The Impact of Bicycle-sharing on Conventional Commuting Travel Structure

Jingyao Qu[1],Wei Wang[2], Qi Fan[1] and Mujie Lu[1]

[1] *School of Transportation, Southeast University, Nanjing, Jiangsu, China*

[2]*Jiangsu Key Laboratory of Urban ITS, Jiangsu Province Collaborative Innovation Center of Modern Urban Traffic Technologies, School of Transportation, Southeast University, Nanjing, Jiangsu, China*

f_author@220162623@seu.edu.cn, s_author@wangwei_transtar@163.com,t-author@fanqi0617@163.com,f-author@ mujielu_seu@163.com

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Abstract: As a new travel mode, the emergence of bicycle-sharing (BS) can effectively solve “last mile” problem which causes inconvenience in public transportation travel. More and more travelers choose using bicycle-sharing instead of conventional travel modes. Previous researches about BS mostly were only based on the large data, while the mechanism of how BS impacts the conventional travel structure can hardly know. Multinomial Logit Model (MNL), a discrete selection model, can be used to compare the differences before and after the emergence of BS. Based on the RP (revealed preference) survey results, the paper uses Stata software to perform the logit analysis about the travel mode choice of travelers. The main factors impact travel model choices are selected and parameters are also calculated. Finally, the utility function of each travel modes are calculated. The results are compared, providing a reference for future traffic planning and the adjustment of traffic management policy.

1 INTRODUCTION

Advantages like flexible parking points, little limitation for users, economic security and payment convenience make the sharing bikes become the new trend of people’s travel choice.

The emergence of bicycle-sharing (BS) leads to a solution of “last mile” problem with its flexible parking property. The emergence of BS still has a huge impact on conventional travel structure. From the "Bicycle-sharing and Urban Development White Paper in 2017", it can be seen exactly that the emergence of sharing bicycles directly leads to a strong increase of bicycle travel in city. It also leads to a significant reduction on car travel, especially unlicensed cabs.

As a new mode of traffic travel, there is relatively little research about bicycle-sharing. NPV, IRR model are used to analyze the profitability of shared bicycle companies with ofo and moblike as examples (Li, 2017). The characteristics and functions of sharing bikes are analysed (Wang, 2017).

Plenty of researches were done about public bicycle, a traffic mode which is relatively similar to the BS pattern. A survey is always carried out before travel satisfaction analysis (Liu, 2016) and travel mode selection analysis (Shaheen SA, 2013; Zhu, 2012). On this base, the factors that influence likelihood of using public bicycles and frequency are analyzed (Bachand-Marleau, J, 2012; Cao, 2015; Shaheen, SA, 2011). Methods like discrete choice model (Shen, 2015; Luo, 2013), Fuzzy comprehensive Evaluation, empirical analysis of tour-based bicycle use, analysis of IC card data (Cao, 2016) and difference-in-differences regression model (Kayleigh B. Campbell, 2017) are used for traffic needs analysis and to obtain the general proportion of public bicycles in traffic structure.

To conclude, though there are many studies about BS, these studies are limited to a summary of sharing bikes’ large data. However, as a new mode of traffic travel, the study must be proceeded from the analysis of traffic demand. In this way, the travel mechanism of BS can be analyzed, which cannot be obtained from large data. As a similar mode of traffic travel with BS, the research methods of public bicycles can be used to analyze the demand mechanism of BS.

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Thus, the research goals can be determined: (1)The paper takes the travel structure of Nanjing residents as research objective, then uses RP survey to investigate the modes of residents' travel, the results of investigation can be used to identify the main factors that affect the choice of traffic travel. (2)With the data of the investigation, the paper use Stata software to establish the MNL model of residents' travel mode choices before and after the emergence of BS. (3)The paper compares the differences of travel modes choices before and after the emergence of BS, and gives suggestions to government and enterprises for better traffic planning and management.

The rest of the paper is organized as follows: Section 2 describes survey design and data collection process. Section 3 discusses sample characteristics before and after the emergence of BS. Section 4 shows modelling process and results discussion. Conclusions and future directions are provided in section 5.

2 SURVEY DESIGN AND DATA COLLECTION

2.1 Research Objective

As a new way of traffic travel, the emergence of BS has a huge impact on conventional travel structure, which can be studied to make cities' traffic planning and traffic managements. Thus, the paper takes the travel structure before and after the emergence of sharing bikes as study objective to explore the differences between two conditions.

As a similar way of traffic travel with BS, the methods used to investigate public bicycle travel can be used to investigate the travel mode of BS. The sharing bicycles are upgraded version of public bicycles. Similarly, the sharing bicycles are more economically safe and flexible than private bicycles, as a result, it must has a huge impact on conventional travel structure, which is a critical factor to traffic planning and management.

2.2 Survey Design

The questionnaire adopts the method of RP survey (Revealed Preference survey), mainly considering the impact of the personal attributes, transfer characteristics and perceptions of travel satisfaction. Consisting following parts:

(1) Personal attributes: including sex, age, profession, income level, private transport condition, which may affect the mode choice of traffic travel and different people have different travel factors about personal attributes.

(2) Travel characteristics: including travel form and purpose, main travel time period, travel distance, the choice of travel mode, travel expense and travel time consuming. The choice of travel mode can be regarded as the dependent variable of the travel structure study, and other travel characteristics are factors that affect travel mode choosing.

(3) Perceptions of travel satisfaction: including travel considerations, attitude towards public transportation travel, the main reasons that affect the public transportation travel, attitude towards travel. The travel considerations including transfer convenience, travel safety, travel punctuality, green travel, travel comfort and travel expense. The main reasons that affect the public transportation travel including waiting time, traffic transfer conditions, travel comfort, travel speed and expense. The travel attitude values are varied from very dissatisfied to very satisfactory.

(4) The travel characteristics section of the questionnaire is designed in two parts, travel investigation before the emergence of BS and after the emergence of BS.

2.3 Filed Survey and Data Collection

The survey was carried out in different areas in Nanjing, and was carried out concretely near the public transport sites and transport hub in August, 2017, and received 487 valid case, among them, 415 questionnaires are valid questionnaires.

3 DESCRIPTIVE ANALYSIS

The survey covered the traffic travel before and after the emergence of BS. Sample characteristics are explored as follows.

3.1 Passenger Personal Attributes

As shown in Table 1, 53.5% of the respondents are men and 46.5% of the respondents are women, both of which are close to the theoretical value 50%. Over 90% of the respondents' age are between 18 and 50, this is consistent with the age distribution of commuter travelers in the actual situation. Over 50% of the respondents are workers and nearly 40% are students or teachers, all of which are the main forces of the commuting travelers. The distribution of the income is consistent with the actual situation.

Table 1: Passenger personal attributes distribution proportion.

	Personal attributes	Proportion
Sex	Male	53.5%
	Female	46.5%
Age	9-18	3.9%
	18-30	42.9%
	30-40	30.6%
	40-50	20.2%
	>50	2.4%
Profession	Student	21.9%
	Teacher	16.6%
	Enterprise or government staff	33.3%
	Individual business household	9.4%
	Service worker	8.9%
	Others	9.9%
Private transport condition	Private car	31.3%
	Private bicycle	20.5%
	Private electric bicycle	16.4%
	No private transport	49.6%
Income	<1500	21.7%
	1500-3000	18.1%
	3000-5000	32.5%
	5000-8000	14.7%
	8000-12000	7.0%
	>12000	6.0%

Note: Private transport condition has multiple options, so the total probability not equal to 1.

3.2 Travel Characteristics

For commuting travel, the travel characteristics are shown in Table 2. Nearly 2/3 of the respondents' purposes are working and most of their travel time period are distributed in the morning and evening peak hours. Compared with the situation that before the emergence of BS, the travel mode choices of car have significantly reduced and the choices of public transport have significantly improved. The largest increase in travel mode choice is bicycle travel. All of the results shows that the emergence of BS are beneficial for development of public transportation and protecting environment.

Table 2: Travel characteristics of commuting travel.

	Travel characteristics	Before (%)	After (%)
Travel purpose	Working	68.4	
	Go to school	18.6	
	Business	8.4	
	other	4.6	
Travel time (period)	0:00-7:00	12.8	
	7:00-9:00	68.0	
	9:00-14:00	14.9	
	14:00-17:00	16.6	
	17:00-19:00	45.3	
	19:00-24:00	25.3	
Travel distance	<500m	5.5	
	500-1000m	17.3	
	1000-2000m	25.1	
	2000-4000m	20.5	
	4000-7000m	15.2	
	7000-10000m	6.0	
	>10000m	10.4	
Travel mode	Private car	27.7	25.5
	Taxi	16.6	11.3
	Bus & Walk	37.8	25.5
	Bus & Public bicycle	11.6	12.8
	Bus & Private bicycle	8.9	7.0
	Bus & Sharing bicycle	0	22.9
	Metro & Walk	25.1	12.3
	Metro & Public bicycle	4.8	4.8
	Metro & Private bicycle	2.7	2.0
	Metro & Sharing bicycle	0	17.8
	Walk		
	Public bicycle	17.3	16.4
	Private bicycle	6.5	4.8
	Sharing bicycle	13.5	13.3
		0	20.7
Expense(Yuan)	0	8.7	7.2
	0-100	37.1	41.9
	100-200	24.6	23.9
	200-500	18.3	18.3
	500-1000	9.9	7.0
	>1000	1.4	1.7
Time consuming(min)	0-10	8.2	11.6
	10-20	30.4	31.3
	20-30	28.2	29.6
	30-40	18.8	15.4
	40-60	9.2	8.7
	>60	5.2	3.4

Note: Travel time (period) and travel mode have multiple options, so the total probability not equal to 1.

3.3 Travel Characteristics

Before the emergence of BS, 11.1% of commuting travel respondents are very dissatisfied with public transport travel, 16.4% are dissatisfied, 41.9% feeling okay with it, 20.7% are satisfied and 9.9% are very satisfied. The most influential factor in public transport travel is long waiting time (70.8%). After the emergence of BS, only 14.5% of commuting travelers are dissatisfied or very dissatisfied with public transport travel, a significant reduction compared with the proportion before (27.5%). The proportion of inconvenient transfer has a significant reduction, with 37.3% compared with 54.7%. The data reveals that BS is beneficial for development of public transport travel.

4 MODELLING PROCESS AND RESULT DISCUSSION

In this study, the dependent variable y is multiple dependent variable. Before the emergence of BS, the option set is set to a number set changing from 1 to 11 with changing of mode choices. After the emergence of BS, the option set is set to a number set changing from 1 to 14. Thus, the multinomial logit model is appropriate. The independent variables for before A and after B models are defined as x_{a1}, x_{a2}… x_{an} and x_{b1}, x_{b2}… x_{bn} which are factors of personal attributes, travel characteristics and perceptions of travel satisfaction. Taking commuting travel before the emergence of bicycle-sharing for example, the multinomial logit model can be expressed as:

$$P_{in} = \frac{e^{V_{in}}}{\sum_{j \in A_n} e^{V_{jn}}} = \frac{1}{\sum_{j \in A_n} e^{V_{jn} - V_{in}}} \quad i \in A \tag{1}$$

where P_{in} is the probability of traveler n selects travel mode i; V_{in} is the fixed item in the utility function of traveler n selects travel mode i, taking the linear function of the parameter vector θ and the eigenvector X_{in}; A is the travel mode choices set before the emergence of BS.

The utility of the alternatives to the traveler can be expressed in the form of the following functions :

$$V_{in} = \sum_j \alpha_{ij} x_{aij} + c_i \tag{2}$$

where α_{ij} are explanatory variable coefficients, x_{aij} is independent variables that traveler choose mode i, c_i is the inherent dummy variable of traffic i.

4.1 Independent Variables Selection

It is necessary to eliminate factors with less impact on mode choice before modelling. Due to the multiple dependent variable, maximum likelihood ratio test are used to filter variables, the final independent variables are shown in Table 3. For lack of space, we only show the variables of commuting travel:

Table 3: Independent variables and pretreatment before modelling.

Types	Variables	Description
Personal attributes	Sex: Male	0
	Sex: Female	1
	Age	1,2,3,4,5
	Income	1,2,3,4,5,6
	Private transport condition(car)	1,0
	Private transport condition(electric bicycle)	1,0
	Private transport condition(bicycle)	1,0
Travel characteristics	Travel purpose	1,2,3,4
	Travel distance	1,2,3,4,5,6,7
	Expense	1,2,3,4,5,6
	Time consuming	1,2,3,4,5,6
Perceptions of travel satisfaction	Considerations(transfer convenience)	1,0
	Considerations(safety)	1,0
	Considerations(punctuality)	1,0
	Considerations(environmental protection)	1,0
	Considerations(comfort)	1,0
	Travel satisfaction level	1,2,3,4,5

4.2 Model Calibration Results

The model is constructed in Stata. As Table 4 shows, most parameter estimates are significantly at 90% confidence levels with expected sign, which means most of passengers' personal attributes, travel characteristics and perception of travel satisfaction are main factors for travel mode choice. The estimation results are shown in Table 4, for lacking of space, only some results before the emergence of BS are shown, other results are also shown in statistical analysis part:

Table 4: Estimation results of commuting travel before.

Travel mode	Age	Private-car
Private car	~	4.583(0)
taxi	~	1.334(0.030)
Bus & walk	~	~
Bus& public bicycle	~	~
Bus & private bicycle	~	~
Metro& walk	-0.509(0.084	~
Metro& public bicycle	-1.026(0.054)	~
Metro& private bicycle	~	~
Walk	~	~
Public bicycle	~	~
Private-bicycle	**purpose**	**distance**
-2.664(0)	0.537(0.086)	0.319(0.080)
-2.767(0)	~	0.303(0.084)
-2.456(0)	0.495(0.073)	0.288(0.081)
-2.434(0)	~	~
-1.929(0.002)	~	~
-4.032(0)	~	0.486(0.006)
-3.236(0.006)	~	~
~	0.701(0.099)	~
-2.238(0)	~	-0.376(0.048)
-1.145(0.077)	~	~
environmental	**satisfaction**	**constant**
~	~	-3.200
~	0.543(0.017)	-2.533
~	0.516(0.015)	-1.829
1.208(0.056)	0.713(0.004)	-3.535
~	0.638(0.017)	-3.954
~	~	~
~	0.977(0.003)	-6.414
1.597(0.096)	0.949(0.018)	-5.764
1.410(0.021)	0.537(0.023)	~
1.760(0.012)	0.666(0.020)	-3.941
LL(0)	-1433.0822	
LL(β)	-930.14745	
adj. ρ^2	0.253	

Note: The numbers in the box are coefficients, and the numbers in parentheses are significances.

The value of Mc Fadden's adj R squre is 0.253, the value is in the range of 0.2 to 0.4, indicating that the model fitted well.

4.3 Statistical Analysis of Travel Mode Choice

According to the established utility functions of different travel modes, the probability functions of different travel modes can also be obtained. The utility functions of each modes are shown as Table 5. For lacking of space, only some results are shown.

Table 5: The utility functions of commuting travel modes before and after.

Modes	Before/ after	Utility function
Car	B	$V_{car} = 4.583x_{pcar} - 1.559x_{peb} - 2.664x_{pb} + 0.537x_{prp} + 0.319x_{dis} + 2.542x_{cov} + 1.055x_{cmf} - 3.200$
	A	$V_{car} = 3.774x_{pcar} + 0.492x_{dis} - 1.751x_{enp} - 0.519x_{sati} - 0.845x_{pun}$
Taxi	B	$V_{taxi} = 1.334x_{pcar} - 1.586x_{peb} - 2.767x_{pb} + 0.303x_{dis} + 2.585x_{cov} + 0.543x_{sati} - 2.533$
	A	$V_{taxi} = 1.084x_{sex} + 0.436x_{age} - 1.237x_{pb} + 0.512x_{prp} + 1.238x_{cov} - 0.879x_{cmf} - 5.534$
B& priB	B	$V_{B\&priB} = -1.307x_{peb} - 1.929x_{pb} + 3.123x_{cov} + 0.638x_{sati} - 3.954$
	A	$V_{B\&priB} = 0.415x_{dis} - 1.370$
B& B-S	B	—
	A	$V_{B\&B-S} = -0.255x_{inc} + 0.409x_{dis} + 1.052x_{cov}$
M& priB	B	$V_{M\&priB} = -3.176x_{peb} + 0.701x_{prp} + 1.766x_{cov} + 1.597x_{enp} + 0.949x_{sati} - 5.764$
	A	$V_{M\&priB} = 1.653x_{cov}$
M& B-S	B	—
	A	$V_{B\&B-S} = -1.641x_{pcar} + 0.556x_{prp} + 0.788x_{dis} + 1.385x_{cov} - 4.672$
Private bicycle	B	—
	A	$V_{priB} = 0.591x_{age} - 1.056x_{pcar} + 2.129x_{peb} + 2.085x_{pb} - 1.539x_{enp} - 0.585x_{sati}$
Bicycle-sharing	B	—
	A	—

It can be seen from the Table 5, before the emergence, the coefficient of private car ownership condition for private car travel is 4.583, compared with 3.774 after the emergence, which reveals the fact that after the emergence of BS, fewer and fewer travelers choosing car for travel, even they have private cars. It means that BS is beneficial for reducing car travel. Compared with the before condition, the coefficients of satisfaction become negative from positive, it means the travelers' options are no longer violently fluctuating, which is a sign that the emergence of BS is a trend to narrowing the service gap between the different travel modes. Taking Metro& Walk modes for example, the coefficient of private bicycle ownership condition are changed from -4.032 to -2.372, it means that the effect of this ownership condition for choosing of public transport are reducing, this reflects the fact that the emergence of shared bicycles is conducive to the development of public transport.

5 CONCLUSIONS

The paper takes the travel structure of Nanjing residents as research objective. A carefully designed survey was conducted to capture the travelers' travel mode choices before and after the emergence of BS. Then the survey results were analyzed and variables were selected. The paper uses Stata to establish a MNL model for travel choice prediction. After comparing the different travel choices model before and after the emergence of BS, following conclusions about the impact of BS to conventional travel structure are obtained:

Firstly, BS has a huge impact on car travel. It not only directly takes away some original car travellers, but also improves the transfer condition, It improves the roadway utilization efficiency and reduces pollution emission.

Secondly, BS travel also has a huge impact on public transport travel. For bus, BS is playing a competitor role, this is because the speed of bus is relatively slow and buses are often stuck in the traffic congestion during the peak hours. For metro travelers, BS is playing a role of assistant. Most metro users are middle or long distance travelers, at this point, sharing bicycle travel almost has no impact on metro travel. Sharing bicycle travel is also a good solution for the trip from the starting point to subway station. In summary, the impact of shared bicycles on public transport is multifaceted, but overall is playing a positive role to public transport travel.

Several future directions can be proposed based on this study. Firstly, the impact of BS to public transport travel is based on the travel mode, the result of competition between BS and bus seem to be inconclusive. An issue about the relationship between BS and bus based on distance can be a new extension to the paper. Secondly, the results of the model told us that the emergence of BS is a sign that the service gap between the different travel modes are narrowing, the mechanism of this phenomenon can be another extension to the paper.

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