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Research on Planning and Model Design of Micro-cycle Bus Line Based on Metro Station Connection

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ABSTRACT

Public transport coverage fails to keep pace with urbanization and urban expansion, which makes the "last kilometer" problem of residents' travel increasingly prominent". However, the practice has proved that micro-circulation public transportation plays an important role in expanding the coverage of public transportation and promoting the integration of public transportation. Therefore, this paper takes a city bus community as an example. Firstly, it analyses the bus travel demand of commuters connecting to the subway station during the early workday rush hours on basis of IC Big Data, obtains candidate stations of microcirculation bus lines through K-means clustering. Secondly, it establishes the model, the target of which is to minimize the cost residents' travel and bus operation, under the limited condition of walking distance, passenger number, station spacing and departure frequency. Finally, the genetic algorithm is used to find the optimal solution of the model, so it's no doubt that the most feasible circular bus route is obtained. The results have positive significance for promoting the construction and operation of public transport integration and promoting the convenience and efficiency of public transport travel.

1. Introduction

With the rapid development of urbanization and the continuous expansion of urban areas, more and more urban residential areas or active areas are far away from public transport stations such as buses and metros. Research has proved that "the increasing speed of traffic demand is always faster than the speed of the reconstruction and expansion of municipal roads", and the existing coverage of public transport has not yet fully met the needs of public transport travel. Therefore, in order to solve the "last kilometer" problem of residents' travel, many cities, including Guangzhou and Shenzhen, have opened microcirculation buses with

the main purpose and function of "connecting urban rail transit" and "filling the gap of branch bus network". Microcirculation bus, also known as "pocket bus", is called the capillary of public transport. It has the characteristics of small vehicle type, agility, few stations, short distance, fast speed and concentrated passenger flow distribution. It can not only realize the effective series connection of community, school, vegetable market, hospital, bus station and subway station in the region, but also promote the convenience and efficiency of public transport travel. It can also play the role of efficient connection and rapid distribution of passenger flow at stations, and promote the construction and operation of public transport integration.

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2. The Current Research

There are plenty of achievements in the study of microcirculation bus route planning, design and optimization model at home and abroad. In terms of relevant research results abroad, Kuah (1987) established a model to determine the route direction and frequency of community bus fleet based on the fleet size under the assumption that "passengers start from multiple starting points and destination transfer stations are the same", and found that the model is also applicable to the "multi-to-many" demand model^[1]; Nagm-chai and Lovell (2003) are based on passengers and buses. Total cost minimization is used to study the optimization of bus route design^[2]. The genetic algorithm is used to generate the bus route and evaluate the bus route. Avishai Ceder (2010) proposes a new method of bus route design in the circle community, which quantifies the potential population in the community to the community road, so as to maximize the potential bus passenger flow^[3]. In terms of domestic related research results, Zhang Silin (2016) takes into account both resident travel costs and bus operation costs, and constructs a research model for bus station layout in urban rail transit community with constraints of walking distance, full load rate, departure frequency and station spacing, and verifies the rationality of the model through genetic algorithm^[4]; Xie Chao and Wang Anqi (2016) in vehicle purchase costs, and bus operation costs. In the absence of time-division multiplexing of bus parking lots and other reasons that make microcirculation lines difficult to play an ideal role, an optimization scheme of regional microcirculation bus system, including the introduction of small and medium-sized new energy buses, is proposed. The scheme is not only effective and feasible, but also can improve the operation efficiency of microcirculation bus system and reduce the operation cost^[5]. Zhou Jin (2016) is based on double-deck theory and genetic algorithm. Method: Starting from the interests of both bus and passengers, a minibus route direction model is constructed under the constraints of bus route length, non-linear coefficient, departure frequency and bus stops, and the feasibility of the model is verified by taking Tiantongyuan community in Beijing as an example^[6]. Lu Qianjie et al. (2016) constructed an ant colony algorithm for the phenomenon of multiple passengers going to different terminals at different starting points in the system. A path planning algorithm for multi-start and multi-end problem is presented. The feasibility of applying this algorithm to community public transport system is verified by community measurement^[7]. Zhou Xiangdong (2017) introduces the concept of microcirculation bus under block system, takes passenger time demand as the main constraint, builds a microcirculation bus route design model aiming at minimizing enterprise cost, and uses ge-

netic algorithm to solve it. The feasibility and applicability of the solution and validation of the model and algorithm; Li Fei et al. (2018) based on the summary of experience in the planning of microcirculatory public transport network and the characteristics of positioning service, applied the big data of public transport to study and analyze the weak areas and hot areas covered by public transport in Long-gang District of Shenzhen, and to determine the direction of short-distance travel demand, providing data support for the planning and improvement of microcirculatory public transport^[8].

At home and abroad, a large number of studies have been carried out on the design and optimization model and algorithm of microcirculation bus route planning. The theoretical scientificity and practical feasibility of the research results have been verified by examples, but relatively few studies have been carried out on the basis of community commuters' travel needs and the promotion of bus integration. Based on IC card data, this paper identifies the commuter's demand analysis of getting up and down bus station, analyzing passenger flow direction, selecting hot demand station area and so on, and then obtains the candidate bus station by cluster analysis. Then, a microcirculation bus route planning and design model is constructed by minimizing passenger travel cost and bus operation cost, and genetic algorithm is used. The most feasible route operation scheme is obtained.

3. Data Acquisition and Processing

3.1 Data Acquisition

The data used in this study are from IC card data of a city. In order to exclude the influence of holiday factors, the time range of data acquisition is set to November 2018. The main data acquisition contents are bus IC card swipe data (shown in Table 1), bus GPS data (shown in Table 2) and site GIS data.

Table 1. The structure of bus IC card data

Card_id	Deal_time	Deal_amt (¥)	Card_type	Terminal_id	Line_name
510000*****2800	20171116073300	1.2	IC Card	05065000	A
510000*****8640	20171116081522	1.2	IC Card	06800410	B
510000*****2870	20171116220506	2	IC Card	01110612	C

Table 2. The structure of bus GPS data

Time	V _{GPS}	GPSTerminal_id	Line_name	longitude	latitude
20171116081448	5.22	11071103	A	113.5025	23.17637
20171116175502	3.55	11062302	B	113.5314	23.14928
20171113092229	4.54	11059604	C	113.4732	23.17841

3.2 Data Acquisition and Processing

In order to improve the efficiency and accuracy of data analysis and effectively avoid the interference of incomplete data, redundant data, noise data, error data and other abnormal data, it is necessary to carry out pre-processing work such as cleaning, fusion, transformation and reduction of bus IC card swipe data and bus GPS data. After data pretreatment, more than 94 million effective bus IC card consumption data meet the data quality and application requirements, and more than 9,000 bus-operated vehicles correspondingly. There are 332 bus routes that meet the requirements of bus IC card consumption data and bus GPS data integrity. In addition, because this paper takes commuters as the research object, this paper adopts Chen Jun's definition of commuters in 2018: "The total number of first commuters in the peak period of a week is greater than or equal to six times, the total number of first commuters in the peak period and the total number of first commuters in the evening peak are greater than two times", and the non-commuters are excluded.

4. Bus Travel Demand Analysis and Route Planning

This paper establishes a public transport community within 3 kilometers of a large community bus station in a city, and studies the transit demand of commuters in the community and the planning of microcirculation circular bus lines.

4.1 Travel Demand Analysis of Micro-cycle Bus Connecting with Metro Station

4.1.1 Recognition of the Upper and Lower Station Points of Bus Travel Starting from Xiangxue Metro Station

Recognition of boarding station points: (1) Select the swipe card data of an IC card on the working day, rank them according to the transaction time, and regard the subway station where the second swipe card happened on the same day as the transfer station; (2) Select the bus GPS trajectory point closest to the GIS location of the transfer station as the bus entry station; (3) Analyse the similarity of the bus trajectory to identify the actual route of the vehicle, and recognize the spatio-temporal variation of the continuous GPS points. The arrival time of vehicles is calculated by using the speed information data recorded by GPS. (4) The arrival time of passengers is matched with the arrival time of vehicles. The nearest arrival time is chosen as the boarding time, and the corresponding station of GPS is the boarding point.

Recognition of disembarkation points: Bus lines usually adopt the "one ticket" system, swiping cards only when boarding, and no second swiping cards when disembarking. That is to say, IC cards have no record of disembarkation swiping cards, so it is necessary to infer the disembarkation points of passengers according to the results of identification of passengers' boarding points. Referring to Hu Jihua et al. (2017) based on the inference method of travel chain, this paper infers that the bus departure point^[9], which connects the bus departure points above the station points on the same day as the departure and departure points, can form a closed-loop travel chain. Because most of the commuter's routes are the same, the bus departure points in the evening rush hour are the early rush bus departure stations. Point.

4.1.2 Recognition of Bus Departure and Departure Points Based on Xiangxue Metro Station

Recognition of boarding station: (1) Select the data of IC card swiping on working day, read one card data in turn according to the order of transaction time, judge whether it is the first time to swipe card, if not the first time to swipe card, then delete the data; (2) analyze the bus GPS trajectory point closest to the bus station as the entry station; (3) Analyse the similarity of bus line trajectory to identify the actual route of the vehicle, and base it on the analysis of the similarity of bus line trajectory. Vehicle arrival time is calculated by using the speed information data recorded by GPS. (4) The arrival time of passengers is matched with the arrival time of vehicles. The nearest arrival time is chosen as the boarding time, and the corresponding station of GPS is the boarding point.

Recognition of disembarkation point: Passengers generate IC card transaction data when they transfer to the subway, and match the IC card information of the first Metro trip on that day with that of the bus trip on the station. If the card number is the same, the bus station nearest to the GIS location of the subway station will be selected as the disembarkation point.

4.2 Passenger Flow Analysis and Regional Identification of Popular Demand Sites

Passenger flow direction and travel demand are the premise and basis of the planning and design of microcirculation bus line and the key to the opening of the line. On the basis of identifying the starting and ending points of the subway station, the flow direction of passenger flow is analyzed and the corresponding passenger flow is counted. The station area with 100 passengers or more on or off the early peak is selected as the hot demand station area, and

then the conclusion is drawn. The main passenger flow direction starting from Xiangxue Metro Station and the main passenger flow source starting from Xiangxue Metro Station (as shown in Table 3).

Table 3. The travel demand of main hot sites at early Peak

Sites	The passenger flow form Xiangxue Metro Station	The passenger flow to Xiangxue Metro Station
Huochun	53	117
Kaiyuan Avenue	47	114
Huapu Village	38	126
Yangcheng School	43	137
Yuyan Road	41	113
Hecun	35	102
Xiangxue Apartment	113	39
Luogang Village	101	46
Jeep Electronics	115	35
Liucun	106	30
Development Zone	118	37

In the early peak period, the passenger flow with Xiangxue Metro Station as the terminal point mainly comes from six areas, namely Huochun, Kaiyuan Avenue, Huapu Village, Yangcheng School, Yuyan Road, Hecun. The main residential areas in the above areas are Xiangxue Apartment, Luogang Village, Jeep Electronics, Liucun and Development Zone. Industrial parks and other five regions, the above areas are mainly commercial and industrial parks.

4.3 Bus Travel Station Clustering Analysis

On the basis of identifying nine hotspot demand sites, K-means method is used to cluster the similar travel demand sites in these regions. The specific steps are as follows:

- (1) Suppose that i sample set $\{X_i, i=1,2,\dots,N, i \in Z\}$ classifies the data points in the sample set into K clustering centers $Z_k, K=\{1,2,\dots,N, k \in Z\}$ in the corresponding category;
- (2) Calculate the sum of squares of distances from similar data points to cluster centers, select the cluster centers with the smallest distances, and classify the corresponding travel demand sites into clusters C_k ;
- (3) Update the demand points in each cluster, calculate the average value of each cluster and use it as the new cluster center Z_{k1} ;
- (4) According to formula (1), the sum of squares of in-

tra-class errors is calculated.

$$E = \sum_{i=1}^n \sum_{p \in C_k} \|p - z'_k\|^2 \quad (1)$$

Among them, P is the demand point in the cluster C_k and the Z_k is new demand point in the cluster C_k .

(5) The E value is calculated iteratively for several times, and when the change of E value stops or is not large, the operation is terminated; otherwise, the steps (3) to (5) are repeated.

In this paper, the maximum walking distance threshold of passengers is 500 m, and the existing station with the largest passenger flow near the cluster center is the micro-circulation bus stop, which can not only ensure the fine-grained bus passengers, but also avoid the cost investment of new stations. According to the clustering results, eight candidate stations, including Xiangxue Apartment (49), Luogang Village (11), Yuyan Road (34), Yangcheng School (7), Liucun (4), Hecun (63), Jiepu Electronics, (21) and Development Zone (40), were obtained to construct microcirculation bus loop.

5 Model Setting and Analysis

5.1 Model Setting

Based on the principle of "minimizing the total cost of passenger travel and bus operation", this paper aims to build the model as follows:

(1) The operation cost of microcirculation bus consists (C_b) of the vehicle operation cost and labor cost generated during the operation of bus. Assuming that the bus runs at a uniform speed, the running cost of the bus can be measured by the running time of the bus, and the labor cost can also be measured by the working time. Then the minimization function of the operation cost of the circular bus is set as follows:

$$C_b = C_m V_e \sum_{i \in S} \sum_{j \in SU} \sum_{k \in K} t_{ij} y_{ijk} + C_n \sum_{i \in S} \sum_{j \in SU} \sum_{k \in K} t_{ij} y_{ijk}$$

Among them: S stands for bus station; S_0 stands for bus station; K stands for bus $k \in K$; C_m stands for operation cost per kilometer, including fuel consumption cost and bus maintenance cost; C_n indicates labor cost per hour; V_b indicates vehicle speed; t_{ij} indicates average travel time of bus station i and j ; y_{ijk} is 0-1 decision variable, if the next bus station K is j after visiting bus station i , Set a value of 1, otherwise 0.

(2) Passenger travel cost (C_p) of walking time, waiting time and on-the-way time and fare of passengers from the original station to the station. Then the passenger travel cost function is set as follows:

Among them: S_1 expressing the original station point; S_{S1}^i expressing the number of passengers boarding at station i ; V_b expressing the value of travel unit time; $V_b t_b$ expressing the cost of walking time, $V_b t_b$ expressing walking time; t_b expressing the cost of waiting time, $V_b \frac{1}{2}$ assuming that waiting time is 1/2 of departure interval (h); $V_b t_{ij}$ expressing the cost of on-the-way time, t_{ij} expressing the travel time from station i to station j ; f expressing the bus fare.

(3) Path optimization model and constraints

$$MINC = MIN \{ \alpha C_b + (1 - \alpha) C_p \}$$

$$S.T. \left\{ \begin{array}{l} L_{S1} \leq L_b \\ M \leq \sum Q_{ij} \leq M_{max} \\ L_{min} \leq L_{ij} \leq L_{max} \\ F_{min} \leq F \leq F_{max} \end{array} \right.$$

Among them: and $1-\alpha$ the weight coefficients of two objective functions are expressed separately; L_b expressing the maximum walking distance, L_{S1} is expressed as the walking distance from the original station to the waiting station; $\sum Q_{ij}$ expressing the number of micro-cycle bus passengers from station i to station j , M is expressed as the number of bus seats, M_{max} representing the maximum number of passengers; L_{ij} is expressed the station spacing between station i and station j , L_{min} and L_{max} are expressed as the minimum and maximum station spacing between station i and station j respectively; F expressing departure frequency, F_{min} and F_{max} respectively expressing minimum departure frequency and maximum departure frequency..

5.2 Model Analysis

5.2.1 Overview of Algorithms

Genetic Algorithms (GA) is a common intelligent algorithm for solving multiple feasible solutions, which has the characteristics of "directly using the objective function as search information; inherent parallelism; and adaptive search", and can be applied to the study of optimal solutions. Therefore, this paper uses GA algorithm to study the minimization of passenger travel and bus operation costs in micro-cycle bus route planning. The algorithm process is as follows:

(1) Setting initialization parameters. When the number of public transport is a , the input parameters are: population size N , crossover probability P_c and mutation rate P_m .

(2) Initial line generation. Based on the coding rule of 0-1 variable, the number of chromosomes of the population is generated randomly, that is to say, the initial line is

obtained.

(3) Calculate the fitness function. Fitness function is $G = +\alpha C_b + (1 - \alpha) C_p + \sum_{i=1}^4 p_i$, in which: p_1 for penalty items, including walking distance penalty items p_1 , passenger number penalty items p_2 , station spacing penalty items p_3 , departure frequency penalty items p_4 . The fitness function was calculated and the population was sorted according to the size, and the chromosomes with higher fitness were evolved into the next generation population.

(4) Cross-variation. The new generation of chromosomes can be obtained by random pairing and crossover of the evolutionary chromosomes.

(5) Check the number of iterations. When the number of iterations reaches the maximum number of iterations, at the end of the iteration, the optimal value and chromosome can be output, that is, the bus line and its station can be obtained, otherwise step 4 will be returned.

(6) Scheme comparison. The scheme with the minimum objective function value is chosen as the optimal scheme.

5.2.2 Model Computation

(1) Parameter Setting

Assuming that the number of microcirculatory buses is 6, the optimal solution is obtained when the input parameters are based on Visual C++ 6.0 platform: Max GEN is 50, population size N is 40, crossover probability is 0.6 and mutation rate p_m is 0.1. At the same time, set the following parameters, as shown in Table 4.

Table 4. Parameter Settings

NO,	Parametric Item	Parametric Value	NO.	Parametric Item	Parametric Value
1	C_n	49¥/h	9	F_{max}	16times/h
2	V_b	20¥/h	10	L_{max}	4km
4	L_b	500m	12	p_1	1000
5	V_e	300m/min	13	p_2	1000
6	C_b	2.5¥/km	14	p_3	1000
7	M_{max}	30	15	α	0.4
8	F_{min}	4times/h			

(2) Operational Results

As shown in Figure 5, according to the current road traffic conditions, this paper proposes to establish micro-cycle bus routes connecting the above eight candidate stations with the subway stations. According to the different running directions, the clockwise (Plan A) and anticlockwise route (Plan B) schemes are formulated, and the genetic algorithm is used to optimize the route schemes.

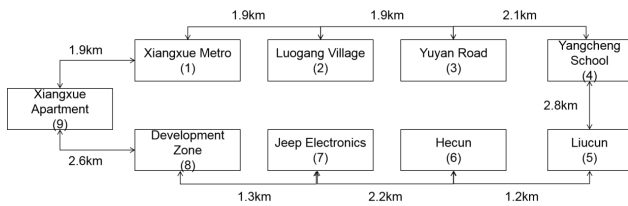


Figure 5. The guess of operation route of Microcirculation Bus

As shown in Table 5, after optimization, the passenger travel cost C_p , bus operation cost C_b and target cost C_t of microcirculation bus clockwise operation decreased by 5057 yuan, 383 yuan and 3187.4 yuan, respectively, compared with those before optimization, with the decreases of 28.36%, 20.88% and 2.86%, respectively. This shows that the model is effective in optimizing the layout of line stations and reducing the cost of passenger travel and bus operation.

Table 5. The cost comparison before and after optimization of clockwise operation route of Microcirculation Bus

Plan	Station line	Optimized state	C_p (¥)	C_b (¥)	C_t (¥)
A	(1)-(2)-(3)-(4)-(5)-(6)-(7)-(8)-(9)-(1)	before	17832	1834	11432.8
	(1)-(3)-(4)-(5)-(7)-(9)-(1)	after	12775	1451	8245.4

Furthermore, as shown in Table 6, after optimization, the passenger travel cost, bus operation cost and target cost of microcirculation bus are reduced by 5347 yuan, 407 yuan and 3371 yuan respectively, with a decrease of 29.99%, 22.19% and 3.03% respectively, which also shows the effectiveness of the model in optimizing the layout of line stations and reducing the cost of passenger travel and bus operation.

Table 6. The cost comparison before and after optimization of counter-clockwise operation route of Microcirculation Bus

Plan	Station line	Optimized state	C_p (¥)	C_b (¥)	C_t (¥)
B	(1)-(9)-(8)-(7)-(6)-(5)-(4)-(3)-(2)-(1)	before	17416	1829	11181.2
	(1)-(8)-(6)-(4)-(3)-(1)	after	12069	1422	7810.2

Finally, since the target cost of the optimized anti-clockwise route scheme is lower than that of the clockwise route scheme, the anti-clockwise route scheme of the micro-circulation bus is more feasible according to the

principle of minimizing the total cost of passenger travel and bus operation.

6. Conclusion

Based on IC data of a city, this paper uses IC card data, identifies commuters'needs of getting up and down bus stops, analyses passenger flow direction, and chooses popular demand stops area, and then obtains eight candidate bus stops by clustering analysis. It establishes the goal of minimizing the sum of resident travel cost and bus operation cost, and takes walking distance as the goal. The optimization model of microcirculation bus line with the constraints of passenger number, station spacing and departure frequency is presented. According to the difference between the current road traffic situation and the direction of bus operation, the optimal solution of microcirculation bus line optimization model is obtained by using genetic algorithm on the platform of Visual C++ 6.0, and the optimal microcirculation bus line connecting rail transit according to the objective function and constraints is obtained. The validity of the model is illustrated, which has a positive significance for guiding the planning and design of microcirculation bus routes and promoting the development of public transport integration.

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