Citation: Gong Dijia, Hu Xiuqin. Mode Choice and Optimization for Short-Distance Travel in Peripheral Areas of City Center: A Case Study of Guanghua District in Wenzhou [J]. Urban Transport of China, 2019 (03): 84–95.

Mode Choice and Optimization for Short-Distance Travel in Peripheral Areas of City Center: A Case Study of Guanghua District in Wenzhou

Gong Dijia, Hu Xiuqin

Department of Urban and Rural Planning, Zhejiang Normal University, Jinhua 321004, Zhejiang Province, China

Abstract: Public transit service for short-distance travel is one of the short slabs to be complemented in developing transit metropolis. Aiming at the peripheral areas of city center in big cities, this paper compares four possible travel modes in several aspects: the adaptation of people and climate, occupation of land resource, degree of permeability to alleys and cul-de-sac, fitness of OD distribution, integration of public transit system, and limitation of operation time. The paper proposes a public transit service structure for short-distance travel with regional operating community bus as the main body, internet bike sharing as auxiliary, and public bikes and community bus with fixed lines as supplementation. Taking Guanghua district in Wenzhou city as an example, the paper analyzes residents' cognition, demand and expectation as well as the problems of operating community buses through field observation, questionnaire survey, and interviews. Based on the theory of public economics, the paper proposes integrated strategies in several aspects: reallocation of right-of-way, system design of parking benefit districts, optimization of operation modes, and design of fare system and price. **DOI:** 10.13813/j.cn11-5141/u.2019.0309-en

Keywords: transportation planning; public transit; peripheral areas of city center; short-distance travel; community bus; Wenzhou City

0 Introduction

Transit priority and building transit metropolises are important strategies for big and medium cities in China to ensure the sustainable development in a high-density living environment. Public transit lines can be classified into three levels: main lines, regular lines, and branch lines. Compared with cars which have the natural advantage to provide door-to-door service, main lines and regular lines of public transit can only provide stop-to-stop service. The quality of the last kilometer is one of the key factors for the competitiveness of public transit. Only investing heavily in main lines and regular lines while neglecting branch lines in the construction of public transit will get half result with double effort.

In recent years, some big cities with developed economics have started to operate community buses to connect rail transit stations with surrounding residential and commercial areas. These community buses belong to branch lines and basically run on fixed routes. However, most lines have little passenger flow and are facing serious operating losses. Reducing operating costs by decreasing departure frequency is ineffective or even counterproductive. Residents have also raised many doubts about the operating hours, the headway, the bus stop locations, etc. Illegal taxis serving short-distance trips (including the trips to connect high- and medium-capacity public transit and trips inside the communities) have not disappeared despite repeated prohibitions, which also reflects the undesirable operation effect of community buses from one aspect. Currently, there are few studies on community buses, which are mainly composed of the practice and reflections on community bus operations in specific cities [1–5]. Other types include the operation mode and planning strategies of community buses [6–8], the public participation during the improvement of community bus operations [9], etc. Very few studies focus on the adaptability of different types of community buses to different urban locations, or the relationship among community buses, public bikes, and internet rental bikes which also aim to solve the last kilometer problem.

With the continuous increase in car ownership, the problem of excessively high proportion of short-distance car trips is gradually becoming prominent. For instance, the car trips that are under 5 km accounted for 37% of all car trips in Wuhan, Hubei Province, China in 2013 [10]. The fourth comprehensive traffic survey in Beijing shows that short-distance car trips, which are under 5 km, accounts for over 40% of all car trips, twice the number of Copenhagen [11]. Traffic congestion has spread from urban major arterials to roads inside communities, occupying a large amount of land resources

Received: 2018-03-26
Supported by: The General project of Zhejiang Department of Education, China (Y201738649)
First author: GONG Dijia (1984–), male, from Shanghai, Master's degree, lecturer, is mainly engaged in the research on urban transportation and land use as well as transportation planning and design. E-mail: frankgong3393@126.com

while deteriorating the travel environment. The lack of high-quality public transit service for short-distance trips needs more attention and need to be addressed.

In terms of short-distance trips, walking has limited travel distance and is affected by physical strength. Other alternative modes of (quasi-) public transit include public bikes, internet rental bikes, and community buses. These three modes have their own characteristics, which are suitable for different areas of a city. Taking the peripheral area of the central district in big cities as the study scope, this paper explores the rational structure of transportation modes for short-distance trips except walking and proposes the optimization strategies for the planning, design, operation, and management of the main modes.

1 Definition of the study scope

The big cities studied in this paper mainly refer to the cities with permanent residents of 1 to 3 million in the urban central area, most of which are prefecture-level cities. These cities can be roughly divided into three types of areas: core areas, peripheral areas, and suburbs or new urban areas. The core area is usually the urban business, commercial, cultural and entertainment center. It has the highest density of public transit network and stops with good implementation results on public transit priority and strict and effective traffic demand management on cars. In such areas, the combination of public transit and walking can not only efficiently complete door-to-door trips but also add vitality to the streets. The Transit-oriented Development (TOD) mode can be implemented in the reconstruction of suburban areas or the construction of new urban areas. In the TOD mode, large- and medium-capacity public transit run on main transit corridors, the development mode of small blocks with narrow roads, and a dense road network are implemented, and the right-of-way is rationally distributed. The walking and cycling environment is improved, and the high-intensity development around public transit stations is formed. Moreover, the car traffic demand is regulated and managed to improve the competitiveness of public transit from the origin. There have been many theoretical studies, policy documents [12–13], and planning and construction practices (e.g., Sino-Singapore Tianjin Eco-city and Kunming Chenggong New City) in this field.

Most big cities in China have a single-center structure with many old residential areas distributed across the peripheral area of the central city. Due to the underprediction of the car growth rate in the old plans, there is the ubiquitous historical problem of insufficient supply of basic parking spaces. The issue of car parking on sidewalks or motorways is serious and the overall travel environment is poor. Moreover, the control of the old plans is insufficient, so that the road network is often unsystematic inside the area. Although the roads seem to conform to the characteristics of narrow roads and a dense road network, the distribution of right-of-way is obviously biased towards motor vehicle traffic. There are many cul-de-sacs, which makes it difficult for regular buses to enter, so they can only run on the major and minor arterials with service level far lower than that in the core area of the central city. Some cities have fallen into a vicious circle of "the low level of public transit service and the decline in the share of public transit trips–the rapid increase in car use–the pursuit of immediate interests in planning and design–the occupancy of scarce road resources by cars–the deterioration of travel environment of green transportation modes–the decline in the share of public transit trips".

2 Comparison of short-distance trip modes in peripheral areas of the central city

The (quasi-) public transit modes for short-distance trips include public bikes, internet rental bikes, and community buses. Community buses can be further divided into buses running on a fixed line (hereinafter referred to as "fixed-line community bus") and buses running in a fixed area but not on a fixed line (hereinafter referred to as "fixed-area community bus"). A multi-perspective comparison is helpful to determine the reasonable structure of short-distance trip modes that is suitable for the study scope.

2.1 Adaptability to population and climate

Compared with public bikes and internet rental bikes, community buses are more age-friendly and easier to use, which can better serve the trip demands of the elderly in severe aging areas. Children under the age of 12 are prohibited from riding internet rental bikes. However, if fixed-area community buses can provide door-to-door service, they will help reduce the probability for parents to drop off and pick up their children by driving private cars.

Cyclists are sensitive to climate. In cities with long rainy seasons, hot summers or cold winters, cycling becomes less attractive. However community buses have protective devices, so they can adapt to various climate conditions.

2.2 Occupation of land resources

A sidewalk should have a minimum effective width of 1.5 m (i.e. wide enough to allow two pedestrians walking in opposite directions and carrying no luggage to pass each other). If a parking zone for non-motorized vehicles is to be marked out on the sidewalk, the sidewalk should be no less than 3 m wide. However, more than 50% of sidewalks in the peripheral areas of the central city have a width less than 3 m. Therefore, it is difficult to set up parking zones for non-motorized vehicles on sidewalks due to limited land resources, and these parking zones, moreover, will seriously affect the comfort and safety of walking. In contrast, community buses do not have a parking demand while transporting residents to their destinations, and they occupy

less static space. Meanwhile, community buses carry more passengers than cars. Therefore, if part of the short-distance travelers could shift their trip mode from cars to community buses, more dynamic road space could be saved.

2.3 Permeability to streets, alleys and cul-de-sacs

Public bikes, internet rental bikes and small community buses (fewer than seven seats) have flexible access to streets, alleys and cul-de-sacs. They can effectively make up for the defects of regular buses which are unable to provide in-depth services. However, their land occupancy may vary, depending on the land use on both sides of the road. Mixed land use helps achieve the balance of the inflow and outflow of public bikes and internet rental bikes, while single land use leads to problems, such as the imbalance between supply and demand and the lack of parking space for public bikes and internet rental bikes in a certain period of time. Small fixed-area community buses can avoid such phenomenon by flexibly adjusting routes and departure intervals.

2.4 OD distribution patterns inside the peripheral areas

Providing residential and living facilities is the main function of the peripheral area of the central city. An on-board survey was conducted on community buses during different periods of time in Guanghua District of the City of Wenzhou, Zhejiang Province, China and collected the OD data for 216 pairs of ODs (see Figure 1). The data shows that the OD distribution of different people groups and different trip purposes presents the same characteristic of overall dispersion and local concentration. During the morning peak hours on weekdays, commuting and elderly people's medical trips are concentrated, with the flow from residential areas to BRT and regular bus stops, schools and hospitals. On weeknights and weekends, the passenger flows are concentrated between residential areas and community shopping centers. In other time periods, the passenger flow distribution is quite balanced with no specific patterns. Fixed-area community buses and internet rental bikes can well adapt to such OD distribution patterns. A reasonable amount of public bikes can be arranged at main passenger hubs as a supplement. During peak hours, some fixed-line community buses may be operated to supplement fixed-area community buses to meet the regular trip demands.

2.5 Integration with the public transit system

The public transit mode for short-distance trips helps form a more clearly stratified and more rational public transit system, enabling different levels of systems to serve passengers with various trip distances. In terms of the main lines and regular lines of public transit, the increase in stop distance helps reduce the in-vehicle travel time, but only if there is an efficient connecting transportation mode for the last kilometer. From the optimal stop distance model (1)[14], which is based on the objective function of the minimum travel time, it is clear that the stop distance has a positive correlation with the moving speed from the starting point to the stop or from the stop to the destination of the trip. In the peripheral built areas, the average cycling speed is no more than 10 $km \cdot h^{-1}$ due to the poor cycling environment, while the speed of community buses can reach 15 $km \cdot h^{-1}$. With the same connection time, community buses can reach a larger range, which is beneficial to the rise of stop distances for regular buses and BRT to promote the service efficiency and quality of medium- and long-distance trips, thus helping long-distance trips shift from cars to public transit.

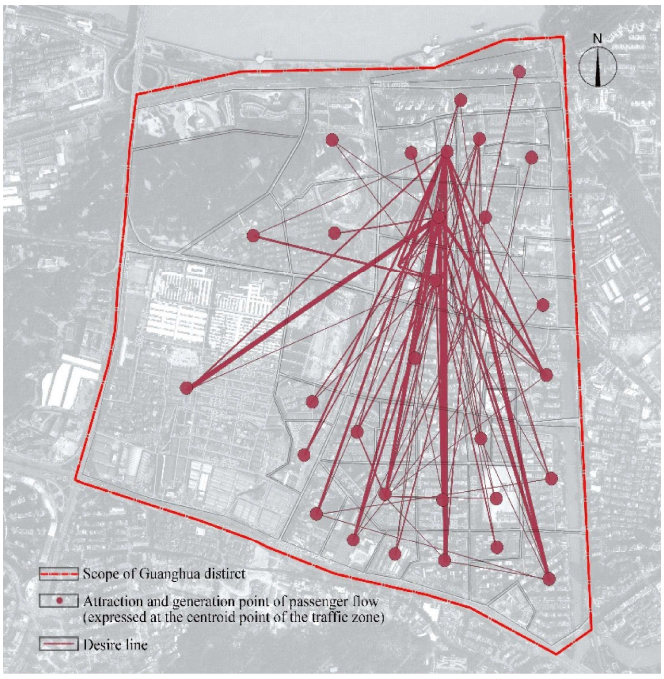

Figure 1 OD distribution collected by on-bus investigation

Parking space for internet rental bikes near regular bus stops is quite limited, and parking in chaos goes against the waiting environment and walking comfort. Community buses can directly stop at regular bus stops or BRT stations, enabling passengers to transfer on the same platform. If the fare system of community buses can be integrated with that of regular buses and BRT, community bus passengers will have a lower travel time and cost compared with internet rental bike users. However, in terms of connecting to BRT, if the parking space for internet rental bikes can be reserved while building the BRT system, internet rental bikes can play their supplementary role in the last kilometer more effectively and mitigate community buses' disadvantage of not able to carry away all connecting passengers at one time when the passenger flow is high.

(1) The optimal bus stop distance refers to the stop distance with the shortest riding time, which can be calculated from the formula $d(2t_w + t_r)/dl_s = 0$, and $l_s = (V_w L_r t_g/30)^{1/2}$. In this formula, t_w is the time to walk to and away from the stop (min); l_s is the average bus stop distance; V_w is the walking speed ($km \cdot h^{-1}$); L_r is the average riding distance (km); t_g is the time for passengers to get on and off the bus at bus stops (min).

2.6 Limitation of operation time

The advantage of public bikes and internet rental bikes is that they can provide 24 h service, while community buses have limited operation hours. At night outside community bus service hours, the elderly and children are less likely to travel, and public bikes and internet rental bikes can provide supplementary short-distance trip service for the young.

2.7 Summary

In the peripheral areas of the central city, a suitable public transit service structure for short-distance trips should have fixed-area community buses as the main body, internet rental bikes as the auxiliary, and public bikes and fixed-line community buses as the supplement. For internet rental bikes, the main task in planning is to design or pre-control parking space at major passenger hubs and to improve the cycling environment. However, this task is difficult to be completed in the short term for built areas, and improvements may be gradually carried out along with the opportunity of urban renewal (such as demolition and reconstruction). In built areas, the number of internet rental bikes released by bike rental companies should be controlled to avoid the negative impact of a large number of bikes on the comfort level of walking environment. In the near term, fixed-area community buses can effectively meet the residents' short-distance travel demand in built areas, which needs to be studied as a focus.

3 Investigation and analysis of community bus operation in Guanghua District of Wenzhou City

3.1 Overview of (quasi-) public transit for short-distance trips

According to the central city boundary defined in *The Master Plan of Wenzhou* (*2003–2020*) (2017 Edition), the population in Wenzhou was close to 3 million in 2017. Before 2011, tricycles were concentrated in crowded areas, running through streets and alleys to provide point-to-point service for short-distance trips with a rate of CNY 5 or above. However, it was common for tricycles to occupy roads illegally, park without following parking rules, and charge unreasonably, which seriously affected road capacity and easily caused traffic accidents [4]. In 2012, the city government of Wenzhou banned illegal short-distance vehicle operation and started community bus service in succession to meet the residents' needs for short-distance trips. By the end of 2017, a total of 23 community bus routes had been opened, among which 14 were fixed-line routes and nine were fixed-area routes.

The investigation selects the typical Guanghua District as the case study and analyzes the operation effect of community buses and the gap of their service with the residents' travel needs and expectations by means of field surveys, questionnaires (2) and interviews. This paper then put forward an optimization scheme from the perspective of integrating design, operation and management and summarized the application conditions and promotion strategies.

Guanghua District is located to the west of the central city of Wenzhou, bounded by West Wangjiang Road (BRT running on this road) in the north, National Highway 104 in the south, Qinfen Road in the east and Cuiwei Avenue in the west. The total area is 2.76 km^2. Guanghua District is mostly a residential district with supporting public service facilities in communities, such as commerce, schools and hospitals, and Wenzhou Huanglong Trade Market (a city-level professional market) is in the southwest of Guanghua District (see Figure 2). There are many old residential communities in this district, with more than 20% of residents over the age of 60. With the young people moving out, the aging trend is becoming more and more obvious. The current road network density is 13.61 km·km^{-2}, in which the density of branch roads and alleys is 8.7 km·km^{-2}.

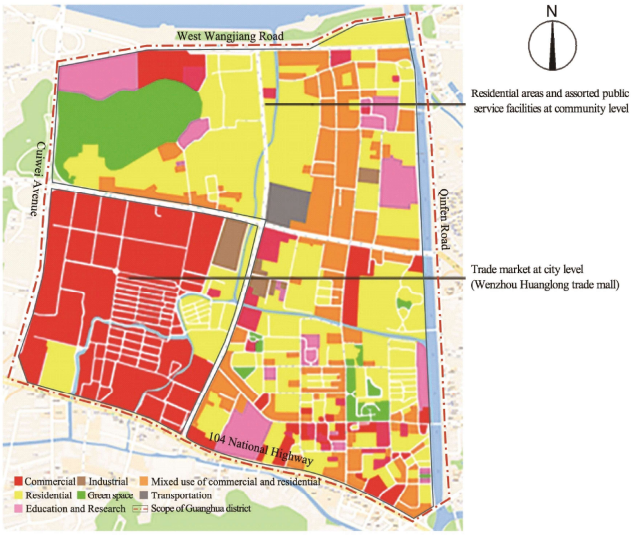

Figure 2 Scope and land use development of Guanghua District

The community bus in Guanghua District started its fixed-area operation service in 2015 (see Table 1). Passengers can stop and get on a bus by waving hands at any location as long as the stop does not jeopardize road safety, and they can tell the bus driver where they want to get off. The bus driver transports passengers to their destinations following the order in which they get on the bus. Eight buses are now in operation with the daily passenger flow of approximately 900. In terms of the passengers' trip purpose, the top three are shopping,

(2) In this survey, different questionnaires were distributed to community bus passengers and residents in Guanghua District who had never taken community buses. For the former, the survey aims to understand their trip purposes, riding frequencies, the reasons for choosing community buses and the problems encountered, and 201 valid samples were collected. For the latter, the survey aims to understand the reasons for not riding community buses and the possibilities of mode transfer, and 134 valid samples were collected.

Table 1 Community bus in Guanghua District

Bus information					Overview of operation			
Size (length × width × height)	Number of seats	Maximum speed	Range	Cost of a bus	Operating hours	Departure interval	Fare	Right-of-way
3.8 m×1.45 m×2.15 m	6	30 km·h^{-1}	80 km	Approximately CNY 50, 000/bus	6:30—19:30	Not fixed	CNY 3/person	Can use bus-only lanes and non-motorized vehicle lanes during traffic congestion

Source: http://www.bjlhdpc.com/content/?112.html

leisure and entertainment, and commuting with the share of 37.7%, 25.1% and 13.4%, respectively. Other trip purposes are quite diverse, including visiting relatives and friends, seeking medical treatment and dropping off/picking up children, etc. The riding frequency of the elderly over the age of 60 is far higher than that of the young and middle-aged population.

There are 19 public bike rental stations with 454 parking racks in Guanghua District. Due to the restriction on land supply, rental stations are all distributed along arterial roads and can cover 37.9% of the district if the service radius is assumed to be 150 m (see Figure 3). Obviously, it is difficult to meet the travel needs of all residents, and due to the lack of maintenance, the comfort of cycling is greatly reduced. In addition, there are a certain number of internet rental bikes in this district.

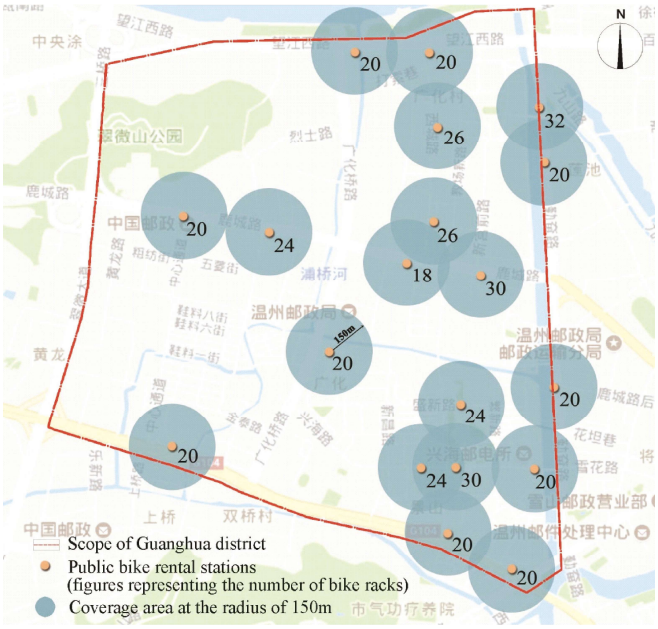

Figure 3 The layout of bike sharing system and number of parking piles in Guanghua District

3.2 Residents' perceptions of the community bus and reasons for choice

Residents believe that the function of community buses is similar to that of manual tricycles and regular buses. Manual tricycles have the characteristics of going into streets and alleys to provide point-to-point convenient and rapid service, while regular buses can provide cheap and safe transit service. The interview shows that the attribute of the community bus service expected by residents is just the combination of the advantages of both modes, which is consistent with the governments' original intention of opening community buses.

Community bus passengers mainly shifted from the modes of regular buses, walking and bikes, with the proportion of 41.3%, 28.3% and 10.9%, respectively (see Figure 4). The top three reasons for choosing community buses include that "community buses can transport passengers directly to destinations"; "community buses are small and flexible, thus less affected by traffic congestion"; "the waiting time for community buses is short".

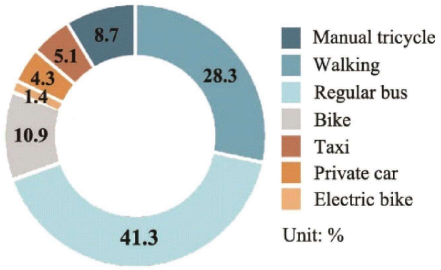

Figure 4 Shift proportion of community bus passengers' travel modes

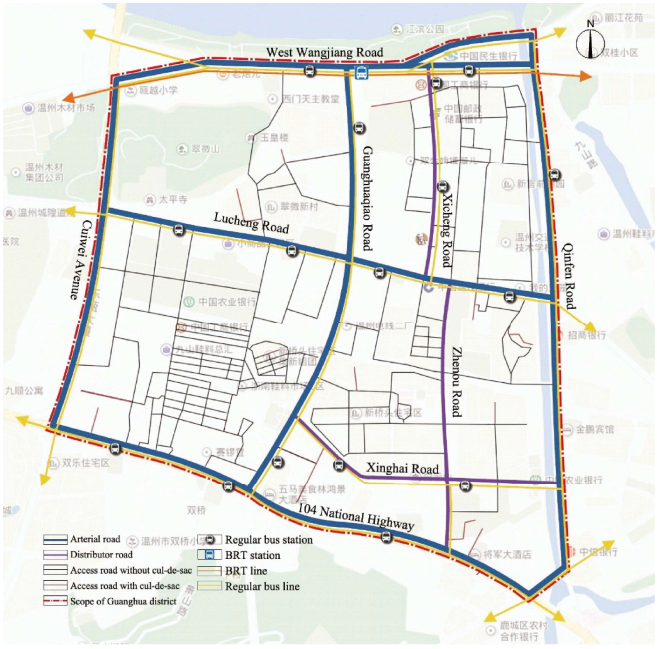

Figure 5 Roadway classification, public transit routes, and stations in Guanghua District

All the BRT and regular buses run on arterial and distributor roads in Guanghua District. The length of branch roads accounts for 64% of roads of all grades (57.6% are not cul-de-sacs and 6.4% are cul-de-sacs) (see Figure 5). All branch roads have mixed traffic with motorized vehicles and non-motorized vehicles, and nearly 100% have on-street parking, which deteriorates the travel environment for bikes. However, as community buses are small, they can access branch roads easily and make a U-turn even in a cul-de-sac without much difficulty, thus realizing the extension service from stations to doors. In terms of travel speed, community buses are close to cars, but they can use marked or physically separated non-motorized lanes when the motor vehicle lanes are congested, so community buses have higher travel time reliability and therefore are more attractive to residents.

Although community buses have no fixed departure intervals, the average waiting time is 4 to 5 min based on the investigation, which is less than the average departure interval of 7 min for regular buses. In addition, Guanghua District is located in the middle of all existing through routes of regular buses, which have low capacity to take additional passengers. The passenger density of these buses during peak hours is even as high as six people per square meter, and the riding comfort level is low. Passengers of regular buses not only have to walk for a certain distance but may not have a seat when riding, which becomes the main reason for short-distance passengers to shift from regular buses to community buses.

3.3 Operation of community buses

3.3.1 Poor service

The questionnaire collected the information about community bus passengers' time consumption in walking to the stop (access time), waiting for the bus (waiting time), walking from the stop to the destination (egress time), and riding the bus (in-vehicle travel time). It shows that the first three items (i.e., out-of-vehicle travel time) accounts for over 60% of the total time. Theoretically, community buses can run into branch roads and alleys, but in the current actual operation, less than 5% of passengers get on or get off the bus in branch roads and alleys. The main reason is that it is difficult for community buses to run into branch roads and alleys smoothly in practice. The number of private cars in Guanghua District is much higher than the number of parking spaces, with the parking space gap as high as 1,142, so illegal parking along the distributor and branch roads become the last option for some drivers. On-street parking occupies 2.5 m out of the 8 m motorway, and the remaining 5.5 m still need to bear the two-way traffic flow of motorized and non-motorized vehicles. This traffic disorder brings about the difficulty for community buses to enter branch roads and alleys smoothly. A comprehensive policy of parking management and right-of-way redistribution should be adopted to improve the service level of community buses.

3.3.2 Gap between service capacity and residents' travel needs

Residents between the age of 27 and 45 and over the age of 60 respond that the departure frequency of the community buses during 7:00–9:00 and 18:00–19:30 is low. Further analysis shows that the former residents' trip purpose is mainly commuting (transferring to BRT or regular buses), while the latter residents' trip purpose in the morning peak hours is physical exercise, grocery shopping,and dropping off children, while in the evening, return from shopping. All these trips are mandatory trips. Since the riding time in community buses is short, people tend to overestimate the waiting time [15] and become quite anxious when it is over 2 to 3 min, which causes the residents' perception of departure frequency to be low. Considering the large passenger demand during peak hours, the departure frequency of community buses can be increased in this period.

Similarly, 27.7% of the residents between the age of 27 and 45 and 23.4% of the residents between the age of 61 and 70 respond that the last community bus is too early. Their trip purposes are mainly night shopping and picking up students from cram schools respectively. They make trips mostly after 19:30 and are forced to choose private cars, taxis or regular buses due to the stop of community buses, which leads to higher travel costs and reduced convenience. They want to extend the last bus service to 20:30 to meet the demand of evening trips.

The fare is one of the most important factors in the choice of travel modes. The investigation shows that 20.8% of the residents consider the fare to be too expensive to accept and 77.6% can accept the fare but expect it to be reduced. In fact, the fare of CNY 3 for community buses serving short-distance trips is obviously expensive, and no transfer discounts or joint fares with regular buses or BRT is not conducive to the implementation of public transit integration. The original intention of such pricing is to reduce operating losses, but it is easy to fall into the awkward dilemma of more loss due to high fares attracting less passengers. Community buses in Wenzhou are operated by public transit enterprises, and the resulting policy losses are subsidized by the government according to the year-end passenger satisfaction assessment. However, from the perspective of sustainable development, innovation ideas shall be applied to integrate the fare systems of community buses and other public transit modes, shifting from relying on subsidies to "self-supporting", so as to attract passengers with high-quality services and affordable prices.

According to the questionnaire survey, 40.7% of the residents consider the service area of community buses as small. In-depth interviews show that the current service area is not able to meet the residents' needs to connect to bus terminal stations by taking community buses. Sanqiao Bus Terminal to the northwest and West Station Bus Terminal to the southeast are both adjacent to Guanghua District, but they are not

included in the service area. Furthermore, the residents living in Shuangle Residential Area to the south of National Highway 104 head for the public service facilities in Guanghua District for their daily shopping and leisure, but this area is not included in the community bus service area due to the obstruction of the highway. Therefore, these residents have to choose private motorized vehicles for their travel. It is suggested to include the above mentioned areas in the community bus service area to match the main destinations of residents' short-distance trips with the service area of community buses (see Figure 6) and to improve the share of community buses in short-distance trips.

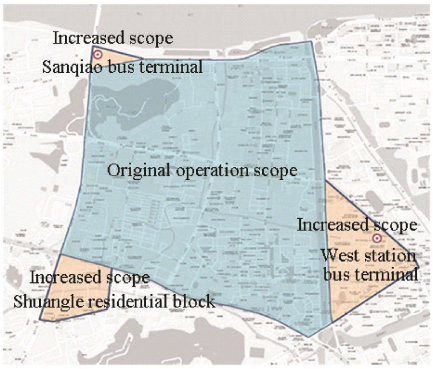

Figure 6 Adjustment of the community bus operation scope

3.3.3 Preference of operation modes

The investigation team surveyed the passengers on their preferences of operation modes and bus stop locations during morning peak hours (7:00–9:00), evening peak hours (18:00–19:00), and other time periods. It turns out that in all time periods, passengers preferring fixed-area operation have a less or similar out-of-vehicle travel time than those preferring fixed-line operation (see Figure 7). This result shows that passengers have realized the advantages of fixed-area operation, e.g., bypassing the congestion location and direct access to the final destination. For passengers preferring fixed-area operation and passengers preferring fixed-line operation, the differences in the time consumption of walking to the stop and waiting for buses are even larger in off-peak hours than in peak hours. The reason is that trips in off-peak hours are less regular than those in peak hours, so the flexibility of fixed-area operation is more prominent.

The interview shows that the residents' core expectation of community buses is convenient boarding and rapid arrival. Therefore, public transit enterprises should develop a refined and differentiated operation mode in response to the travel demand in different time periods. To better serve the regular trips in morning and evening peak hours, we can add fixed-line operation to the current fixed-area operation as a supplement.

3.4 Mode shift potential for short-distance trips by private cars

The survey on residents who do not take community buses for short-distance trips inside Guanghua District shows that 14.2% of the residents choose private cars, among which approximately two-thirds choose this mode because it is convenient to drive and park a car (including illegal parking). However, using private cars for short-distance trips saves no time, wastes road resources, and causes air pollution. One of the important reasons for private cars to take a high proportion of short-distance trips is the lack of parking management: It is free to park along the streets and there is no punishment for illegal parking.

From the model [16] to determine the competitiveness of community buses and private cars based on the generalized cost, the equilibrium point

$$L_0 = \left[\alpha/(\alpha-1)\right]\cdot(\Delta C-\Delta T\cdot P_T)\cdot V_b/P_T\ , \quad (1)$$

where L_0 is the trip distance (km) at which community buses and private cars have the same generalized cost; α is the transport speed ratio of private cars to community buses; ΔC is the difference between the travel cost of private cars (e.g., parking costs, fuel charges, etc.) and the fare of community buses (CNY); ΔT is the difference of out-of-vehicle travel time between community buses and private cars (min); P_T is the value of time (CNY·min^{-1}); and V_b is the transport speed of community buses (km·h^{-1}). When L_0 grows, community buses become more competitive than private cars, which can be realized by increasing V_b, reducing α, reducing ΔT or increasing ΔC. The increase in V_b and the decline of α can be realized by expanding community buses further into streets and alleys so as to get closer to the origins and destinations of residents' trips. The decline in ΔT can be realized by matching supply and demand more quickly through "internet +". The increase in ΔC can be realized by enlarging the parking cost of private cars and reducing the fare of community buses.

The questionnaire survey on private car users confirms the adaptability of the model shown above. When asked under what circumstances they are willing to shift to community buses for short-distance trips, private car users chose the following as the top four answers: "The distance between the drop-off spot and the destination is less than 150 m"; "the waiting time is less than 5 min"; "the exact location of the community bus can be checked through smart phones"; and "the fare is no more than CNY 2". These are the key solutions to make a breakthrough to improve the competitiveness of community buses.

4 Optimization scheme

4.1 Optimization framework of the community bus service system based on public economics theory

In the public economics theory, social goods are classified into public goods, quasi-public goods and private goods according to the severability of utility, the exclusivity of

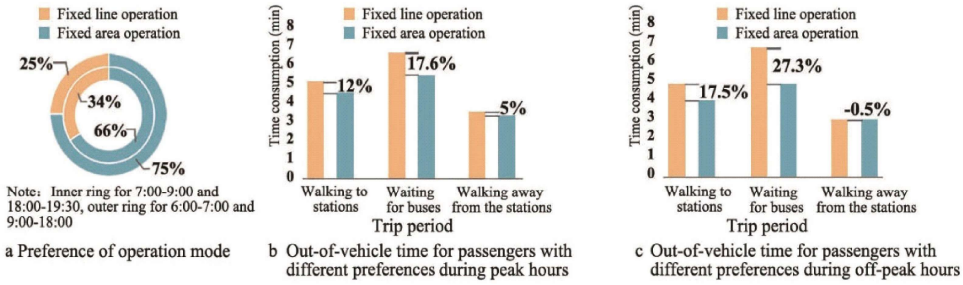

Figure 7 Passengers' preference on the operation mode of community bus and their time consumption outside the bus

consumption, and the exclusiveness of income [17]. On-street parking space is usually misinterpreted as a public good that should be provided by the government. In fact, on-street parking space has partial severability of utility (the products can be used partially), partial exclusivity of consumption, and partial exclusiveness of income. Therefore it is a quasi-public good and should be shared by both the government and the market.

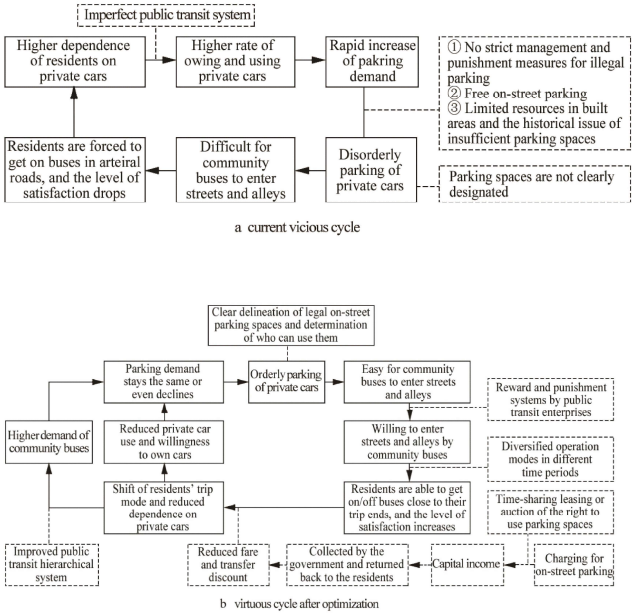

Figure 8 Comparison on community bus service

A professional parking management company should be introduced into Guanghua District, responsible for the time-sharing leasing or auction of the right to use parking spaces and the fee collection and management of legal on-street parking spaces. Part of the revenue is turned into a reasonable profit for the company and the rest is passed to the government and returned back to the residents of the district.

On the basis of transit priority, the government should redistribute the right-of-way within the district, clearly designate the legal on-street parking spaces, and determine who can use these spaces, in order to achieve the orderly parking of private cars and the easy access of community buses. As for the historical problems of insufficient parking spaces in built areas, it is suggested to build parking garages during the renovation of old districts (appropriate over-allocation of parking space is allowed) or to stagger the parking hours to share parking spaces with the commercial or business buildings.

The public transit enterprise should formulate a reward and punishment system as soon as possible to encourage the bus driver to drive the community bus into the street or alley so that the passenger can get on the community bus in the street near home, on the premise of orderly parking of cars. Meanwhile, residents' travel demand should be tracked and investigated in time, and the operation mode for different time periods should be designed in an elaborate and diversified way.

Through the comprehensive measures on the operation and management parties discussed above, the vicious circle caused by disorderly parking of cars can be turned into the virtuous circle of orderly parking of cars and increasing travel share and level of satisfaction of community buses (see Figure 8).

4.2 Redistribution of right-of-way

On-street parking spaces should be removed in arterial roads and distributor roads with significant traffic functions. For other types of roads, on-street parking can be allowed for certain periods of time after the redistribution of right-of-way. Four typical roadway cross sections are shown in Figure 9.

For the streets with no reduction of capacity after the redistribution of right-of-way, on-street parking is allowed all day long. The right to use these parking spaces in a certain time period (from 19:00 to 7:00 the next day) is auctioned, and for other time periods, the parking fees are charged on an hourly basis. On-street parking rate should be higher than off-street parking, which is tentatively set at CNY 10 per hour. For the streets with reduced capacity after the redistribution of right-of-way, the right to use these parking spaces in a certain time period (from 19:00 to 7:00 the next day) is auctioned, and for other time periods, the street is still used as a roadway with on-street parking prohibited. On-street parking out of the designated parking spaces or during non-specified periods is considered as illegal parking, which is supervised and fined by the traffic law enforcement department assisted by parking management companies.

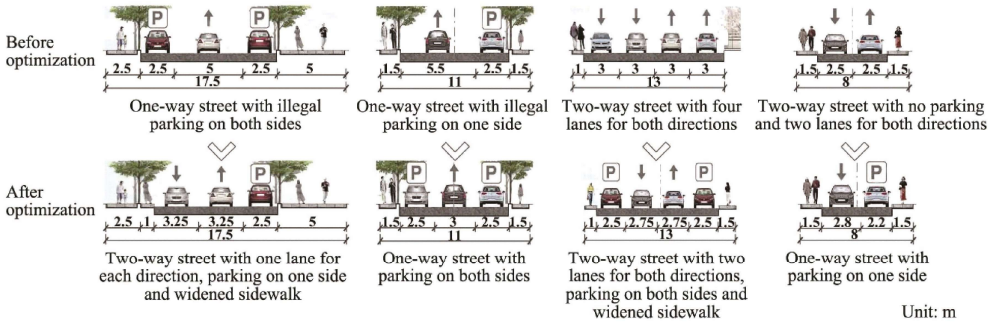

Figure 9 Optimization of roadway cross-section

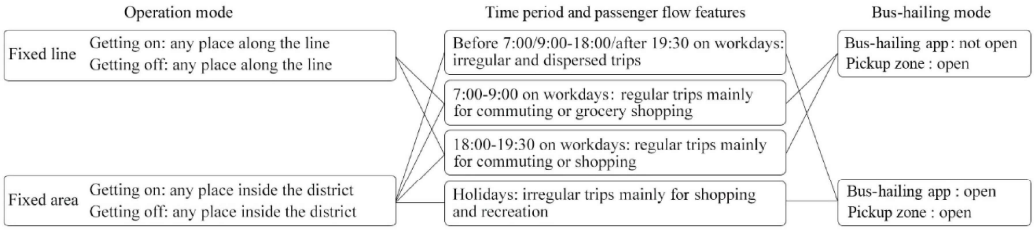

Figure 10 Design of operation and appointment mode in different time periods

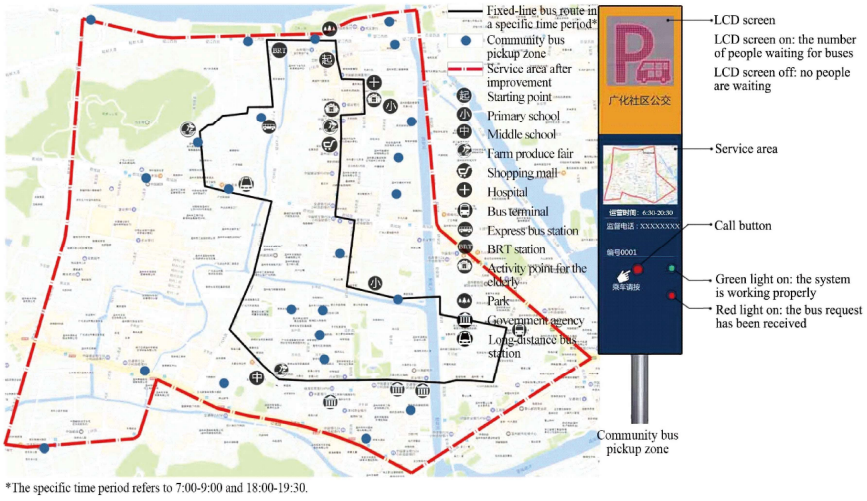

Figure 11 Design of a fixed route in a specific time period and beckoning stations layout

Note: Special time periods refer to 7:00–9:00 and 18:00–19:30.

4.3 Optimization of operation mode

According to residents' actual travel demand, Sanqiao Bus Terminal, West Station Bus Terminal, and Shuangle Residential Area should be included in the service area of Guanghua community buses. The number of buses needed in this district is

$$W = M_{\mathrm{dtw}} \ /\left(m\eta V_{\mathrm{o}}\ h\right), \tag{2}$$

$$M_{\mathrm{dtw}} = P\alpha\beta \cdot 2L_{\mathrm{r}}, \tag{3}$$

where W is the number of community buses needed; M_{dtw} is daily passenger flow for two directions (rides); m is the number of seats per community bus (taking the value of six seats); η is the bus load factor (taking the value of 85%); V_{o} is the operation speed (taking the value of 20 km·h^{-1}); h is the operation time (hours); P is the population of the service area (taking the value of 63,294 persons); α is the trip ratio (taking the value of 60%); β is the share of community bus trips in all short-distance trips (taking the value of 12%); L_{r} is the average riding distance (taking the value of 1.8 km). The result shows that twelve community buses are needed in the adjusted Guanghua District.

Fixed-line and fixed-area operation modes are adopted according to the passenger flow characteristics in different time periods, i.e., non-peak hours on weekdays, morning peak hours on weekdays, evening peak hours on weekdays, and the whole day of holidays (see Figure 10). In the current practice, passengers can only access community buses to a large extent by chance, which is inefficient. Twenty-one

Table 2 Travel time consumption by community bus before and after improvement

Stage	Average walk access time to the bus stop (min)	Average waiting time (min)	Average walk egress time from the bus stop (min)	Average in-vehicle travel time (min)	Proportion of out-of-vehicle travel time (%)
Before improvement (based on survey)	5.07	4.55	3.21	6.98	64.7
After improvement (target)	2	3	1.5	8.48[1)]	43.4

1) It is assumed that the average in-vehicle travel time increases by 1.5 min since the community bus will enter streets and alleys after improvement.

community bus pickup zones are suggested to be installed at main passenger hubs, such as main entrances of residential areas, schools, grocery markets, hospitals, and shopping centers (see Figure 11). By matching these pickup zones to the trip generations points, we can reduce the average walk time to access community buses to about two minutes. When residents need to take the community bus, they can just push the button on the digital board in the pickup zone. The LCD panel lights up to show the number of people waiting for the community bus (each push means one additional passenger). Meanwhile, the management platform of the public transit enterprise will, based on the number of people waiting, send a command through cloud computing to the community bus that is nearest to the pickup zone and has enough capacity so that the community bus can arrive at the pickup zone in the shortest time to pick up passengers. In the future, a community bus hailing app like Didi Taxi will be developed to realize the rapid match and response between passengers and buses. The waiting time will be reduced to less than 3 min and the proportion of out-of-vehicle travel time will be reduced to less than 45%, which will greatly improve the travel experience of community buses (see Table 2).

At some places that may generate instantaneous high passenger flow, such as near the entrance of a middle school and a BRT station, a certain area of available land should be allocated to park internet rental bikes to the fullest extent possible to alleviate the capacity shortage of community buses in a short time. When the weather is bad, the public transit enterprise should try to enlarge the number of community buses (e.g., dispatching backup buses) to provide more frequent community bus services and minimize the possibility of short-distance trips shifting to cars.

4.4 Setting of fare system

The fare system and fares of community buses should be incorporated with transit main lines and regular lines. The base fare for taking a regular bus in Wenzhou City, Zhejiang Province, China is CNY 2. Residents over the age of 65 can take the bus free of charge with the “love card”, and other residents can enjoy a 10% discount off the base fare with the transit card. The base fare for community buses is suggested to be CNY 1, and other discount policies should be consistent with regular buses. For transfers between community buses and regular buses or BRT, it is suggested to take a 50% discount for the second leg of the trip. If a passenger takes a community bus for a short-distance round trip and the two trip legs are within 90 min, it is suggested for this passenger to enjoy a 50% discount for the return leg of the trip (i.e. CNY 0.5) (see Figure 12).

4.5 System design of parking benefit district

A parking benefit district (PBD) is an effective way of managing on-street parking by monetizing the value of on-street parking areas to raise funds for public services [18]. It has been successfully implemented in California, Austin, Houston, Beijing and so on. After implementing PBDs in Guanghua District and designating legal parking spaces, we should deduct the operation cost and reasonable profit from the revenue of the rental and auction of the parking spaces, and the remaining fund should be handed over to relevant government departments as the special fund for community buses, which should be used by the public transit enterprise to operate community buses and invest in the infrastructure to improve service quality. This “self-supporting” mechanism can not only enable public transit enterprises to significantly reduce fares but lower the pressure of the government to provide public transit subsidies for policy considerations.

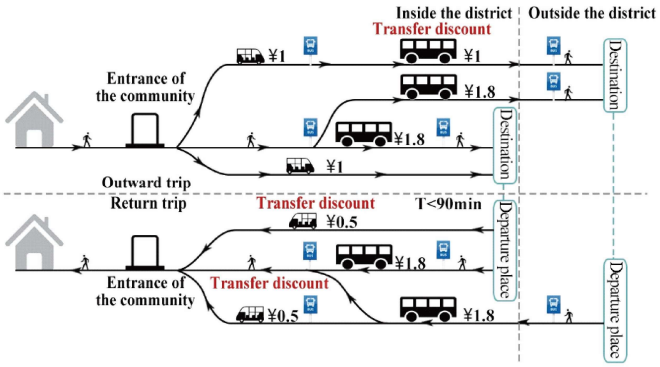

Figure 12 Fare system and price setting

After the redistribution of the right-of-way, 500 legal on-street parking spaces can be added in Guanghua District. These parking spaces are auctioned with a starting price of CNY 600 per space per month. Therefore, the minimum annual revenue is CNY 3.6 million. A parking management company should be selected through bidding and 10 parking space attendants should be hired with each managing 50 parking spaces (parking fees are collected by parking space attendants in the early stage, which should be gradually changed to parking meters to save labor costs and standardize parking management). Assuming each parking space attendant is paid at CNY 3,000 per month, the total annual salary is CNY 360,000. The minimum annual operating cost and

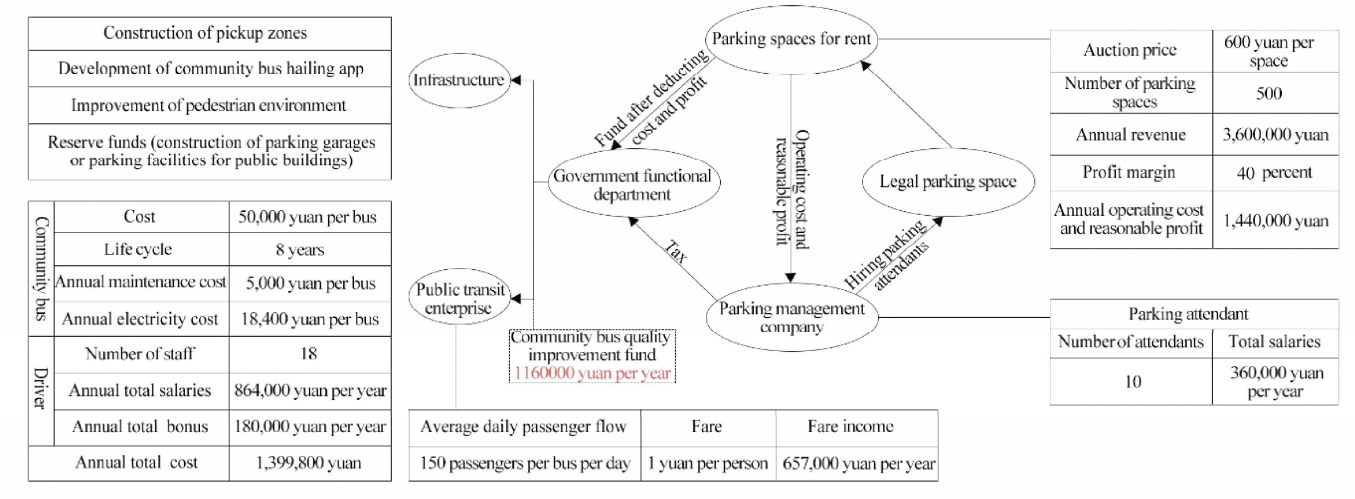

Figure 13 Capital allocation based on the system of parking benefit districts

reasonable profit (assuming a profit margin of 40%) that the parking management company should keep is CNY 1.44 million. The rest will be handed over to relevant government departments as the special fund for community public transit. After paying taxes for the CNY 1.44 million, the parking management company should use the remaining money to pay parking space attendants as salaries and to deposit to the enterprise development reserve fund (e.g., for the construction of the parking meter system in the future) (see Figure 13).

The average daily passenger flow of a community bus after improvement is assumed to be 150 passengers per bus per day. The number of buses in operation needs to grow to 12 due to increased passenger flow. When the fare is reducedto CNY 1 per person, the annual farebox revenue can reach CNY 657,000. However, the annual total investment in all vehicles and all personnel of the community bus enterprise is CNY 1,399,800, considering that each community bus costs CNY 50,000 with life cycle of eight years, annual maintenance cost of CNY 5,000, and annual electricity cost of CNY 18,400. Moreover, 18 employees need to be hired with the annual total salary of CNY 864,000 and annual total bonus of CNY 180,000 according to the current salary system of the public transit enterprise. Therefore, the annual subsidy would be CNY 742,800. Considering unforeseen subsidies, the government could take out CNY 1 million annually from the special fund of community public transit to support the operation of community buses. The remaining CNY 1.16 million per year could be used for various projects to improve the quality of community buses (e.g., the construction of community bus pickup zones, the development of the community bus hailing app, and the improvement of pedestrian environment, etc.). It could also be used as a reserve fund for the timely construction of parking garages or the over-allocation of parking facilities in public buildings in the future.

5 Conclusion

The peripheral areas of the central district in big cities are mainly residential areas with supporting public facilities. They usually have high population density, high aging level, and high road network density, which are in serious shortage of basic parking spaces for cars. A suitable public transit structure for short-distance trips should have fixed-area community buses as the main body, internet rental bikes as the auxiliary, and public bikes and fixed-line community buses as the supplement. This structure is more suitable for the following cases: an area in which there are few regular bus lines and most bus stops are not the ends of bus lines, so the capacity to carry additional passengers is low; or an area in which the quality of regular bus service is low, which induces the car dependence of short-distance trips; or an area in which it is difficult to build parking spaces for internet rental bikes across the area due to the lack of space (e.g., narrow sidewalk); or an area in which there is a high proportion of cul-de-sacs and it is difficult to demolish existing buildings to turn cul-de-sacs to through roads.

To improve the service quality of community buses, we should fully understand residents' basic trip characteristics, such as trip purposes and departure times and deeply analyze the psychology of short-distance travelers, so as to determine a reasonable service area of community buses and to determine the number of buses, the time of the first and last bus, the operation mode, and the fare system that match the residents' travel demand. Public transit priority should include not only the support for public transit but the management and control of private cars. Therefore, the linkage between the community bus service and the parking management of private cars is necessary. On the basis of understanding that on-street parking spaces are quasi-public goods, the system of parking benefit districts should be adopted to clarify the responsibilities among government functional departments,

parking management companies, and public transit enterprises and to sort out the relationship in fund allocation. Through the redistribution of the right-of-way and strict parking management and on the basis of solving the cash flow problems, the vicious circle development dilemma caused by disorderly parking of private cars will be gradually turned into a virtuous development model of orderly parking and short-distance trips dominated by green transportation modes.

Certainly, community buses are not the solution for all issues. The convenience of internet rental bikes and its advantage to provide 24 h service should not be ignored. Although it is difficult to spread out internet rental bikes over a large area due to land restrictions, they are still an effective supplement to distribute instantaneous passenger surge from public buildings and to connect to BRT. Parking spaces for internet rental bikes should be installed as early as possible in places with little land restriction to better provide personalized service for people suitable for cycling.

References

[1] Chen Fei. 社区巴士运行特征分析与优化对策 [J]. Journal of Highway and Transportation Research and Development, 2012, 8 (8): 346–348 (in Chinese).

[2] Tang Anjing. 浅析社区巴士的运营和发展模式: 以上海市宝山闵行两区社区巴士为例 [C]. /中国城市规划学会. 多元与包容: 2012 中国城市规划年会论文集. Kunming: Yunnan Scientific Publishing Press, 2012: 930–937 (in Chinese).

[3] Han Bing, Fan Jun, Wu Hong, et al. 苏州市社区巴士运营特征分析及规划研究 [C]. /中国城市规划学会城市交通规划学术委员会. 交通变革: 多元与融合: 2016 年中国城市交通规划年会论文集. Beijing: China Architecture Publishing & Media Co., Ltd., 2016: 1295–1304 (in Chinese).

[4] Yuan Liang, Lu Yingdong, Xia Miaolei. The Operation Analysis and Development Thinking of Community Bus in Longwan District WenZhou City [J]. Urban Public Transport, 2017 (11): 32–34 (in Chinese).

[5] Ji Wenting, Zhou Zhihui, Xue Shuqing, et al. 乌鲁木齐市社区巴士车运营现状及满意度调查研究报告: 以众泰社区为例 [J]. Chinese & Foreign Entrepreneurs, 2017 (22): 177 + 185 (in Chinese).

[6] Wu Jiaorong. 社区巴士的定位与运作模式探讨 [J]. Public Utilities, 2011, 25 (6): 6–7 (in Chinese).

[7] Zhu Tao, Lin Bin. 基于社区特征的社区巴士规划研究 [C]. /中国城市规划学会城市交通规划学术委员会. 协同发展与交通实践: 2015 年中国城市交通规划年会暨第 28 次学术研讨会论文集. Beijing: China Architecture Publishing & Media Co., Ltd., 2015: 113 (in Chinese).

[8] Zhou Huaqing, Le Xiaohui, Zhang Huixuan, et al. Supply Community Transit Service in Shenzhen Transit Metropolis [J]. Urban Development Studies, 2016, 23 (10): 73–78 (in Chinese).

[9] Xu Xiaodao. 全过程公众参与: 促进社区巴士可持续发展的一种策略 [C]./中国城市规划学会城市交通规划学术委员会. 交叉创新与转型重构: 2017 中国城市交通规划年会论文集. Beijing: China Architecture Publishing & Media Co., Ltd., 2017: 40 (in Chinese).

[10] Sha Jianfeng. 快速机动化时期的机动车发展调控措施研究 [J]. Trafici Construction and Administration, 2014 (16): 214–217 (in Chinese).

[11] Li Ming, Song Guohua, Cheng Ying, et al. Research on Excessive Short Distance Car Trips in Urban Area [J]. Journal of Beijing Jiaotong University, 2014, 38 (3): 15–21 (in Chinese).

[12] The Central People's Government of the People's Republic of China. 中共中央国务院关于进一步加强城市规划建设管理工作的若干意见 [EB/OL]. 2016 [2018-03-06]. http://www. gov. cn/gongbao/content/2016/content_5051277. htm (in Chinese).

[13] Ministry of Housing and Urban-Rural Development of the People's Republic of China. 城市轨道沿线地区规划设计导则 [R]. Beijing: Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2015 (in Chinese).

[14] Xu Xunchu, Huang Jianzhong. 城市道路与交通规划 (下册) [M]. Beijing: China Architecture Publishing & Media Co., Ltd., 2007 (in Chinese).

[15] Fortin C, Rousseau R. Interference from ShortTerm Memory Processing on Encoding and Reproducing Brief Duration [J]. Psychological Research, 1998, 61 (4): 269–276.

[16] Liu Xianteng. Competition Among Travel Modes: Exploring the Development of Urban Transit in Chinese Major Cities [M]. Nanjing: Nanjing University Press, 2012 (in Chinese).

[17] Quan Yongshen, Pan Zhaoyu. Development Strategy for Marketing Transportation System of Chinese Metropolis [J]. Urban Transport of China, 2017, 15 (2): 1–8 (in Chinese).

[18] Donald Shoup, Yuan Quan, Jiang Xin. Charging for Parking to Finance Public Services [J]. Journal of Planning Education and Research, 2017, 37 (2): 136–149.

(Translated by GONG DJ)

