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Pre-Evaluation of Parking Charge Policy Based on the Classification of Urban Complex

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Abstract: In order to evaluate the effect of parking charge policy in different types of urban complex, this paper categorizes the surveyed urban complexes into two types: metropolitan and regional, based on impact range, travel distance, and level of service of public transit using K-Means clustering algorithm. Compared with regional complex, metropolitan complexes have larger impact range, longer travel distance and higher level of service of public transit. This paper develops a traveler behavior choice model for urban complex, using SP/RP survey data for model calibration so as to eliminate the deviations caused by survey bias. Considering the relationship between parking charge policy and level of service of public transit, the model can effectively describe the contributions of increasing parking fee and improving level of service of public transit to travel choice behavior. The findings are expected to be reference of differentiating parking charge policy by areas.

Keywords: urban complex; metropolitan; regional; parking charge policy; pre-evaluation

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0 Introduction

Urban complex is kind of multi-functional, high-density urban development mode, which enters a period of rapid development in recent years in China. While increasing the vitality of cities and businesses, urban complexes are often the most densely populated and most active places for urban space activities, resulting in a series of problems such as high traffic concentration and parking difficulties[1]. As a result, several policies have been launched, including increasing parking fee, adjusting parking standards[2-3] and encouraging residents to travel by public transit instead of driving cars. The following two issues are encountered when we plan to implement refined and differentiating parking charge policy in urban complex:

1) Lack of urban complex classification methods based on differentiating parking charge policy. In recent research, urban complexes are mainly categorized into various types, such as office, commercial or thematic complex, according to the development performance or main format[4]. Some scholars have also carried out binary classification methods based on the scale, geographical location or other factors[5]. However, these classification methods can not directly reflect the travel characteristics of residents' activities. Even in the same format, city complexes in the same location may have significant differences in residents' travel characteristics, parking behavior and parking intention, which makes it difficult to support differentiating parking fee policy formulation.

2) It is very difficult to predict the impact of parking charge policy on residents' travel behavior and its actual benefits. Parking charge policy evaluation has gone through the process from macro to micro, and then back to macro. Early studies established parking charge models based on the principles of economics and benefit analysis, to explore the relationship between parking charge and macroeconomic indicators such as parking facility construction, operation costs and road congestion costs[6-7]. The disadvantage of this type of pricing model is that it neglects residents' preferences and tolerates towards parking fee. Later, many scholars used logit model to investigate the impact of parking fee on residents' travel behavior and parking choice behavior at the micro level[8-9]. However, the application of such non-statistical models is mostly based on Stated Preference (SP) data, which inevitably leads to the prediction error accompanying the assumed in-

tentional data error[10]. In recent years, with the implementation of differentiating parking charge policies in cities such as Beijing, Shenzhen and Ningbo, the object of policy appraisal has gradually shifted to the macro-level indicators such as car parking space occupancy rate, journey speed, commercial vitality, and atmospheric environment[11-14]. But most of these policy evaluation methods are mainly aimed at urban centralized built-up areas or central business districts (CBDs) and are difficult to apply directly to the micro-scale of urban complex areas. Therefore, it is difficult to analyze the impact of parking charge adjustment, improvement of level of public transit service or changes of other external factors on the behavior change of travelers in different types of urban complex areas.

In order to effectively analyze the effectiveness of parking charge policy in different types of urban complexes, we sorted out the parking policy of Shenzhen from 2014 to 2016: In July 2014, after comprehensively evaluating and optimizing the on-street parking charge policy, we selected 4 sub-regions within the original SAR for pilot operation; In January 2015, 12,000 on-street parking spaces within the original SAR were fully activated; In July 2015, on-street parking rates were lowered and free parking time was extended. Since July 2015 till now, the existing policies have been implemented for more than a year. Knowing how to improve the parking charge policy and when the opportunity is, so as to achieve the best condition for urban complex traffic, has become an urgent problem to be answered.

This paper first classifies the surveyed urban complexes based on spatial and temporal characteristics of residents' activities. And then constructs a parking charge policy logit model based on RP-off-SP survey data, to identify the contribution of policy adjustments such as increasing parking fee to residents' travel mode choice in different types of urban complexes. The purpose of this paper is to be reference of implementing refined parking charge policy in different types of urban complex.

1 Research Design and Data Resources

1.1 Research Design

First of all, on the basis of the survey on the activity travel of residents in city complexes, the characteristic indexes such as impact range and residents' travel distance of the urban complex are extracted, and the surveyed complexes are classified by K-Means clustering algorithm. Then, taking the travel costs of different travel modes such as self-driving and public transit as the starting point, a logit behavior choice model based on SP-off-RP data is constructed, and the change of residents' travel behaviors under the changes of parking fee and level of public transit service is analyzed. Finally, we explore the differentiating impact of parking charge policy on residents' travel behavior in different types of urban complex, so as to provide targeted parking charge policy recommendations, including the timing of policy implementation and the price adjustment of parking fee (see Fig.1).

1.2 Data Resources

Twelve Shenzhen urban complexes were selected to conduct a survey of parking behavior and willingness in 2015 and 2016 respectively (see Fig.2). Among them complexes like Grand Theater and Exhibition Center are mainly composed of offices, in which most of the respondents are com-

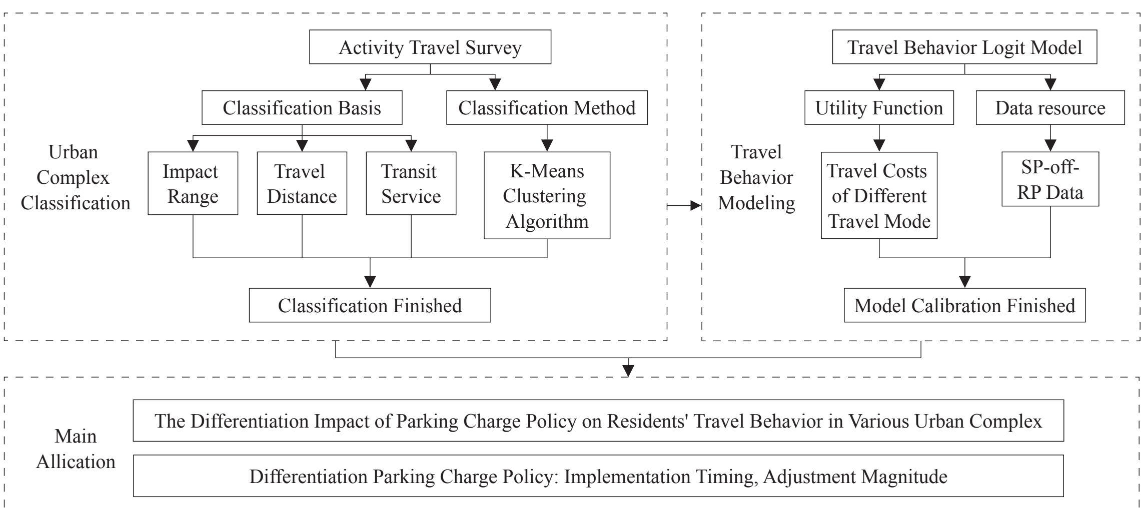


图1 研究技术路线

Fig.1 Technical framework

muters. And complexes like MIXC and Coastal City are mainly shopping mall, where most of the respondents are non- commuters. The questionnaire is divided into three parts: personal social-economic properties, travel and parking behavior characteristics and parking willingness. At the same time SP-off-RP survey method is adopted. The RP survey includes travel mode (whether driving or not), distance traveled, parking fee, etc. The SP survey primarily investigates residents' sensitivity to parking fee and the level of public transit service.

For quantitative analysis such as clustering and discrete choice models, when the sample size is 800-1000, the coefficients of variation of all the parameters are estimated to be 0.1 or less, that is, the 95% probability that the relative error of the parameter estimation is within 20% [15]. Therefore, a total of 1300 questionnaires were distributed in this study. Questionnaires were distributed and collected by investigators in selected parking lots and on-street parking areas, of which 1,080 were valid (757 drivers and 329 non-drivers). The effective questionnaire rate is 83.5%.

2 Complex Classification and Analysis of Characteristic Indexes

In this paper, a clustering algorithm based on similarity is adopted to carry out an urban complex classification research towards differentiating parking charge policy, which not only considers the impact range of urban complex and the service level of public transit system, but also considers

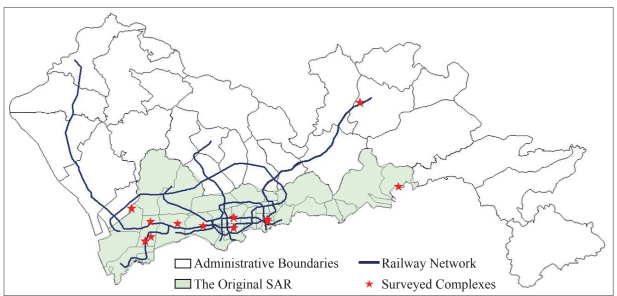


Fig.2 Distribution of surveyed urban complexes

Tab.1 Estimated cluster center of urban complex classification

Variable	Clustering	
	Regional	Metropolitan
Number of Clusters	8	4
Number of Covered Street Offices	18	23
Percentage of cross-district travel	43.2	66.1
Travel Distance/km	10.8	14.9
Travel time ratio	1.93	1.62

the travel distance of residents adopting different modes of transportation.

2.1 Classification Method based on K-Means Clustering

The urban complex classification based on parking charge policy often involves a piece of area, the area may contain activities like working, shopping, dining, leisure and entertainment. Due to the difference of location, stage of development and development mode in different urban complexes, the complex area presents different resident travel characteristics. K-Means clustering algorithm is used to classify the urban complex in the original SAR of Shenzhen according to three factors: the impact range of population attraction, the travel distance of residents and the level of public transit service. The impact range is characterized by two variables: the number of sub-district offices covered by the respondents' original points and the proportion of trips across administrative regions. While the level of public transit service is reflected in the door-to-door consumption ratio of public transit and private car (hereinafter referred to as "travel time ratio"). The final cluster center divide the 12 urban complexes into two categories: metropolitan complex and regional complex (see Tab.1). Among the researched complexes, Exhibition Center, Outlets, Hi-tech Park and Xinhe Plaza are metropolitan, while the 8 other complexes such as Grand Theater and Costal City are regional(see Fig.3).

Compared with regional complexes, the clustering center of metropolitan urban complexes show a broader impact range. The sources of attracting population cover more street offices (23), and the percentage of trips across administrative regions is as high as 66.1%, with a longer distance traveled (14.9 km). The difference between the two types of urban complexes is not only reflected in the impact range and the corresponding travel distance, but also in significantly different levels of public transit service. The travel time ratio of metropolitan urban complex is only 1.62, much lower than that of the regional complex of 1.93. It has been shown that public transit will be more attractive to residents when traveling at a time ratio not greater than 1.5. The travel time ratio in metropolitan complex is apparently closer to this level, showing that its public transit service is more perfect.

2.2 Rationality Test of Urban Complex Classification

Although K-Means algorithm has been used to cluster the urban complexes, due to the fact that K is given in advance

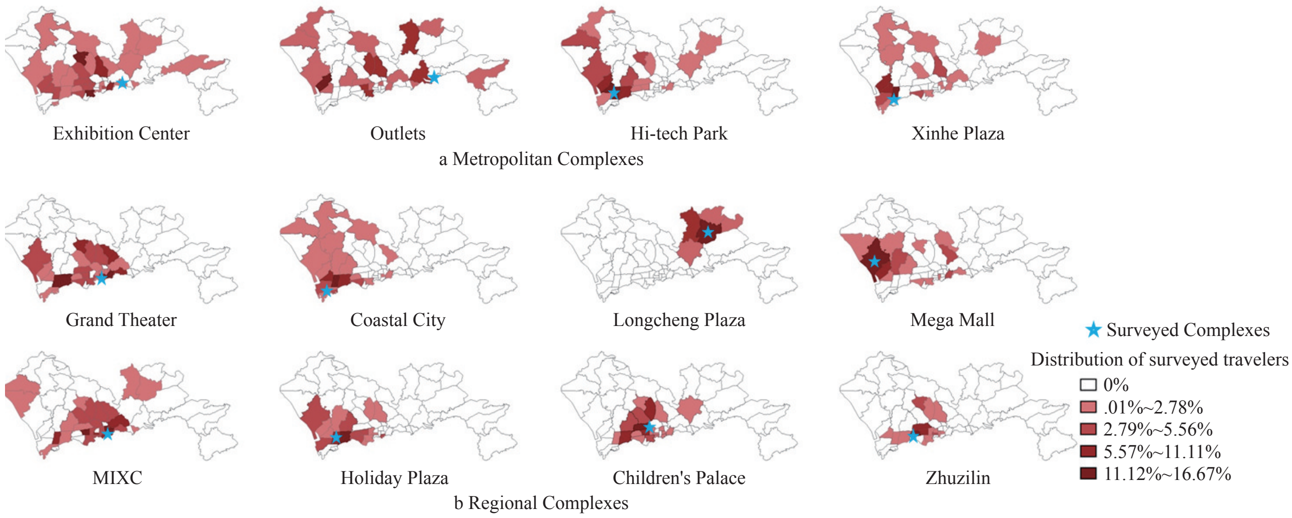


Fig.3 Distribution of surveyed travelers in urban complex

in the K-means algorithm, there is some doubt on the rationality. T-test was used to verify the rationality of the classification method. The t-test uses the t-distribution theory to deduce the probability of the difference, so as to compare whether the difference between the two sample data is significant. Due to the normal distribution of residents' travel distance and travel time consumption ratio, it is possible to carry out independent sample t-test on the two sets of data. The following two basic assumptions are made in the inspection process: H1, there is no difference in residents' travel distances between the two types of complexes; and H2, there is no difference between residents in the two types of complexes when traveling. Results show that test results of distance traveled and travel time ratio are significant (see Tab.2), so we can reject the original hypothesis H1 and H2. It means that the data of metropolitan and regional complexes do exist significant differences, so clustering through K-Means algorithm is reliable.

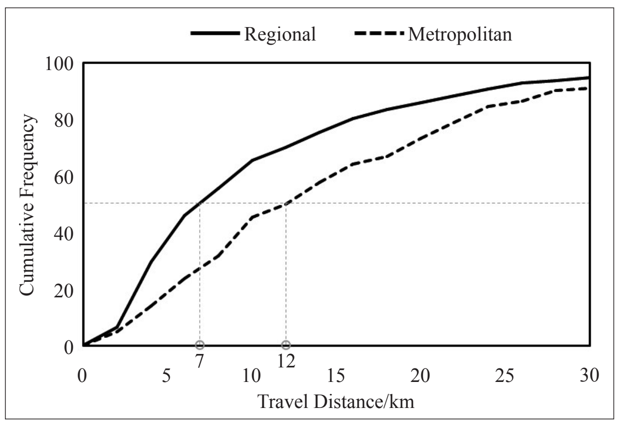
2.3 Comparison Analysis of the Characteristics in Different Types of Complexes

Comparing the cumulative frequency curves of travel distance in the two types of urban complexes (see Fig.4a), it is found that the travel distance of regional complexes is relatively shorter. About 50% of the travel distance is within 6-8 km and 85% of the travel distance is less than 20 km. It can be seen that the impact range of the regional complex decays rapidly with the increase of travel distance. 6-8 km is the strong impact range of regional complex, and 20 km is the impact boundary. However, travel distance of metropolitan complex is relatively longer, and weak peaks appear in the mid-long distance circles such as 10 km, 16 km and 25 km. The 50% and 85% quantile of travel distances are 12 km and 26 km.

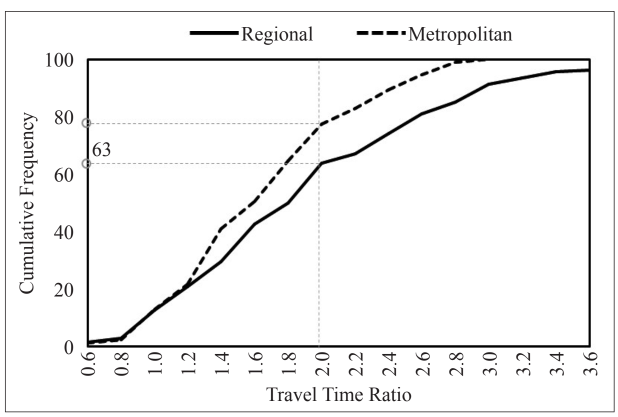
Comparing the cumulative curve of travel time consump-

Tab.2 Independent sample test results of metropolitan and regional urban complex

Project	Sample Size	t-value	Sig.	Hypothesis H
Travel Distance	1 086	6.67	0.000	Refuse
Travel Time Ratio	1 086	1.97	0.050	Refuse



a travel distance



b travel time

Fig.4 Cumulative frequency curve of the residents' activity characteristics in urban complex tion ratio in the two types of complexes (Fig.4b), it can be seen that 50% of the residents in metropolitan complex can enjoy public transit service with travel time ratio less than 1.6 and about 15% with travel time ratio greater than 2.2. In regional complexes, only about 39% of residents' travel time ratio are less than 1.6, while the ratio of about 37% residents is larger than 2. In general, public transit trips are almost unattractive to all passengers when door-to-door public transit travel consumes nearly twice as much travel time as driving private cars.

It is noteworthy that regional and metropolitan complexes almost coincide when travel time ratio is less than or equal to 1.2, that is, about 20% of the population in both types of complex can enjoy convenient public transit service. This reflects that both regional and metropolitan complexes have some competitive advantages in small-scale and medium-to-short-distance travel, but regional complexes lack fast and direct public transit service when it comes to long-distance travel.

3 Resident Travel Behavior Model in Urban Complex

3.1 Logit Model Building

In general, the majority of travelers in each urban complex are quite familiar with the complex. Therefore, under the assumptions of rational people, binary Logit discrete choice model is constructed to quantitatively analyze the impact of price adjustment of parking fee on travel choice behavior in different types of urban complexes. In addition to travel time and parking fee, the utility function also joined 3 factors that are significantly related to travel choice behavior: the complex type, household income and travel purposes. Assuming that the fixed term of the utility function has a linear relationship with the explanatory variables, the utility of traveling by car or public transit for travelers is described as:

$$U_{Cn}=\theta_1 I_n+\theta_2 T_{Cn}+\theta_3 C_n+\varepsilon_{Cn}, \qquad (1)$$

$$U_{Bn}=\theta_4 M_n+\theta_5 K_n+\theta_6 T_{Bn}+\varepsilon_{Bn}, \qquad (2)$$

Where n is the sample size, I_n is household income, and M_n is travel purposes, which is divided into commuting and non-commuting. K_n is a binary dummy variable that reflects the type of urban complex. T_Cn 、T_Bn is travel time needed respectively by private car and public transit. C_n is parking fee and ε_in is the random item in utility function. Finally the binary Logit model becomes:

$$P_{Cn}=\frac{1}{1+e^{-(U_{Cn}-U_{Bn})}}, \qquad (3)$$

$$P_{Bn}=1-P_{Cn}, \qquad (4)$$

Where P_Cn and P_Bn are respectively the probability for traveler n to choose to travel by private car or public transit.

3.2 Parameter Calibration and Interpretation

Because the SP survey data may be eventually inconsistent with the respondents' actual behavior, calibration of Logit model parameters with SP data is prone to deviations. In order to reflect both traveler's actual travel mode choice and the tradeoff in the process of willingness investigation, this study uses SP-off-RP data, to solve the regression coefficient through maximum likelihood estimation. The model calibration results are shown in Tab.3. The ρ¯^2 in Tab.3 is the excellent ratio after the adjustment of freedom degree, whose value is 0.29, showing that the model has high accuracy. In addition, judging from the model calibration results, the significant test values of all the explanatory variables are less than 0.1. It can be considered that the household income, travel purposes, travel time, parking fee, the type of urban complex and other variables have a significant impact on travel mode on a confidence level of 90%. The regression parameter of travel purposes is positive, indicating that residents tend to choose travelling by private car in non-commuter activities. However, the coefficients of parking fee and public transit travel time are both negative, indicating that the higher the parking fee and the bet-

Tab.3 Calibration results of binary Logit Model

Variable	Parameter Value	Sig.
Household Income	0.113	0.038
Travel purposes	0.278	0.021
Travel Time (Car)	−0.037	0.000
Travel Time (Bus)	−0.018	0.000
Parking Fee	−0.13	0.076
Type of Complex	−0.31	0.094
$-2(L(0)-L(\theta))$	17.05	
$\bar{\rho}^2$	0.29	

Tab.4 Parking behaviors by travel purposes in different types of urban complex

Travel purposes	Type of Complex	Parking Fee/yuan	Parking Time/h
Commuting	Metropolitan	18.5	3.0
	Regional	20.1	3.6
Non-commuting	Metropolitan	14.1	1.7
	Regional	13.1	1.5

ter the public transit service, the easier it is for travelers to give up travelling by private car. In addition, the parameter of the dummy variable of the type of urban complex has an estimated value of -0.31, indicating that residents who are active in metropolitan complexes tend to choose public transit trips and their dependency on private car is significantly lower than that of the residents in regional complexes.

4 Policy Effectiveness Evaluation and Strategy

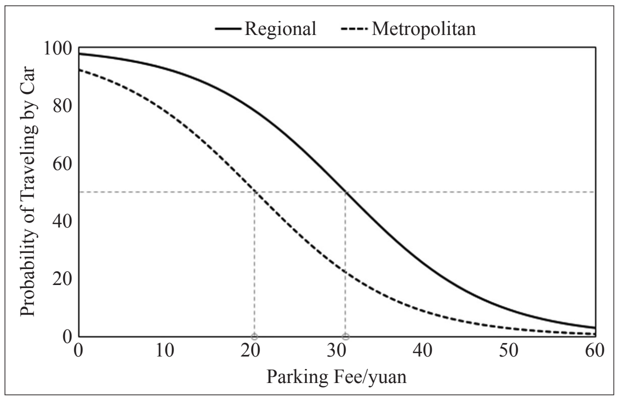
4.1 The Effect of Parking Price on Personal Travel Mode Choice

There are no significant differences between the 12 surveyed urban complexes in parking charge standard. And there is no significant difference between the two types of complexes, whether in commuting or non- commuting trips, when it comes to parking fee and parking time (see Tab.4). Although there is no significant difference in parking time and parking costs, residents in both types of urban complexes had significant differences in their willingness and sensitivity to increasing parking fee.

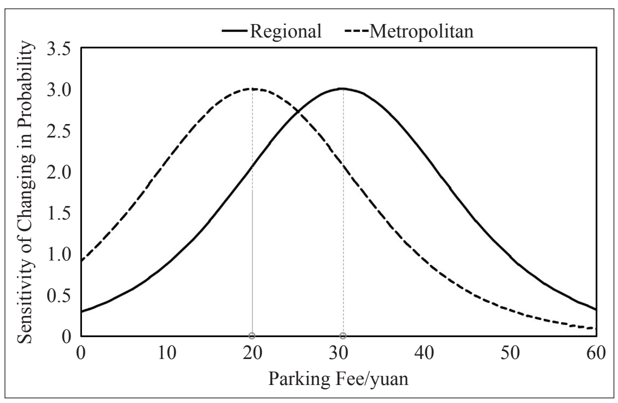
The probability of travelling by private car with the increase of parking fee was tested based on the Logit model. The trend of probability curves in different types of urban complex was found to be very similar. That is to say, with the increase in parking fee, the probability of continually travelling by private car may decrease gradually (see Fig.5a). However, the difference lies in that residents in metropolitan complexes are more sensitive to the rise of parking fee. Under the same parking price (for example, 15 yuan), the probability of travelling by car in a metropolitan complex for personal travel is 62.9%, which is obviously lower than that in a regional complex (86.1%). The parking cost is 20 yuan and 31 yuan, respectively in metropolitan and regional complexes, corresponding to the probability threshold (P=0.5) for residents to travel by private car.

The sensitivity analysis results of both types of complexes are parabolic, that is, as the parking fee increases, the sensitivity of travelers to price changes gradually increases and then gradually decreases after reaching the peak (see Fig.5b). Compared with regional urban complexes, the peak value of sensitivity curve of metropolitan complexes is relatively on the left. In metropolitan urban complexes, when parking fee reaches about 24.3 yuan for each commuter trip and 17.4 yuan for each non-commuter trip (regardless to parking duration time), that is, an increase of about 30% at the status quo, the residents' sensitivity will reach maximum, and the probability of travelling by car declines rapidly. In order to achieve the same result, regional complexes need to increase the parking fee for each commuter and non-commuter trip to 34 yuan and 24 yuan respectively, so that policies can play an effective role.

Differences in the level of public transit service play an important role in the sensitivity differences between the two types of complexes. Compared with travelling by car, public transit service in metropolitan complexes is relatively



a proportion of mode choice



b sensitivity of proportion changes

Fig.5 Change of driving probability when increasing parking fee

Tab.5 Policy implementation scenarios and pre-evaluation contents

Classification of Complex	Scenarios	Pre-evaluation Contents
Regional Complex	1) Increasing parking fee under the status quo of public transit service; 2) Lowing down the travel time ratio from 1.93 to 1.7 while increasing parking fee;	1) The most sensitive interval of increasing parking fee; 2) The contribution of improving public transit service to giving up driving compared with increasing parking fee; 3) Opportunity of increasing parking fee
Metropolitan Complex	3) Increasing parking fee under the status quo of public transit service; 4) Lowing down the travel time ratio from 1.62 to 1.5 while increasing parking fee;	

perfect, so that when the travel cost of driving private cars increases, the resident's travel mode can be more easily transferred from driving to public transit. However, due to the lack of attractive public transit as a substitute in regional complexes, residents are less sensitive to the increase of parking fee.

4.2 Pre- assessment of Differentiated Parking Fee Policy

Based on the binary Logit model, policy effects under different parking fee increases and level of public transit service in regional and metropolitan urban complexes are predicted respectively. For each type of urban complex, two scenarios are set up respectively: 1) to raise the parking price under the status quo of public transit service; and 2) to implement the public transit improvement strategy and parking charge policy at the same time (see Tab.5). The average travel time ratio of 1.7 and 1.5 are two important thresholds for residents' travel perceptions, and thus they are respectively used as the scene targets for public transit service improvement in regional and metropolitan complexes.

Because metropolitan complexes already have better public transit service, the effect of scene 1 is more obvious than that of scene 2 (see the black solid line and black dashed line in Fig.6), that is, residents are more sensitive to increasing parking fee in metropolitan complexes. When parking fee increases by 30% on the current basis, the proportion of residents who give up driving rapidly rises to about 20%. When parking fee continues to increase to 50%, the proportion of residents who give up driving will increase at a significant level. It can be considered that this rate is the most sensitive area for residents in metropolitan complexes, and the economic leveraging of parking fee policy is effective. However, the effect of improving public transit service in metropolitan complexes is very limited. Assuming that the current level of public transit service is

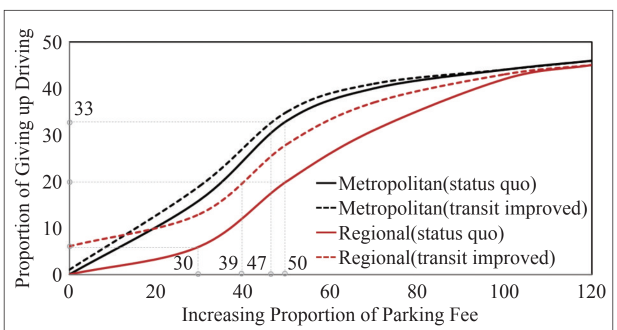


Fig.6 Proportion of residents which will abundant self-driving when increasing parking fee under four scenarios

maintained, that is, the average travel time ratio is 1.62, 33% of residents are expected to give up driving cars when the parking fee is increased by 50%. If we lower down the travel time ratio to 1.5, we will also find that 33% of the travelers will give up driving when the parking fee is increased by 47%, which is only 3 percentage points lower than the situation that we directly increase the parking fee. This reflects that the strategy of improving the level of public transit service in metropolitan urban complexes has less contribution to the transition of drivers' travel behavior than the policy of increasing parking fee directly.

Scene 4 is more effective than Scene 3 in regional complexes (see the red solid line and red dashed line in Fig.6). Under the current level of public transit service, only about 6% of travelers is expected to give up driving private cars when the parking fee is increased by 30%, which means that promoting parking fee directly makes quite little effect. However, if the level of public transit service is to be upgraded first to reduce the average travel time ratio from 1.93 to 1.7, intercept will be shown in the travel mode forecast curve. About 8% of travelers will give up their driving at the current parking charge level, which is even better than a 30% increase in parking fee. In addition, in the face of the same increase in parking fee, the proportion of residents who give up driving cars will increase significantly after the improvement of public transit service. For example, under the current level of public transit service (travel time ratio = 1.93), it is expected that 20% of the travelers will give up driving when the cost of parking is increased by 50%. If the travel time ratio is lowed down to 1.7, 20% of the residents will give up driving when the parking fee is increased by only 39%. This shows that the strategy of improving the level of public transit service in regional urban complexes first contributes greater to the transition of drivers' travel behavior than the policy of increasing parking fee directly.

4.3 Policy Strategy

For metropolitan complexes, increasing parking fee continually should be regarded as the core policy. The proposed rate of increase in parking fee is suggested to be controlled at 30% to 50%, and the expectation that parking fee will continue to increase should be given through publicity. And then measures should be launched to enhance the level of public transit service in order to consolidate the effectiveness of parking charge policy.

For regional complexes, the public transit service should be upgraded recently, and relevant initiatives should be launched, aiming to reduce the average travel time ratio to 1.7. And then parking charge adjustment policy should be implemented. The proportion of residents who give up driving will be significantly increased when parking fee is increased by 35% to 60% on the basis of the status quo. Therefore, it is suggested that the increase of parking fee be controlled in this interval.

It is noteworthy that if the parking fee in the two types of complexes continue to increase by 80% to 100%, the growth of residents who give up driving will slow down and become stable gradually. The final percentage of residents who give up driving will stable at about 40% and hardly increase. This should be the upper limit of the effect of increasing parking fee on residents' travel mode choice at this stage. Because there are always some loyal travelers who insist on driving cars, they do not easily give up driving with the increase of parking fee. On the other hand, if the parking charge in urban complexes increases too much, some drivers will abandon the area and choose to go to other urban complexes for activities.

5 Conclusion

This paper presents an urban complex classification method based on residents' travel characteristics and the level of public transit service. Logit model is used to evaluate the differential effect of parking charge policy in different types of urban complexes. The evaluation method uses the SP-off-RP data to estimate the parameters, which not only reduces the bias caused by the willingness survey but also considers the correlation between the parking fee policy and the level of public transit service. And it can effectively analyze the contribution of increasing parking fee and public transit service improvement to residents' travel choice behavior in urban complexes. The follow-up study will continue to collect survey data of parking behavior in different urban complexes, so as to track and verify the validity of this model. And we will establish behavioral analysis models for different cities and carry out model suitability analysis, to provide reference for formulating differentiating parking charge policy in urban complexes.

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