Study on the Coordination of Community Bus Departure Time Connected to Subway Stations

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Abstract: The community bus connected between the subway and residential community, can alleviate the existing bus peak capacity shortage and solve community residents "the last kilometer" travel problems. But the actual operation effect is not very ideal, it's also needs to further improve the traffic plan. Through summarizing and analyzing the characteristics of community bus operation and passenger flow at the transfer station, this paper mainly focused on the coordination of community bus departure time connected to subway stations. A community bus coordination model is established, and the most effective results can save up to 18.42% of total passenger waiting time.

1. Introduction

With the continuous development of the urbanization level in China and the improvement of people's quality of life, the demand for travel of urban residents is getting larger and larger, resulting in a long travel distance and traffic congestion [1]. Community bus is a transportation that connects residential communities with nearby urban rail transits, schools and commercial areas. It can effectively increase the coverage of public transport network and improve bus and subway transfer connectivity [2]. Another major role of community bus service is to alleviate the problem of insufficient capacity of existing buses, mainly reflected in the morning and evening peak hours on weekdays [3]. In this paper, we mainly considered the difference in walking speed among people of different ages. Then we minimized the total waiting time for all transfer passengers by coordinating the departure time of the community bus at the transfer station.

2. Problem statement

2.1 Operation characteristics of community bus

Summarizing the actual operation of some community bus lines in Beijing, the main operating characteristics of the community bus lines connected to subway stations are:
(1)The line mainly connects residential communities and subway stations;
(2)The length of the service line is generally around 5-10km;
(3)Operating hours are generally during morning and evening peak hours throughout the day, mainly depends on the passenger flow characteristics of the service line;
(4)The headway is generally around 10 or 15 minutes, larger than that of regular bus.

2.2 Coordination analysis

In generally, the headway of community bus is around 10 minutes, and the headway of subways during peak hours is almost within 4 minutes. Therefore, the total waiting time for transfer passengers from the community bus to rail transit is shorter than the opposite situation. In other words, passengers who transfer from rail transit miss the community bus, they will have to wait for a long time to the next bus. Fig. 1 shows the coordination transfer process between rail transit and community bus. A_r, D_r, A_b, D_b Represent the arrival and departure time at the transfer station

respectively. t_{wbr} and t_{wrb} indicate the transfer walking time in both directions. If $A_r + t_{wrb} > D_b$ or $A_b + t_{wbr} > D_r$, the process of transfer coordination is a failure, otherwise successful.
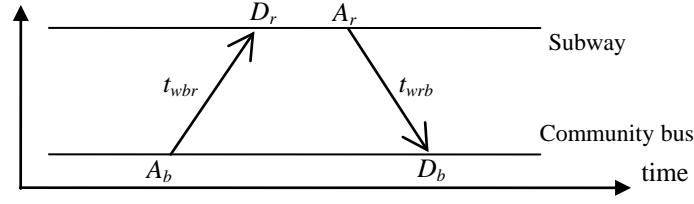

Fig. 1 Schematic diagram of coordinated transfer of rail transit and community bus

2.3 Passenger flow characteristics

According to the existing research on pedestrian behavior, people of different ages and genders have different walking speeds. Table 1 shows the walking speed at urban rail transit stations.

Table 1 Statistical table of walking speed in different age groups

Pedestrian type	man(m/s)	woman(m/s)	average(m/s)
Seniors	0.31	0.17	0.24
Middle-aged	1.64	1.57	1.61
Young	1.94	1.76	1.82
Children	1.13	1.07	1.10

Taking the community bus headway 10 minutes and the subway headway 4 minutes as an example, according to the walking speeds of the passengers of different ages, the distribution of the number of transfer passengers from the urban rail transit at the community bus station is shown in Fig. 2.
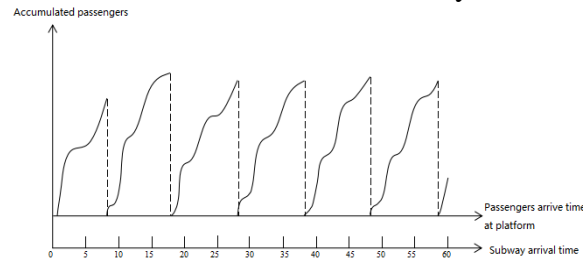

Fig. 2 Passengers' distribution at the transfer bus station

3. Mathematical model

3.1 Notations and parameters

Table 2 lists all the relevant subscripts and parameters used in the model.

Table 2 Description of the notations and parameters

Notations	Definition
t	Total waiting time of all transfer passengers in a cycle T(60min)
h_b	The community bus headway
h_r	The urban rail transit headway
$t_{b,0}$	Departure time of the first community bus at the transfer station
$t_{b,i}$	Departure time of the i-th community bus at the transfer station
m	The maximum number of departures of community buses in a cycle T
$A_{r,0}$	Arrival time of the first subway train at the transfer station
$A_{r,j}$	Arrival time of the j-th subway train at the transfer station
n	The maximum number of departures of rail transit trains in a cycle T
t_{wk}	Travel time for people of different age groups
P_k	The number of transfer passengers of different ages from each train
s_o	Transfer distance
v_k	Travel speeds of people of different ages

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3.2 Model assumption

This section makes the following assumptions to simplify the problem:

(1) The timetable for urban rail transit is known. Trains run strictly in accordance with the timetable, with no delay or overtaking;

(2) Community buses' headway are equal in each period;

(3) The Interval operation time of community bus remains unchanged, regardless of the congestion of the line and the impact of traffic lights.

3.3 Systematic constraints

In this subsection, systematic constraints will be formulated to meet the passenger demands, improve transfer efficiency and guarantee the passenger safety.

Eq. (1) represents the departure time of the i-th community bus at the transfer station, while headway of the community bus keep constant.

$$t_{b,i} = t_{b,0} + i \cdot h_b \tag{1}$$

Eq. (2),(3)represents the first departure time should be within one departure interval.

$$0 \leq t_{b,0} \leq h_b \tag{2}$$

$$0 \leq A_{r,0} \leq h_b \tag{3}$$

Eq. (4) limits the departure time of the last car not later than the selected period T.

$$T - h_b \leq t_{b,m-1} \leq T \tag{4}$$

Eq. (5),(6) gives the maximum number of departures in a period T.

$$m = [T/h_b] \tag{5}$$

$$n = [T/h_r] \tag{6}$$

Eq. (7) ensures that passengers' waiting time is positive, and eq. (8) gives the range of transfer time based on the transfer distance and the walking speed of different pedestrians.

$$A_{r,j} + t_{wk} \leq t_{b,i} \tag{7}$$

$$s_0/v_{\max} \leq t_{wk} \leq s_0/v_{\min} \tag{8}$$

The total waiting time for all transfer passengers at the transfer bus station is described in Eq. (9).

$$\min t = \sum_{k=1}^{4} \{ [t_{b,0} - (A_{r,0} + t_{wk})] \times P_k + \sum_{i=1}^{m-1} \sum_{j=1}^{n-1} [t_{b,i} - (A_{r,j} + t_{wk})] \times P_k \} \tag{9}$$

3.4 Flow chart of model solution

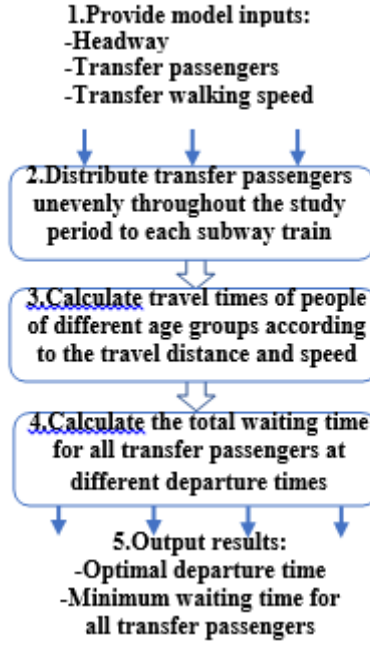The solution flow chart is shown in Fig. 3.

Fig. 3 The flow chart of model solution

4. Case study

4.1 Introduction

This paper selected one community bus line in Beijing as the study route. The terminal of this line connects two different residential areas, and the middle station of the line connected with one subway station. The total length of this bus line is 5.43km. According to the data of the existing IC card and filed research, the values of the parameters in the model are shown in Table 3.

Table 3 Model-related parameter values

Line	Parameters	Value
Community bus line	Headway h_b (min)	10
	Maximum number of departures	6
	Interval operation time(min)	30
Subway line	The first subway train arrival time A_{r0}	0
	Headway h_r (min)	4
	Maximum number of departures	15
	Transfer distance s_0 (m)	320

4.2 Model result

Take the evening peak 17:00-18:00 as the calculation period, 1 minute as the minimal calculation unit, the model solution results are shown in Table 4.

Table 4 Model solution results

The first vehicle departure time	17:10	17:09	17:08	17:07	17:06	17:05	17:04	17:03	17:02	17:01
Total waiting time(minutes)	1919.29	1623.22	1881.71	1598.07	1944.28	1651.22	1958.81	1665.25	1943.65	1649.30

From table 4, the optimal result is: $t_{b,0} = 7$, $\min t = 1598.07 \min$

Compared with other results, the optimal solution can save up to 18.42% of the total passenger waiting time. Therefore, the model optimization results are obvious.

5. Conclusions

Under the established situation of the community bus line and station, this paper analyzed the operation characteristics and passenger flow rule of community bus line, then mainly studied the connection between the community bus and the subway at the transfer station. Through the solution of the community bus departure time coordination model, up to 18.42% passenger waiting time can be saved from the optimal results. In the future research, community residents' travel demand survey and analysis, the company's operating costs, passenger travel costs, social costs and other factors is worthy of further studies.

Acknowledgments

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