersedly” in place for flexible demand, such as parks, supermarkets and recreation places.

In term of government, three policy suggestions could be taken into account: 1) Payment system integration. This is similar to the first recommendation as for operators, but a different technological mean is applied. The government can build a payment system that integrates FFBS and public transit, to implement transfer discount as for transfer users directly. 2) Technological innovation of PBS. The integration of FFBS and Internet technology has attracted a large amount of users. In the face of competition, PBS can learn from it. For example, the residents can register by mobile phone rather than going to bicycle operation management department. The residents can rent a bike from PBS system not only by the magnetic stripe card but also by scanning code using smartphone. Also, "no-deposit" strategy could also be considered, which may attract more young people and users without registered permanent residence to use. 3) Construction of free bicycle maintenance service locations. As the result shows, the maintenance cost of PB is high. The government can set up bicycle maintenance service locations to provide free repair service for PB users. PBS and FFBS operators can also encourage users to repair faulty public bike-sharing at these maintenance locations by rewarding the riding times or issuing some coupons to them.

The present paper still has some limitations. Further research is needed to fill the following gaps. Firstly, this paper does not consider the characteristic differences of bicycle trips between weekdays and weekends, the comparison may be interesting. In addition, more meteorological data, such as temperature, weather and air quality, could be considered in future studies.

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