

Operation Organization of Express/Local Train for Urban Rail Transit

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Abstract. The operation organization of express/local train for urban rail transit is widely used nowadays. In order to improve service level of passengers for urban rail transit, this paper establishes an optimal express/local train stop schedule plan model, taking express/local train frequencies, the express trains' cross-station sequence and the overtaking-station place as decision variables. In the case analysis, compared with the train of stopping station by station, express/local train operation can reduce passengers' total in-vehicle time and travel time by 14.49% and 1.07% respectively.

Keywords: Urban rail transit, express/local operation, stop schedule plan, case analysis.

1. Introduction

The combination operation of express and local trains is an important part of the urban rail transit organization, which can improve the service quality for passengers and operation efficiency for transportation system [1], hence express/local operation is widely used in some developed countries, like Subway line 7 in New York, Heathrow Connect in London. Much research about what components affect express/local operation organization has already been done. Based on the analysis of the interval characteristics of urban rail transit trains during weekdays and holidays, Jamili and Aghaee study the train operation mode of urban rail transit under uncertain conditions [2]. Abdelhafiez mainly considers the station layout form, takes the average travel time of urban rail transit as the objective function, and establishes a nonlinear integer programming model, the case results show that the cross-stop scheme saves about 10% less than the station-stop scheme of total travel time [3]. Jang combines with the method of timetable and determination of train stations, achieves the stop schedule plan, and proposes heuristic solution algorithm [4].

Express/local operation organization is running two kinds of trains, one is express trains that can cross some stations, and the other is local trains that stop at every station. The most obvious effect of express/local operation organization is that total travel time has been saved, which is related to many factors. However, the operation organization of urban rail transit is hard to get the best place, how to decide the frequency of express/local trains and the overtaking station is the question worth studying.

2. Analysis of Optimal Model of Express/local Operation Organization

2.1 Parameter Definition

i, j, k, m, t — serial number of stations;

N - total number of stations;

T - studied time period;

v - train velocity in an interval, km/h;

h_{e-l} - departing time interval between pre express train and post local train at departure station;

h_{l-e} - departing time interval between pre local train and post express train at departure station;

h_{l-l} - departing time interval between pre and post local trains at departure station;

h_{e-e} - departing time interval between pre and post express trains at departure station;

I_{\min} - minimum tracking interval, s;

f_l - departure frequency of local trains;

- f_e - departure frequency of express trains;
 f_{\min} - minimum frequency of trains;
 x_k - to determine whether the express train stops at k-th station, 0-1 decision variable;
 $x_k = 1$, express train stops at k-th station; $x_k = 0$, express train crosses k-th station;
 x_m - to determine whether the express train overtakes m-th station, 0-1 decision variable;
only $x_m = 1$, express train overtakes m-th station;
 t_k - dwell time of train at k-th station, s;
 t_{ij} - interval running time from station i to j, s;
 $p(r)$ - probability of travel selection for the r-th scenario;
 q_{ij} - total amount of passengers from origin station i to destination station j;
 C_z - personnel quota of a train;
 Q_{\max} - maximum section passenger flow;
 η_{\max} - upper limit of average load factor in highest passenger flow section;
 η_{\min} - lower limit of average load factor in highest passenger flow section.

2.2 Assumptions

- Single direction operation of train in peak hour;
- Single and straight route, only express and local trains with the same technical parameters;
- Balanced departure of the same kind trains at departure station, proportion of express and local trains is 1:1;
- Even passenger arrival, no retrograde and stranded passengers;
- If there is an express connection between the two stations, the passenger can only choose express train; passengers from local departure station can only choose local train; passengers from express departure station to local destination station can be considered transfer;
- Urban rail transit line with double track and every stations of the line with overtaking conditions;
- Only one overtaking behavior for every single train in station.

2.3 Analysis of Overtaking Mode

The location of overtaking station is related to the running state of express/local trains. It's necessary to determine whether the arrival interval of the trains will meet the minimum tracking interval constraint.

At m-th station, when the interval between adjacent trains is less than minimum tracking interval, then m-th station is determined as the overtaking station:

$$h_{l-e} - \sum_{k=2}^m [(1-x_k)t_k] > I_{\min} \quad (1)$$

Overtaking situation leads to dwell time of local trains at m-th station increase:

$$t_m = 2I_{\min} \quad (2)$$

2.4 Transfer Behavior of Express/local Passengers

According to different properties of stations, passengers can be divided into 4 types:

Type 1: passenger that origin and destination stations are express, can only choose express train, the amount of type 1 passengers is Q_1 ;

Type 2: passenger that origin station is local, can only choose local train, the amount of type 1 passengers is Q_2 ;

Type 3: passenger that origin station is express, destination is local and with no transfer, can only choose local train, the amount of type 1 passengers is Q_3 ;

Type 4: passenger that origin station is express, destination is local and with transfer, can choose express trains at first, then transfers to local train at t-th station, the amount of type 1 passengers is Q_4 .

For passengers of type 3 and 4, it is essential to study the probability of transfer selection. For ease of calculation, walking time of transfer does not considered. Researches show that logit model is used to described transfer behavior of express/local passengers [5].

The transfer selection scheme of passengers of type 3 and 4 is $V(r)$, total travel time is t^r , $\alpha = -0.3043$ [6]:

$$V(r) = \alpha t^r \quad (3)$$

The probability of transfer selection can be represented:

$$p(r) = \frac{e^{V(r)}}{\sum_j e^{V(j)}} \quad (4)$$

3. Optimal Model of Express/local Train Stop Schedule Plan

3.1 Objective Function

1) Amount of passengers in different types

$$Q_1 = \sum_{i=1}^{N-1} x_i \sum_{j=i+1}^N x_j q_{ij} \quad (5)$$

$$Q_2 = \sum_{i=1}^{N-1} (1-x_i) \sum_{j=i+1}^N q_{ij} \quad (6)$$

$$Q_3 + Q_4 = \sum_{i=1}^{N-1} x_i \sum_{j=i+1}^N (1-x_j) q_{ij} \quad (7)$$

2) Total waiting time of passengers at origin stations

Research shows that the value of waiting time at origin station of one passenger equals the half of departure time.

The total waiting time of passengers at origin stations:

$$T_{\text{waiting}} = (Q_1 + Q_2 + Q_3 + Q_4) \frac{T}{2f_l} \quad (8)$$

3) Total in-vehicle time of passengers at segments

$$T_{\text{in-vehicle}} = Q_1(t_{ij} + \sum_{k=i+1}^{j-1} x_k t_k) + (Q_2 + Q_3)(t_{ij} + \sum_{k=i+1}^{j-1} t_k) + Q_4(t_{ij} + \sum_{k=i+1}^{j-1} x_k t_k + \sum_{k=i+1}^{j-1} t_k) \quad (9)$$

4) Total transfer time of passengers

$$T_{\text{transfer}} = Q_4 t_{\text{transfer}} \quad (10)$$

$$t_{\text{transfer}} = \begin{cases} \sum_{k=i+1}^{t-1} [(1-x_k)t_k] + h_{e-t}, & \text{station } t \text{ position in front of } m \\ \sum_{k=i+1}^{t-1} [(1-x_k)t_k] - h_{l-e}, & \text{station } m \text{ position in front of } t \end{cases} \quad (11)$$

5) Total travel time of passengers of express/local operation organization

$$Z = T_{\text{waiting}} + T_{\text{in-vehicle}} + T_{\text{transfer}} \quad (12)$$

Above all, the objective function is $\min Z$.

3.2 Constraint Conditions

Express trains must stop at the first and last station and at least cross one station

$$x_1 = x_n = 1 \quad (13)$$

$$\sum_{k=1}^N x_k < N \quad (14)$$

Proportion of express and local trains is 1:1

$$f_l = f_e \quad (15)$$

$$f_{\min} \leq f_l + f_e \leq T/I_{\min} \quad (16)$$

Overtaking situation only occurred once

$$I_{\min} \leq h_{l-e} \leq \frac{T}{f_l} - I_{\min} \tag{17}$$

$$h_{l-e} + \frac{T}{f_l} - \sum_{i=2}^{N-1} (1-x_k)t_k \geq I_{\min} \tag{18}$$

Upper limit of load factor should be kept within a certain range

$$\frac{Q_{\max}}{C_z \eta_{\max}} \leq f_l + f_e \leq \frac{Q_{\max}}{C_z \eta_{\min}} \tag{19}$$

4. Case Analysis

4.1 Overview of Urban Rail Transit Line

The urban rail transit line of a certain city is connected city center to periphery. The line length is 18.15km and there are 12 stations along the line. Based on the operational planning perspective, every single station has overtaking conditions. From the perspective of actual operation, 6-A vehicle with 1860 persons of capacity is used over the line.

The principle of express/local operation organization of upstream and downstream is the same, so express/local operation organization of downstream direction is the study case.

4.2 Analysis of Passenger Flow Characteristics

According to the passenger flow from origin to destination stations in peak hour, the distribution of section passenger flow volume in each interval is as Fig. 1.

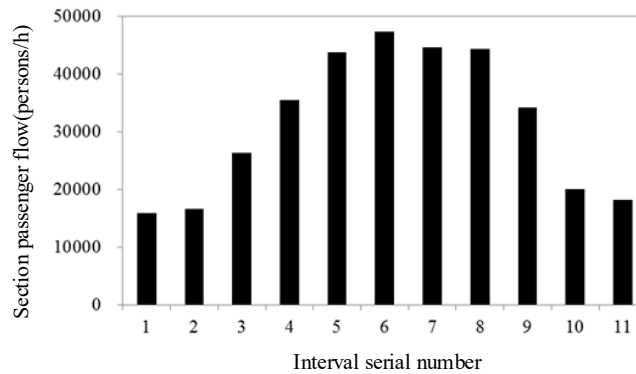


Fig. 1 Optimal express/local operation organization

From Fig.1, the overall passenger flow of each section presents convex, coefficient of Non-equilibrium section passenger flow is 1.513, bigger than 1.5, it presents that the distribution of section passenger flow of downstream is uneven. The express/local operation organization is fit for this situation.

4.3 Optimal Solution

Values of model parameters are shown in Table.1.

Parameter	Value
T	1h
v	80km/h
t_k	60s
C_z	1860 persons
I_{\min}	120s
f_{\min}	12 trains/h
η_{\min}	0.5
η_{\max}	1.3

Based on optimal model and its parameters, the optimal model is solved with genetic algorithm. The optimal solution is shown as Table 2 and Fig. 2.

Table 2 Optimal express/local scheme

f_l	f_e	$k(x_k)$	$m(x_m)$
10trains/h	10trains/h	5,6,8	5

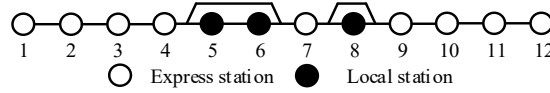


Fig. 2 Optimal express/local operation organization

Under the case given conditions, local trains stop at every station and express trains only stop at station 1,2,3,4,7,9,10,11 and 12, station 5 is also the overtaking station.

The stations that express trains stop at have larger boarding and alighting passengers. It is reasonable that express/local operation organization is used for the certain urban rail transit line.

4.4 Comparative Analysis of Operation Organizations

Under the same departure frequency of 20trains/h, the effect comparison of express/local and normal operation organization respectively is shown in Table 3.

Table 3 Three Scheme comparing

Time index	Express/local	Normal	Variable quantity	Change rate
$T_{in-vehicle} /min$	609153	712364	-103211	-14.49%
$T_{waiting} /min$	185536	92768	+92768	+100%
$T_{transfer} /min$	1812	-	1812	-
T_{travel} /min	796501	805132	-8631	-1.07%

From Table 3, under the same departure frequency of 20trains/h, the total in-vehicle time decreases while the total waiting time and transfer time increase, and the total travel time of express/local plan decreases from the global aspect. So, the express/local operation organization is effective to save total travel time for passengers of urban rail transit line.

The reasons of changes of time indexes are as follows:

1) Total in-vehicle time

On the express/local operation organization, the express trains cross some certain stations and sometimes the local trains stop at stations a little longer. Under the case conditions, the decreased time of the express is more than the increased time of the local, so the total in-vehicle time is saved.

2) Total waiting time

To the assumptions above, departure interval of trains is balanced, and passengers arrive evenly, so the departure interval of the same type trains is equal. The value of waiting time of one passenger is equal to half of departure interval. On the normal operation organization, the trains all over the urban rail transit line are identical. While on the express/local operation organization, there are two types of trains, the express and local. One passenger of express/local plan can only wait for the express or local train, so the total waiting time of express/local plan is double to normal plan.

3) Total transfer time

Passengers of normal operation organization do not need to transfer while of express/local do. Passengers who choose to transfer can save the in-vehicle time. It is random for some passengers to decide whether to transfer.

4) Total travel time

The change of total travel time is the result of total in-vehicle time, waiting time and transfer time. The express/local operation organization has practical significance only when the saved total in-vehicle time is more than the sum of total waiting time and transfer time.

Above all, the changes of stop schedule plan have an obvious impact on the effects of operation for urban rail transit. The express/local operation organization should be made scientifically.

5. Conclusions

The combination operation of express and local trains is a kind of transportation organization mode for urban rail transit, which is of great significance to save the total travel time and reduce the travel cost for passengers. From the perspective of passenger benefits, with the objective function of minimizing the total travel time of passengers for urban rail transit, the optimal model of the express/local operation organization is put forward. Combined with the case, comparative analysis of express/local and normal operation organizations has been done. The conclusions are as follows:

1) express/local operation organization can save travel time for passengers. Compared with the train of stopping station by station, express/local train operation can reduce passengers' total in-vehicle time and travel time by 14.49% and 1.07% respectively.

2) effect of express/local operation organization presents on the total saved travel time which is influenced by in-vehicle time, waiting time and transfer time. When the decreased time is more than increased time, the passengers' benefits can be gained in the urban rail transit system.

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