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Effects of perception on public bike-and-ride: A survey under complex, multifactor mode-choice scenarios

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ABSTRACT

Bicycles are an environmentally-friendly, energy-saving mode of transportation. Public bike-and-ride is a term used to describe the use of public bicycles combined with transit as a means of transportation. A new stated preference (SP) design scheme based on the factors respondents felt were most important was proposed to augment the traditional SP design under complex multi-factor and multi-level situations. iPads were used to automatically administer the survey under each design scheme and collect the choice behavior data for public bike-and-ride. The concept of perceived psychological distance was further proposed and used to estimate Logit models. Comparative analysis of these models shows for the traditional SP design scheme, some factors, including perceived psychological distance, have reduced statistically significant effects on public bike-and-ride choice relative to the new SP design scheme. This indicates that in scenarios with complex decisions, the decision-makers would reduce their consideration of some factors and simplify their decision process making the new SP survey design scheme more suitable to analyze their choice behavior in those cases. Model analysis showed that perceived psychological distance for each traveler is the most critical factor during the decision process for travel behavior analysis. Finally, sensitivity analysis was conducted to determine which factors in the new survey design were important to increase the share of public bike-and-ride users. Practical findings for promoting public bike-and-ride use are presented in addition to theoretical references for improving the traditional survey methods.

1. Introduction

With the rapid development of urban economies and the growth of car ownership, traffic congestion is becoming increasingly prominent in metropolitan areas while air quality is getting worse. As a result, it is important to promote the sustainable development of urban transportation systems to address these issues. As an energy-saving and environment-friendly traffic mode, public bicycles, or "bike share" systems have been successfully applied in many cities such as London, Washington D.C., and Hangzhou. The implementation of public bicycle systems can promote low carbon travel, improve the operational efficiency of urban transport and reduce both pollution and traffic congestion.

As of December 2014, the subway operating mileage in Beijing was over 527 km and the daily passenger volume has exceeded ten million passengers. As an environmentally-friendly access mode for subways, public bicycle systems increase

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the accessibility and attractiveness of public transit. In 2012, Beijing officially launched a trial operation of public bicycle system. Forty-thousand public bicycles have been deployed as of December 31, 2014. As part of the "One Hundred Congestion Mitigation Projects" initiative by the Chinese government in 2015, ten-thousand public bicycles will be added to cover the central business districts and residential districts within about 3 km of subway lines. However, the public bicycle system in Beijing is still not perfect due to the low density of rental stations and the inconvenience of borrowing and returning bicycles in some areas. Moreover, the riding environment for cyclists in most areas isn't cyclist-friendly due to mixed traffic flow, limited space and air pollution. Thus, the utilization of some public bicycle rental stations is not high enough.

As an integrated multi-modal travel choice, public bike-and-ride, defined as the combined use of public bicycles and the subway, can effectively improve the usage of public bicycle system. There are many factors affecting the choice behavior of travelers for public bike-and-ride such as travel environment, mode-related factors and psychological factors. The effective acquisition and analysis method of travelers' behavioral data for public bike-and-ride, especially the effect of psychological factors, under multi-factor and multi-level decision scenarios still needs to be explored in depth. The research results will help to identify key factors that can increase the share of public bike-and-ride and provide insight into the behavioral mechanism.

2. Literature review

Several researchers have discussed the applications of public bicycle systems and the traffic policies that may encourage the use of the system. Martens (2004) discussed the use of bike-and-ride in Netherlands, Germany and United Kingdom (UK) with widely differing bicycle cultures and infrastructure. Midgley (2009) and Shaheen, Guzman, and Zhang (2010) reviewed the bike share systems in several European cities which often operate as part of the city's public transport system. In terms of traffic policies related to the bicycle system, Martens (2007) proposed a country-wide program to secure bicycle parking at train stations and the introduction of flexible rental bicycles to facilitate the combined use of bicycles and buses. Pucher, Dill, and Handy (2010) found that integrated policies including infrastructure provisions, supportive land use planning, and restrictions on car use are required to improve the use of bicycles. Meanwhile, Lumsdon and Tolley (2001) also discussed the national cycle strategy (NCS) in UK, finding that many local authorities needed to utilize a more robust cycling strategy to accomplish national targets for increased bicycle use.

In terms of study methodology, several studies have analyzed public bicycle choice behavior using a stated preference survey and disaggregate models. Taylor and Mahmassani (1996) conducted a stated preference survey to analyze the choice preferences of automobile only, park-and-ride, and bike-and-ride. A nested logit model was established to conclude that bike lanes and wide curb lanes are an incentive for experienced bicycle users to use bike-and-ride. Wardman, Tight, and Page (2007) built a multinomial logit model to analyze the propensity toward bicycles based on revealed preference and stated preference data. The model results show that a completely segregated bike path has the greatest impact on encouraging bicycle use. Campbell, Cherry, Ryerson, and Yang (2016) employed a stated preference survey and multinomial logit model to suggest that the bicycle choice for people in Beijing is strongly, negatively impacted by trip distance, temperature, precipitation, and poor air quality.

Some studies used social equilibrium models, mathematical network models and other similar methods to analyze the travelers' public bicycle choice behavior. Fukuda and Morichi (2007) used the social equilibrium equations to analyze the conformity effects of bicycle users on the choice of bicycle parking locations. Lin and Yang (2011) proposed a mathematical model to describe the bicycle network and routing choices. Sensitivity analysis was also performed to gain important factors affecting the system use such as the fixed cost of locating a bicycle station and the construction costs for a bicycle lane. Vogel, Greiser, and Mattfeld (2011) used a Geographical Business Intelligence process, which includes a cluster analysis, to gain insight into the complex bicycle activity patterns, based on the operational data from bicycle sharing system. Borgnat et al. (2011) analyzed the behaviors of shared bicycles users based on spatial–temporal data of bicyclists' movements.

Descriptive statistical analysis has been used to deal with public bike-and-ride related studies. Both Rietveld (2000) and Keijer and Rietveld (2000) proposed that bicycles are an attractive access mode for railways. Findings indicated that unavailable or insufficient parking facilities for bicycles are primary factors that affect the use of bicycles. Krizek and Stonebraker (2010) analyzed factors related to the combined use of bicycle and transit such as transit mode, access and egress distance, and trip purpose. Several studies have explored the impact of weather on bicycle use. Brandenburg, Matzarakis, and Arnberger (2007) used a Psychological Equivalent Temperature rating system to conclude that recreational bicycle users are most sensitive to ambient temperature and precipitation. Flynn, Dana, Sears, and Aultman-Hall (2012) found that rainy days would reduce the likelihood of bicycling for commuters and higher temperatures would increase the likelihood of bicycling. In addition, Pucher and Buehler (2006) found that bicycle-friendly infrastructure can compensate for some weather impacts.

Social and psychological factors such as attitude, perception, subjective norms, social interactions and neighborhood effects are inherent determining factors that affect travel choice (Brock & Durlauf, 2001, 2002; Morikawa, Ben-Akiva, & McFadden, 2002; Morikawa, Tanaka, & Ogino, 1997). Some scholars also conducted exploratory research to analyze their impacts on bicycle choice behavior. Heinen, Maat, and van Wee (2011) analyzed the influence of commuters' attitudes toward convenience, low cost and health benefits for bicycle use on mode choice. Nkurunziza, Zuidgeest, Brussel, and Maarseveen (2012) examined the effect of various motivators, barriers and policy-related interventions on bicycle use.

Cheng and Liu (2012) and Gatersleben and Appleton (2007) evaluated the effect of attitudes and perceptions on bicycle choice for commuting. The change in public bicycle services quality perception is also quantified by Bordagaray, Ibeas, and dell'Olio (2012). From an environmental point of view, Chen (2016) revealed that perceived pleasure to use and the subjective norms have the strongest influence on the selection of environmentally friendly modes for both bicycle users and non-users. It has also been found that some psychological factors such as psychological distance may have an impact on travel mode choice, but receive less attention. Psychological distance is a cognitive separation between the self and other instances such as persons, events, or times, which was first proposed by Beckerman (1956) and later popularized by Johanson and Vahlne (1977).

Some new survey technologies should be also considered to be applied in travel surveys to investigate the effect of these psychological factors on travelers' choices to use public bike-and-ride. A more recent trend is to use computers, mobile phones, GPS, etc., to augment and audit traditional travel surveys (Wermuth, Sommer, & Kreitz, 2003). Furthermore, Tablet Assisted Interview (TAI), a new survey method, has attracted the attention of scholars in the transportation field, but its application is relatively limited. Reiter, Kramer, Stadler, Geyer, and Fellendorf (2012) discussed the usability of tablet computers in a travel survey and found that the new method can provide questions tailored for the participants and ensure accurately recording for survey data. Reiter, Völkl, and Fellendorf (2013) studied the impact of road pricing on travel behavior and concluded that the tablet computers can improve data quality and increase the willingness of respondents to participate in the survey. In addition, Asbahan and DiGirolamo (2012) found that the use of tablet computers can provide more accurate, reliable, and timely information for transportation construction projects to field inspectors.

This paper will: (1) Propose a new stated preference (SP) method to analyze the decision behavior of travelers under complex multi-factor and multi-level situations. iPads are used to facilitate the survey questions randomly extracted and presented and the survey data automatically collected. (2) Estimate discrete choice models to analyze the effects of key factors on public bike-and-ride choice for the traditional and new SP design schemes. (3) Discuss the concept of perceived psychological distance and its influence on public bike-and-ride choice. (4) Conduct sensitivity analysis based on Logit models with the best fit to gain insights into the choice behavior of travelers.

The remainder of this paper is organized as follows. Section 3 presents SP survey design and data collection. In Section 4, perceived psychological distance is proposed and calculated based on the major influencing factors. In Section 5, modeling and comparative analysis for different SP design schemes are given. Finally, some concluding remarks are discussed in Section 6.

3. Design and implementation of the survey

3.1. Survey contents

In order to analyze the choice behavior for travelers who would use public bike-and-ride, a survey was conducted with the following parts:

Part one of the survey is composed of questions designed to collect personal travel information including daily commute time, the ownership of public bicycle rental cards, and usage of public bike-and-ride in the past.

Part two is about the respondent's present usage situation of public bicycles focused on the respondent's residence including the distance from house to public bike rental station, the number of public bicycle rental stations within 500 m, perceived cycling environment, the convenience of locking and retrieving bicycles, and availability of parking spaces and bicycles.

Part three is about respondent's perception of using public bicycles. The response options consisted of a 3-point scale ranging from "disagree" to "agree".

Part four is the SP experiment designed to obtain the stated choice-data for public bike-and-ride under hypothetical scenarios. There are many factors affecting the choice preference of travelers for public bike-and-ride such as cycling environment, riding time and convenience of bicycle use, and ease of transfer. If more factors are chosen in the design of SP questions, the number of combinations with multi-factor and multi-level survey design would be larger. For example, four factors and three levels will produce $3^4 = 81$ combinations. Even if orthogonal experimental design can be used to reduce the number of combinations and obtain the best combinations of factors, too many factors will increase the burden on respondents and, as a result will affect the reliability of survey data, especially when the affecting factors are equal to or more than four. If less factors are chosen in the design of SP questions, the survey data may not reflect the influences of some important factors on choice behavior. This causes a problem which requires tradeoffs in the SP design.

When faced with complex, multi-factor and multi-level decision-making situations, travelers may only focus on a few key factors important to them and use simple decision strategies to make a decision. In view of this, a new SP design scheme based on factors which travelers are most concerned about for themselves was proposed to collect the stated choice-data. The traditional design method based on multi-factor combinations was also given to compare with the new design method.

According to the preliminary survey for public bicycle users conducted in December 2014 in Beijing, four major factors which affect the usage of public bicycles were chosen in the SP design schemes. These factors included cycling environment, distance from house to rental stations, convenience of using bicycles and availability of parking places and bicycles, and number of public bicycle rental stations within 500 m of the traveler's house.

Table 1 shows the hypothetical levels of these four factors in the SP design which are based on the choice results of each respondent from Part Two of the survey. For example, if the respondent chose Option B for Q4 in Fig. 1(a), the current distance from his or her house to rental stations is between 100 m and 300 m. The hypothetical "Reduced by 50%" for distance in Table 1 means that his or her distance to rental stations is assumed to be between 50 m and 150 m. In this way, under the same hypothetical level, each respondent may have different assumed value according to his or her different present situation for using public bicycle.

(1) New design scheme of SP survey with two factors

In this design scheme, the respondent first chooses the two factors they find are most important among the four major factors and then only gives choice preference for public bike-and-ride under these two chosen factor combinations automatically extracted from an iPad. Each alternative two-factor combination is obtained by dividing the four major factors into pairs. Based on the hypothetical levels in Table 1, the most suitable level-combination of two factors for each pair is generated by an orthogonal experimental design which is a highly efficient method for the multi-factor and multi-level experimental design (Zhu, Chew, Lv, & Wu, 2013). The main idea of this design method is that the optimal levels combinations can be extracted from a full factorial experiment in a way that the points of combinations are distributed uniformly within the test range and thus can represent the overall situation without requiring every situation to be tested explicitly. For example, four SP choice questions can be obtained for the levels combinations of cycling environment and distance to rental stations by this design method as shown in Fig. 1(d). This SP design scheme can reduce the burden on respondents answering the complex multi-factor and multi-level questions and help to analyze the impact of multiple factors on the choice behaviors of travelers.

(2) Traditional design scheme of SP survey with four factors

In order to compare with the new design scheme, the traditional design scheme with four factors was also conducted in a survey. Nine SP choice questions for the levels combinations of the above major four factors were obtained by orthogonal experimental design. These choice questions were divided into three groups marked with A, B and C and each group had three choice questions. Fig. 1(e) shows a group of SP questions.

Part five of the survey is designed to collect the travelers' socio-economic information, such as gender, age, occupation and average monthly income.

3.2. iPad-based survey

The above contents of the survey were converted into graphical user interfaces using the computer programming language, Swift (Swift, 2017), and the development platform, XCODE6.0 (Xcode, 2017). The developed program is released to iPads to automate the collection of survey data.

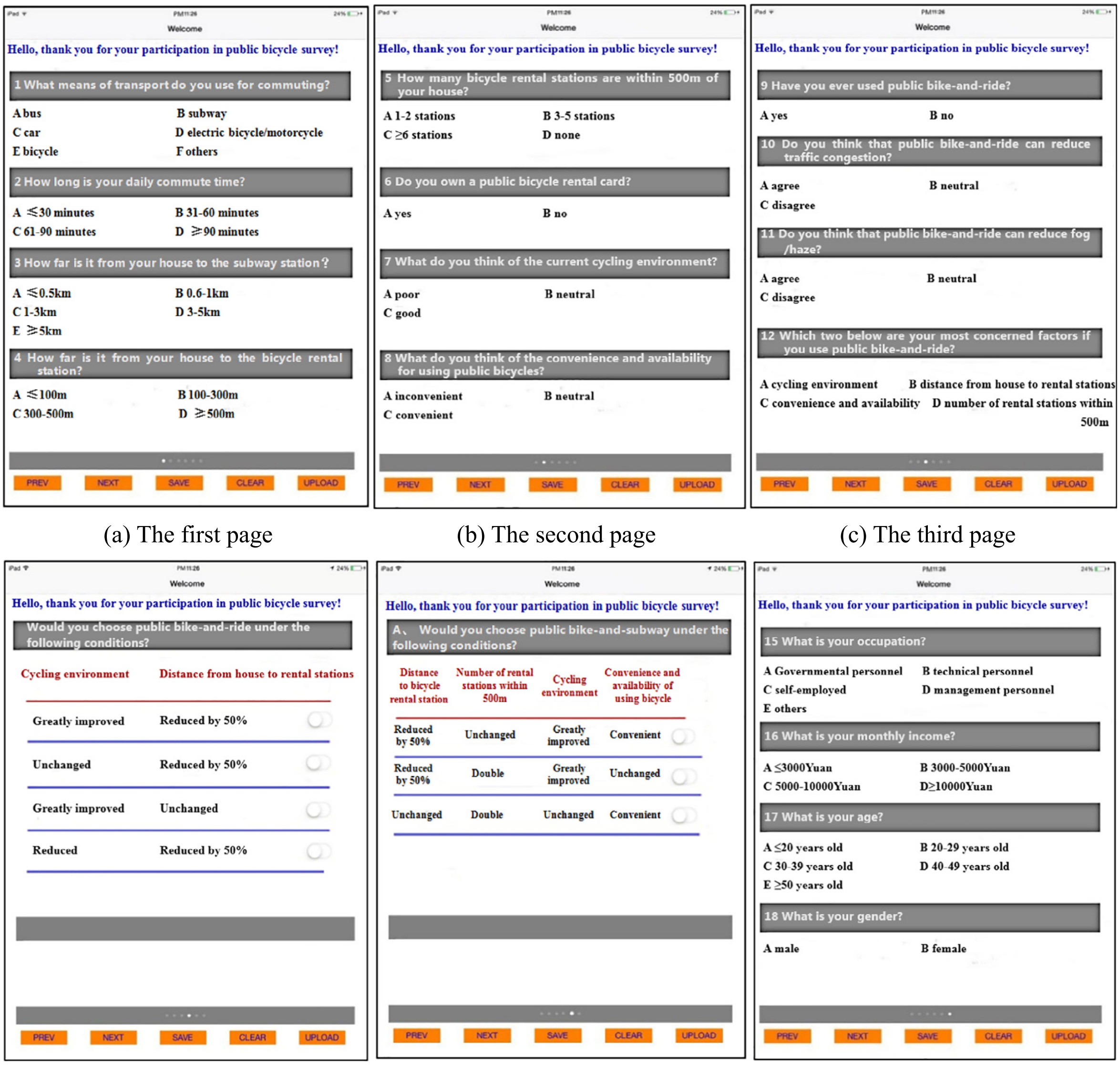
3.2.1. Interface design

The primary principles guiding the design of electronic interfaces are simplicity and clarity. The number of questions on each page does not exceed four. The questions about daily travel information and using situation of public bicycle are set on the first and second pages, shown in Fig. 1(a) and (b). The questions regarding opinion on using public bicycles and most concerned factors are set on the third page in Fig. 1(c). The SP choice questions for the new and traditional design scheme are put on an independent page, respectively shown in Fig. 1(d) and (e). In order to ensure the reliability of survey data for main contents, the questions about individual information are put on the final page. Therefore, a total of six pages were designed in this survey.

In the implementation of the SP design schemes, the respondent first chose two factors they were most concerned about among the given four factors as shown in Q12 of Fig. 1(a). Then the SP questions for these two chosen factor combinations were automatically extracted from the back-end system and presented to the respondent. The respondent viewed information and then decided whether or not they would choose public bike-and-ride under the hypothetical conditions presented.

Table 1
Four major factors and their hypothetical levels in the SP design.

Influencing factors	Hypothetical levels
Cycling environment for public bicycle	Three levels: Greatly improved; Unchanged; Reduced
Distance from house to public bicycle rental stations	Two levels: Reduced by 50%; Unchanged
Convenience of locking and retrieving bicycles and availability of parking spaces and bicycles	Two levels: Greatly improved; Unchanged
Number of public bicycle rental stations within 500 m of house	Two levels: Increased by 100%; Unchanged



(a) The first page (b) The second page (c) The third page

(d)The fourth page (e) The fifth page (f) The sixth page

Fig. 1. The interface design.

Then the respondent needed to answer a group of SP questions randomly presented for four-factor combinations in the same way as the two-factor combinations. At the same time, the application automatically recorded these choice results and the total decision time to make choices for these two SP design schemes.

Compared with the traditional paper-based survey, the iPad-based method can present the questions automatically and clearly in a user-friendly environment, expediting the survey process on-site.

3.2.2. Implementation of survey and data collection

After the survey was released to the iPad handheld terminal, the investigators used the iPad to collect the survey data at designated bus stations outside subway stations in Beijing. The travelers who took bus and then transferred to the subway were chosen as subjects and were considered as the potential public bicycle and subway users. In order to ensure the unbiased representation of the survey data and considering some biases caused by the use of an iPad, two methods were adopted. One was an iPad-assisted personal interview where respondents were asked questions by an investigator handling and helping operate the iPad. The other was iPad-assisted self-interviews where respondents operated the iPad themselves and answered the questions. Once the survey was completed, the response was sent to a designated e-mail account for analysis, thus saving a substantial amount of time that would have normally been spent in both collecting and entering data while reducing labor costs. The survey was carried out in January and March 2015. 102 valid samples were obtained.

In order to facilitate the further analysis, Tables 2 and 3 illustrate the assigned values for coding each response and the statistical characteristics of the survey contents. For the distribution of samples, males accounted for 60% of respondents while females accounted for 40%. Most travelers were below the age of 40 years old, accounting for 83%. Monthly income is mainly distributed between 3000 and 10,000 Yuan, accounting for 87%. The distributions of gender, age, and income for the samples basically matched the demographic statistics of bus travelers for the Fourth Composite Transportation Survey in Beijing released by Beijing Municipal Commission of Transport in 2012. The survey data can be used to analyze the public bike-and-ride choice behavior for travelers.

Roughly 65% of the respondents had less than an hour commute to work. Only 13% of travelers owned one or more public bicycle rental cards and ever used public bike-and-ride for travel. Most travelers acknowledged that using public bicycles can reduce traffic congestion and fog or haze, accounting for 55% and 57% respectively. For the present situation of public bicycle facilities around the residence, 39% of travelers needed to walk more than 300 m to find a public bicycle station. 54% were able to locate one or two rental stations, while 21% of travelers could not find a rental station within 500 m of their house. For the usage information for public bicycles, 74% of travelers thought that the cycling environment in Beijing was either poor or neutral and only 26% felt it was good. 25% of travelers thought that bicycles were inconvenient due to parking, security, and other reasons.

4. Calculation of perceived psychological distance

The perception of each traveler regarding the present usability of the public bicycle system varied by participant. Thus, when the travelers are faced with the SP choice question with the same hypothetical level combination, they will likely have different psychological perceptions. The perceived psychological distance, as defined here, is a measure of the difference between each individual's perception of the current condition of the system and the hypothetical levels in SP choice at which public bike-and-ride becomes a viable and enticing option (Chen, Mitchell, Brigham, Howell, & Steinbauer, in press; Massara & Severino, 2013; Singh, Zwickle, Bruskotter, & Wilson, 2017).

The perceived psychological distance is calculated by Euclidean distance of multi-dimensional attributes. Based on the preliminary survey data, the chosen four factors were the same as the ones in the SP survey design, including cycling environment, distance to rental stations, convenience and availability of using public bicycles and the number of public bicycle rental stations within 500 m of the house. Generally, the greater the psychological distance travelers perceived, the more likely they are to choose public bike-and-ride in the hypothetical scenario.

The calculation of perceived psychological distance d_n is expressed in Eq. (1):

$$d_n = \sqrt{\sum_{k=1}^{m} (a_{k2} - a_{k1})^2} \quad k = 1, 2, \ldots, m \tag{1}$$

Table 2
Statistical characteristics for personal and daily travel information, and opinion on using public bicycles.

Influencing factors		Options	Assigned value	Percentage (%)
Personal information	Gender	Male	1	60
		Female	2	40
	Age	≤29 years old	1	41
		30–39 years old	2	42
		≥40 years old	3	17
	Occupation	Governmental personnel and technical personnel	1	38
		Others	2	41
		Self-employed and management personnel	3	21
	Monthly income	≤3000 Yuan	1	10
		3000–10000 Yuan	2	87
		≥10,000 Yuan	3	3
Daily travel information	Commute time	≤30 min	1	25
		31–60 min	2	40
		61–90 min	3	25
		≥90 min	4	10
	Usage of public bike-and-ride	Ever used	1	13
		Never used	2	87
	Ownership of rental cards	One or more	1	13
		None	2	87
Opinion on using public bicycles	Whether it can reduce traffic congestion	Agree	1	55
		Neutral	2	40
		Disagree	3	5
	Whether it can reduce fog or haze	Agree	1	57
		Neutral	2	31
		Disagree	3	12

Table 3
Statistical characteristics for present using situation of public bicycle.

Influencing factors	Options	Assigned value	Percentage (%)
Cycling environment	Poor	1	20
	Neutral	2	54
	Good	3	26
Distance from house to rental stations	≤100 m	1	25
	100–300 m	2	36
	≥300 m	3	39
Convenience and availability	Inconvenient	1	25
	Neutral	2	37
	Convenient	3	38
Number of rental stations within 500 m of house	None	1	21
	1–2 stations	2	54
	≥3 stations	3	25

where a_{k2} expresses the hypothetical level for factor k in SP choice; a_{k1} indicates the perceived level for the present condition for factor k; m is the number of factors, and equals four in this research.

By assigning values to the perceived present and hypothetical levels for the four major factors, the perceived psychological distance of each respondent can be calculated and shown in Figs. 2 and 3 for each SP survey.

As can be seen from Fig. 2, most travelers' perceived psychological distance was distributed between 7 and 13 under two-factor combinations in the new SP design scheme with a mean value of 10.13 and a variance of 1.04. For the four-factor combination in the traditional SP design scheme, shown in Fig. 3, the perceived psychological distance was mainly distributed between 8 and 15. The mean value was 11.65 and the variance was 1.12. The perceived psychological distance under four-factor combinations was slightly higher than that under two-factor combinations.

5. Modeling and analysis based on the survey data

5.1. Methodology

The basic framework of discrete choice models is based on the economic utility function. It assumes that travelers make rational choices in pursuit of utility maximization by considering all optional modes and choosing the mode with the greatest utility. According to the Random Utility Theory (Hensher & Button, 2000), the utility function that traveler n choose mode i is expressed in Eq. (2):

$$U_{in} = V_{in} + \varepsilon_{in} \tag{2}$$

where V_{in} is the deterministic component of utility for mode i by traveler n; ε_{in} is the random component of utility for mode i by traveler n.

The deterministic component of the utility can be expressed as a linear function of different factors including perceived psychological distance d_{in}, as shown in Eq. (3).

$$V_{in} = \sum_{k=1}^{K} \theta_k X_{ink} + \delta d_{in} \tag{3}$$

where K is the number of factors influencing mode choice; X_{ink} is the kth factor for mode i by traveler n; θ_k and δ are the corresponding estimated coefficients.

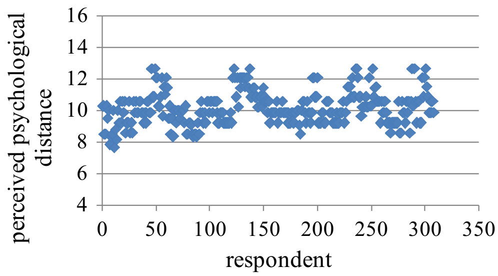


Fig. 2. Perceived psychological distance in the new SP design scheme.

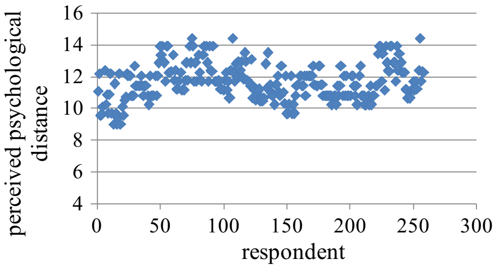


Fig. 3. Perceived psychological distance in the traditional SP design scheme.

Assuming that the random component of the utility follows the Gumbel distribution, the Logit model can be derived and shown in Eqs. (4) and (5):

$$P_{1n} = \frac{\exp(V_{1n})}{\exp(V_{1n}) + \exp(V_{2n})} \tag{4}$$

$$P_{2n} = 1 - P_{1n} \tag{5}$$

There are two alternative travel modes in this study. P_{1n} represents the probability that traveler n does not choose public bike-and-ride, and P_{2n} represents the probability that traveler n chooses public bike-and-ride. The coefficients of the above models were obtained by Maximum likelihood estimation, MLE, using the statistical analysis software NLOGIT 5 (NLOGIT, 2017).

5.2. Comparative analysis of models for different SP design schemes

The four factors chosen for analysis were cycling environment (denoted as "a"), distance from house to rental stations ("b"), convenience and availability of using public bicycles ("c") and number of public bicycle rental stations within 500 m of house ("d"). Under the new design scheme, there are six two-factor combinations respondents could select as the most important. Fig. 4 shows that the most recently chosen combinations are a, c and b, c, accounting for 35% and 31% respectively.

A preliminary correlation analysis between the influencing factors and choice results was done to determine the factors to be included in the estimation of the Logit models in Tables 4 and 5. These factors included commute time, ownership of bicycle rental cards, usage of public bike-and-ride in the past, opinion on using public bike-and-ride, gender, age, income, perceived psychological distance and the four major factors related to the public bicycle system. Tables 4 and 5 only shows the significant factors in model calibration, however, the two binary logit models in each design scheme were trained on the same factors.

For the new SP design scheme with two-factor combinations, the total proportion of travelers who chose public bike-and-ride was 37%. Two binary Logit models were established, shown in Model 1 and Model 2 of Table 4. Since there is a correlation between perceived psychological distance and the four major affecting factors, Model 2 was estimated without the four factors.

The results of Model 1 showed that improving the service level of public bicycle system such as travel environment and station coverage rate would increase the share of public bike-and-ride. Furthermore, the ownership of public bicycle rental cards had a statistically significant and negative effect on the choice results which implies that travelers are more willing to use public bike-and-ride if they already own a public bicycle rental card.

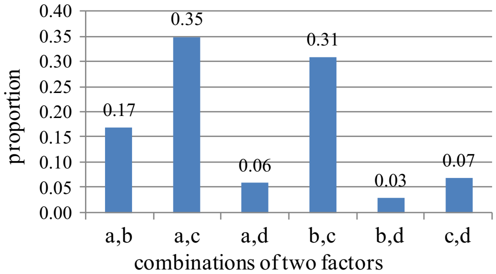


Fig. 4. Choice proportion for the most concerned factor combinations.

Table 4
Estimation of Logit models for the new SP design schemes.

Variables	Model 1		Model 2	
	Coefficient	*t*-test	Coefficient	*t*-test
Constant	−16.86***	−7.31	−12.06***	−6.36
Ownership of public bicycle rental cards	−0.77*	−1.76	−0.72*	−1.89
Cycling environment	2.61***	5.39	–	–
distance from house to rental Stations	1.74***	3.60	–	–
Convenience and availability	2.79***	5.49	–	–
Number of rental stations within 500 m	2.00***	2.91	–	–
Perceived psychological distance	0.32	1.34	1.26***	7.46
Age	0.35	1.59	0.42**	2.14
Log likelihood value	−132.38		−157.21	
McFadden Pseudo R-squared	0.35		0.26	
AIC	286.8		328.4	

Note:
* Indicates significant at the 90% level of confidence.
** Indicates significant at the 95% level of confidence.
*** Indicates significant at the 99% level of confidence.

Table 5
Estimation of Logit models for the traditional SP design schemes.

Variables	Model 3		Model 4	
	Coefficient	*t*-test	Coefficient	*t*-test
Constant	−4.32	−1.62	−1.91	−1.12
commute time	−0.37**	−2.39	−0.28*	−1.90
Usage of public bike-and-ride in the past	−0.88**	−2.02	−0.08*	−1.88
Whether using public bike-and-ride can reduce fog or haze	−0.48**	−2.19	−0.42**	−1.97
Cycling environment	0.75**	2.38	–	–
Convenience and availability	0.99*	1.76	–	–
Perceived psychological distance	0.14	0.93	0.29**	2.43
Age	0.42**	2.08	0.35*	1.83
Log likelihood value	−167.65		−167.65	
McFadden Pseudo R-squared	0.09		0.05	
AIC	344.0		351.3	

Note:
***Indicates significant at the 99% level of confidence.
* Indicates significant at the 90% level of confidence.
** Indicates significant at the 95% level of confidence.

Model 2 focused primarily on the effect of perceived psychological distance on public bike-and-ride choice. It has the greatest significance on the travel choice and is the critical factor during the decision process for travel behavior analysis. Meanwhile, the positive coefficient means that the proportion of travelers who choose public bike-and-ride will gradually increase with the increasing perceived psychological distance. For example, the more insufficient public bicycle facilities, poorer cycling environment, and the higher the inconvenience of using public bicycles at present would increase the perceived psychological distance of travelers when they were presented with the same hypothetical decision scenario, and then lead more travelers to choose an alternative mode of travel. In addition, age had a positive effect and ownership of public bicycle rental cards had a statistically significant negative effect. The older travelers owning a public bicycle rental card are more likely to use public bike-and-ride.

According to the survey data from the traditional SP design scheme with four-factor combinations, the total proportion of travelers who chose public bike-and-ride were 43%. Two Logit models were estimated and shown in Model 3 and Model 4 of Table 5.

For Model 3, only cycling environment, and convenience and availability of using public bicycles among four major factors had important positive effects on public bike-and-ride choice. Meanwhile, the significant effects of these two factors in Model 3 are lower than that in Model 1. This indicates that the travelers may not pay attention to all affecting factors during the decision process when faced with the complex multi-factor and multi-level decision scenario and an increase of information provision. It should be also noted that some other affecting factors have relatively significant effects on choice results. The negative coefficient of commute time means that shorter distance commuters are more inclined to choose public bike-and-ride. The travelers with a strong, approving attitude towards bikes and previous travel experience for public bike-and-ride are more willing to choose public bike-and-ride.

Model 4 estimated without the four factors has similar results with those in Model 2. Perceived psychological distance also has a positive impact on public bike-and-ride choice. Furthermore, the statistical significance of perceived psychological distance, much lower than that in Model 2, could indicate that the reduced attention that travelers pay to all affecting factors under complex decision scenarios will cause the corresponding reduced significance of perceived psychological distance on public bike-and-ride choice. In addition, commute time, usage of public bike-and-ride in the past, opinion on using public bike-and-ride and age are all relatively important factors.

The above analysis shows that complex multi-factor and multi-level decision scenarios may make decision-makers reduce their consideration on major affecting factors in the SP design and simplify their decision process. The reduced effects of four major affecting factors and perceived psychological distance on public bike-and-ride choice in Model 3 and Model 4 support this. In addition, the goodness-of-fit of Model 1 and Model 2 are much higher than those of Model 3 and Model 4. This indicates that the new design scheme for SP survey based on the individual, and important concerned factors to generate factor combinations can improve the model accuracy and are more suitable to analyze the choice behavior for public bike-and-ride.

5.3. Sensitivity analysis of the models under two-factor combinations

Sensitivity analysis of the four major factors for Model 1 and perceived psychological distance for Model 2 is further carried out to reveal the effects of the change of these factors on public bike-and-ride choice.

The levels of four major factors with different scales were converted into an interval from (0, 5). Fig. 5 shows the change of public bike-and-ride choice proportion for every 0.1 increase in the levels of the four major factors. The change of choice proportion for public bike-and-ride gradually reaches its peak when the four major factors related to public bicycle system have been gradually improved. The change of public bike-and-ride choice proportion with distance to public bicycle rental stations and number of public bicycle rental stations within 500 m of house are relatively lower. Every 0.1 increase in the levels of these two factors will result in a change of choice proportion of 4%∼5% during peak intervals. The change of public bike-and-ride choice proportion with cycling environment, and convenience and availability of using public bicycles are relatively higher. Every 0.1 increase in the levels of these factors will result in a change of choice proportion of 6%∼7% during peak intervals. This implies that travelers are more sensitive to the change of cycling environment, and convenience and availability of using public bicycles.

The analysis of the four factors indicates that promoting the service level of public bicycle system, especially the cycling environment, and the convenience and availability of using public bicycles has an important role to increase the share of public bike-and-ride.

As shown in Fig. 6, the values for perceived psychological distance are assumed to range from 5 to 15 and distance was changed by an interval of 0.2. The changes of public bike-and-ride choice proportion are relatively higher when the perceived

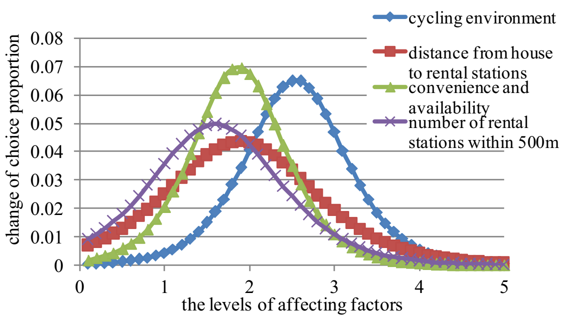


Fig. 5. The change of choice proportion with four major factors.

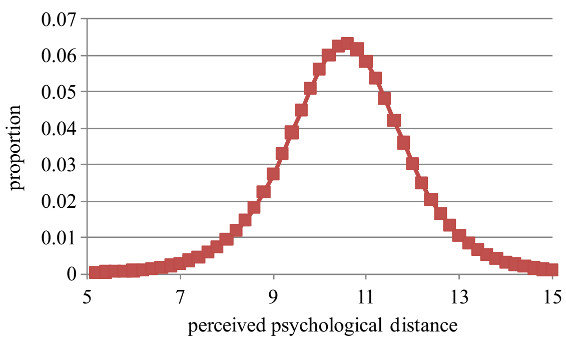


Fig. 6. The change of choice proportion with perceived psychological distance.

psychological distance changes around 10.5 which are close to the perceived psychological distance's mean value of 10.13. The maximum change rate is about 6.5%.

6. Conclusions

As an energy saving and environment friendly traffic mode, public bicycle systems have been successfully implemented in many cities. Connecting public bicycle systems with heavy rail transit is still under development in Beijing, China. This research surveyed travelers at bus stations surrounding the subway stations in Beijing and proposed two different SP survey schemes to collect the choice behavior data for public bike-and-ride. The electronic questionnaire was administered via an iPad. Compared to the traditional paper-based survey, iPad-based surveys can automatically administer complex survey designs while significantly saving time and costs.

For the SP design, cycling environment, distance from house to rental stations, convenience and availability of using public bicycles, and number of public bicycle rental stations around the house were chosen as four major factors which affect the usage of public bicycles according to a preliminary survey. Considering that travelers may only focus on a few key factors and use simple decision strategies to make a decision under complex decision situations, a new SP design scheme proposed in this paper is based on the factors respondents felt most important. The traditional design method based on multi-factor combinations was also given to compare with the new design method.

The survey data shows that the proportion of travelers who chose public bike-and-ride was 37% and 43% for the new and traditional SP design schemes, respectively. Logit models were estimated for each design scheme to analyze the choice behavior of travelers. Comparative analysis showed that the goodness-of-fit of the models under two-factor combinations were much higher than those under four factors combinations, based on AIC. This indicates that the new survey method of extracting the most concerned factors to obtain the SP survey data is feasible and more suitable to analyze the choice behavior for public bike-and-ride under utility maximization. Furthermore, the four factors selected in the SP design had significant impacts for Model 1 which indicates that improving those will increase the share of public bike-and-ride. Compared with the models for the new SP design scheme, the reduced effects of four major affecting factors in models for the traditional SP design scheme show that complex multi-factor and multi-level decision scenarios will make decision-makers reduce their consideration of some factors and simplify their decision process.

The psychological factor of perceived psychological distance also has a great impact on travel mode choice. Perceived psychological distance is a measure of the individual's psychological distance between the hypothetical levels in the SP decision scenario and the perceived present levels of the affecting factors. Model analysis showed that perceived psychological distance for each traveler by himself or herself should be the most critical factor during the decision process for travel behavior analysis. If a traveler feels that the perceived psychological distance is greater based on the current situation, he or she is more willing to choose public bike-and-ride.

Finally, sensitivity analysis of the affecting factors for Models in the new SP design scheme revealed that promoting the service level of the public bicycle system, especially the cycling environment, and the convenience and availability of using public bicycles has an important role in increasing the share of public bike-and-ride.

These research conclusions resulted in some practical findings for promoting the travelers to use public bike-and-ride. At the same time, they have a certain theoretical reference for improving the SP survey method and discussing the applicability of models based on utility maximization. In terms of the future work, it is desirable to expand the samples to reduce the variations and uncertainties of model results.

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