

Feeder Bus Timetabling Optimization for High-Speed Railway Station with Uneven Departure Interval

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Abstract: This paper proposes a bus timetable with uneven departure interval, which is mainly used to optimize the bus timetable at high-speed railway stations. The railway comprehensive transportation hub is an important node for the connection between the internal and external transportation of the city. Efficient transfer efficiency can not only improve the travel satisfaction of passengers, but also enable public transport enterprises to retain passenger flow in the competition with rail enterprises. Therefore, this paper analyzes the travel time distribution law of railway passenger transfer to public transport, constructs a timetable optimization model that adapts to the passenger flow law, and uses genetic algorithm to solve it. The optimization results show that, without changing the departure frequency, the waiting time of passengers in peak hours using the uneven departure interval mode is reduced by 29.6%, and the waiting time in average peak hours is reduced by 16.2%. If the departure frequency is changed, the waiting time of passengers in the uneven departure interval mode will also be shorter than that in the equal time departure mode.

Keywords: Bus schedule optimization, Genetic algorithm, High-Speed rail station transfer, Unequal interval bus departure.

1. Introduction

As an important mode of transportation for intercity travel in China, railway is in a period of vigorous development. By 2021, the railway passenger transport volume accounted for 31.46% of the total operational passenger transport volume of water, air, highway and railway, and the passenger transport volume reached 2.612 billion people. With the further improvement of the national railway network, the railway passenger traffic will continue to increase. Railway passenger transport hub generally has a complete transfer transportation system, in which rail transit and public transport become the main transfer modes for arriving passengers because of their economy and accessibility. However, public transport has the characteristics of low operating cost, flexible routes and convenient transportation. In the study of transfer and transfer services, bus schedule optimization has become the main research object.

The existing optimization of bus timetable includes the optimization of equal time departure interval and the optimization of uneven departure interval. In the study of the former, Niu et al^[1] built an optimization model of bus line departure frequency with the goal of passenger waiting satisfaction, comfort satisfaction and enterprise satisfaction. Sun et al^[2] solved the departure time interval and required vehicle size under the regional dispatching mode and the single-line dispatching mode respectively, aiming at minimizing the passenger cost and the bus operation cost. Cao et al^[3] built an optimization model with the goal of maximum passenger waiting satisfaction to solve the departure frequency of public transit lines at different times. In the study of the latter, Wu et al^[4] applied mathematical formulas to describe the waiting time of passenger transfer, with the goal of minimizing the total time of passenger transfer, and studied the optimization of bus network schedule under the condition of uneven departure interval. Yuan et al^[5] established the optimization model of timetable and bus dispatching system with the goal of minimizing the total transfer time of passengers and the total number of public transport vehicles,

and found that the uneven departure interval schedule can effectively reduce the total transfer time of passengers.

The arrival of railway trains is uneven, and the passenger flow is characterized by centralized arrival. For the bus station with the first departure station next to the railway passenger station, the departure mode with equal time interval cannot well adapt to the characteristics of large passenger volume and strong agglomeration of railway passengers. Therefore, from the perspective of enhancing the transfer efficiency and reducing the waste of transport capacity, this paper studies the arrival law of railway trains, and uses the unbalanced departure mode to optimize the departure time interval between railway passenger stations and bus lines.

2. Modeling Method

The establishment of the regular bus schedule based on the model is affected by many factors, including subjective factors such as scheduling restrictions and scheduling options, as well as objective factors such as the distribution of passenger flow on the line, line operation status, bus technology level and bus service level. The feeder bus at the high-speed railway station should not only consider the above factors, but also consider the impact of the arrival time of the railway train. Make the bus schedule not only meet the needs of most travelers, but also reduce the number of bus departures, so that the bus operators and passengers can achieve a win-win situation. This paper considers the two objectives of transfer passenger time coordination and bus capacity coordination, and optimizes the timetable to minimize the comprehensive target value of total passenger waiting time and bus capacity waste.

2.1. Model assumption and variable description

In order to make the model solvable, the model is established in the study with following assumptions:

(1) It is assumed that the operation plan of the railway train will remain unchanged for a period of time.

(2) It is assumed that the daily passenger flow for bus transfer is basically the same, and the passenger flow movement law fluctuates slightly.

(3) It is assumed that non-railway passengers arrive at the platform evenly

(4) It is assumed that the departure time of the bus is the latest time for passengers.

(5) It is assumed that vehicles will take the remaining passengers away before and after the study period.

Many variables are involved in the text, and the detailed explanation are shown in Table 1.

Table 1. Variable explanation

Variable	explanation
Q	Number of bus departures during the study period
O	Number of train arrivals in the study period
h	Bus number, $h \in \{1, 2, \dots, Q\}$
k	Bus number, $k = \{1, 2, \dots, O\}$
t	Time granularity sequence number in the study period
$A_{bus}(t)$	Number of railway transfer passengers arriving at the bus station at the end of the time granularity
λ	Arrival rate of non-railway passengers during the study period (person/30s)
E	Rated passenger capacity of bus
d_h	Departure time of the bus h
l_h	The latest time for passenger to get on the bus h
∂	Reduction factor of vehicle rated capacity
θ_{max}	Maximum full load rate of vehicle
θ_{min}	Minimum full load rate of vehicle
μ_{max}	Maximum departure time interval of vehicles
μ_{min}	Minimum departure time interval of vehicles
ε	Limit time between two adjacent departure time intervals
n_b^h	Number of passengers who successfully get on the bus
T	Total waiting time of passengers
M	The utilization degree of bus transport capacity
M_i	The utilization degree of ideal bus transport capacity
H	Difference between the utilization degree of bus transport capacity and the utilization degree of ideal bus transport capacity

2.2. Optimization objectives

There are two objective functions, one is the waiting time of passengers, and the other is the matching degree between the boarding passengers and the bus capacity. When the total waiting time of passengers is the shortest and the matching degree of transport capacity is the highest, the result reaches the best.

Passengers taking public transport include railway transfer passengers and non-railway transfer passengers. If the passenger arrives at time t , then $d_h - t$ is called passenger waiting time, and the total waiting time T of all passengers is:

$$T = \sum_{h=1}^Q \sum_{t \in (l_{h-1}, l_h)} (d_h - t) * (A_{bus}(t) + \lambda) \quad (1)$$

Where d_h is the departure time of the train 'h'; $A_{bus}(t)$ is the number of railway passengers arriving at the bus station in the time segment 't'; λ is the arrival rate of non-railway passengers.

Arrival-rate capacity utilization rate M reflects the utilization of vehicle capacity. When the utilization rate is

between 0.86 and 0.90, the utilization degree of public transport is high^[6]. This paper introduces a variable H to express the difference between the utilization degree of transport capacity and the utilization degree of ideal transport capacity. The smaller the H value is, the higher the utilization degree is.

$$M = \frac{\sum_{h=1}^Q n_b^h}{Q * E * \partial} \quad (2)$$

$$H = |M - M_i| \quad (3)$$

Where Q is the number of bus departures during the study period; E is the rated passenger capacity of the bus; M_i is the utilization rate of transport capacity.

In order to make two objective functions with different dimensions can be measured by a unified standard, the objective function needs to be dimensionless. In this paper, the method of extreme difference is adopted. The extreme difference formula is:

$$T' = \frac{T - T_{min}}{T_{max} - T_{min}} \quad (4)$$

$$H' = \frac{M - M_{min}}{M_{max} - M_{min}} \quad (5)$$

The objective function has two objectives, and different weights are assigned to the two objectives μ and ν , The objective function is:

$$\min Z = \mu * T' + \nu * H' \quad (6)$$

$$\mu + \nu = 1 \quad (7)$$

2.3. Constraint condition

Based on the assumption that the study period is independent, there is a vehicle to take the waiting passengers away before and after the study period. The departure time of these two vehicles is:

$$d_0 = 0 \quad (8)$$

$$d_Q = \omega \quad (9)$$

In order to avoid a series of buses and no bus departure for a long time, the departure time interval of two adjacent buses should be restricted:

$$\mu_{min} \leq d_{h+1} - d_h \leq \mu_{max} \quad (10)$$

In order to ensure the interests of the public transport operation company and the travel comfort of passengers, and avoid the waste of transport capacity and passenger space congestion, the upper and lower limits of the full load rate of public transport vehicles are restricted:

$$\theta_{min} \leq \frac{n_b^h}{E * \partial} \leq \theta_{max} \quad (11)$$

$$n_b^h = \sum_{t \in (l_{h-1}, l_h)} A_{bus}(t) + \lambda \quad (12)$$

In order to ensure the continuity of the departure time, the difference between the two departure time intervals should not be too large. The constraints on the adjacent departure time intervals are put forward:

$$|(d_{h+1} - d_h) - (d_h - d_{h-1})| \leq \varepsilon \quad (13)$$

3. Genetic Algorithm Design

The process of genetic algorithm is to encode the parameters of the problem into chromosomes. Then, the information of different chromosomes in the population is exchanged by generating the initial population and iterating continuously to complete genetic operations such as selection, crossover and mutation. When the algorithm meets the convergence condition or reaches the iteration number, the optimal chromosome is output. The main process of algorithm design includes five steps.

(1) Coding

Think of the time segment of the study period as a gene on the chromosome. Each gene has two forms of expression: 0 or 1. 1 means a bus will be sent at the end of the time segment, and 0 means no bus will be sent.

(2) Generating initial species

A certain number of initial individuals are randomly generated, that is, the set of chromosomes representing the departure time, forming an initial population. Each chromosome in the population represents a feasible scheme during the study period, and the encoding method of departure time adopts the binary encoding.

(3) Fitness function

Fitness function is used to measure the adaptability of organisms to the living environment. The fitness function of this model is expressed by the waiting time of passengers. The shorter the total waiting time of passengers, the better the fitness

(4) Selection

The selection simulates the competition rule of "survival of the fittest", making the probability of individuals with high

fitness to inherit to the next generation higher. In this paper, the tournament selection method is adopted. The best individual is directly selected from each generation to enter the subpopulation. Without fitness conversion, the minimum objective function is directly used as the fitness function.

(5) Crossover and variation

The crossover operator is the most effective link of evolutionary algorithm and the main method to generate new individuals. It randomly pairs the chromosomes in the population, and the paired chromosomes exchange some of their genes with each other in a certain way, thus forming two new individuals. Variation operation is to replace the gene value of some loci in the coding sequence of a single chromosome with other alleles of that locus to form a new individual. When new individuals are produced, crossover plays a major role, while variation plays an auxiliary role.

4. Case Analysis

4.1. Scenario description

The research bus line is the No.472 bus line in Chongqing, which starts from Shapingba Railway Station, passes through Shapingba District, Jiulongpo District and Dadukou District to Xinrui District. And the study period include off-peak hour(15:00-16:00) and peak hour(17:00-18:00).

There are no railway trains arriving during the peak hours, and three trains during the peak hour, at 16:58, 17:27 and 17:44, respectively. The departure of No.472 bus in the two study periods is shown in the Table2.

Table 2. Bus departure time

Off-peak hour		Peak hour	
Number	Departure time	Number	Departure time
1	15:10:00	1	17:15:00
1	15:25:00	2	17:30:00
2	15:40:00	3	17:45:00
3	15:55:00	4	18:00:00

Both 15:00-16:00 and 17:00-18:00 are divided into 120 time segments, and the time sequence number is 1-120. Each time segment represents 30S. According to the survey, the number of passengers arriving at the platform by bus 472 varies with time as shown in the Figure1-2.

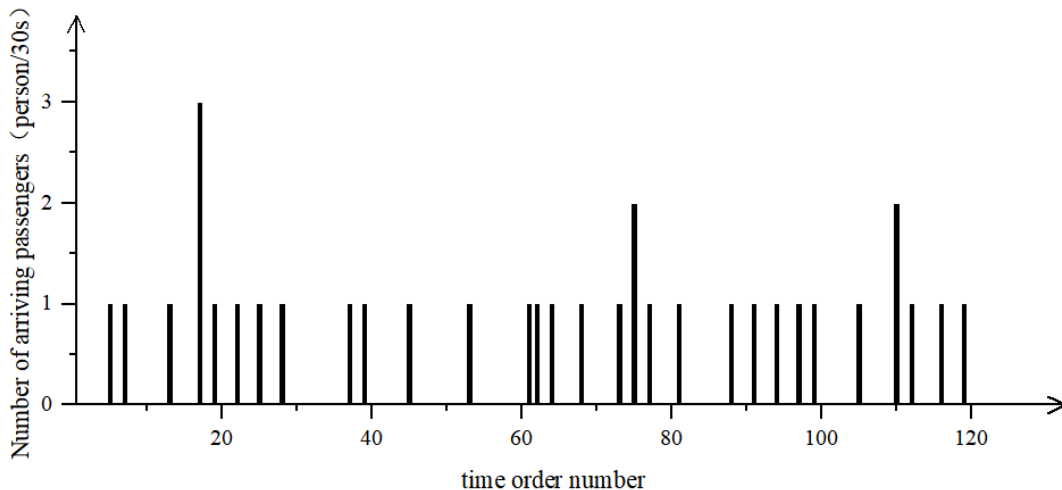


Figure 1. Distribution law of passenger flow from 15:00 to 16:00

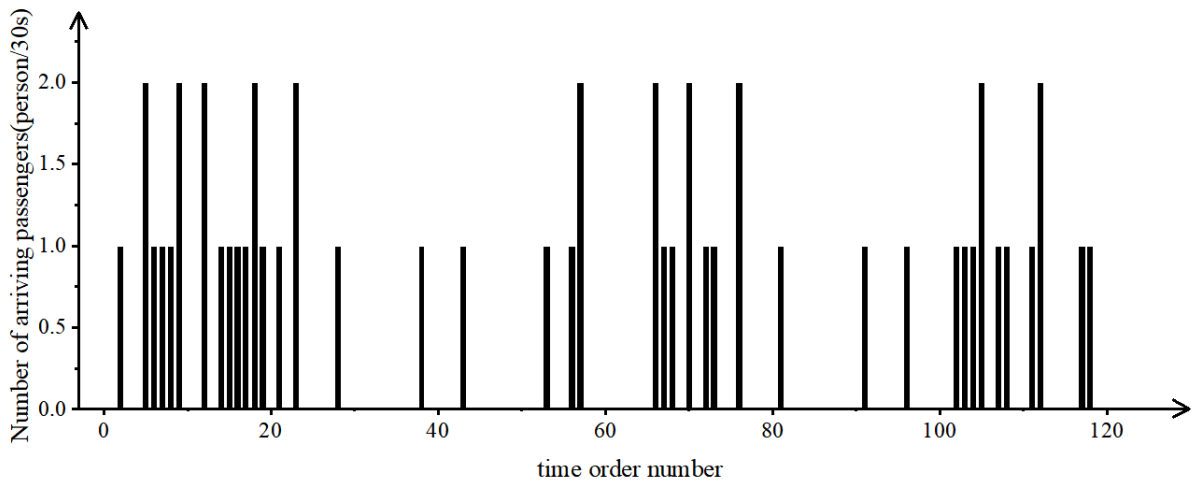


Figure 2. Distribution law of passenger flow from 17:00 to 18:00

4.2. Result analysis

According to the data of the survey and the existing

literature, the parameters of the bus and the parameters of the genetic algorithm are set respectively in Table3-4.

Table3. Bus parameters

Variable	Meaning	Value
E	Rated passenger capacity of bus	60
∂	Reduction factor of vehicle rated capacity	0.6
θ_{max}	Maximum full load rate of vehicle	1
θ_{min}	Minimum full load rate of vehicle	0.2
μ_{max}	Maximum departure time interval of vehicles	20
μ_{min}	Minimum departure time interval of vehicles	10

Table4. Genetic algorithm parameters

Variable	Meaning	Value
<i>option.numAgent</i>	Population size	50
<i>option.maxIteration</i>	Maximum Iterations	500
<i>option.p1_GA</i>	Probability of cross	0.8
<i>option.p2_GA</i>	Probability of variation	0.05

This paper compares and analyzes the difference between the bus equal time interval model and the bus uneven time interval model from two aspects of keeping the bus departure frequency unchanged and changing. According to the timetable optimization model, use Matlab to code and solve, and reach the following conclusions:

(1) Departure frequency remains unchanged

The optimization algorithm in the off-peak hour and peak hour reaches the minimum of the total waiting time of

passengers at 78 iterations and 174 iterations respectively. The departure time and the total waiting time of passengers before and after the optimization are shown in the Table5. After the algorithm optimization, the total waiting time during the off-peak period was reduced from 259.5 minutes to 217.5 minutes, with a reduction rate of 16.2%. The waiting time in peak hours was reduced from 396.5 minutes to 279 minutes, with a reduction rate of 29.6%.

Table 5. Comparison of total waiting time at different departure times

Scenario	time				the total waiting time of passengers (min)
	Bus 1	Bus 2	Bus 3	Bus 4	
Original departure time in off-peak hour	15:00:00	15:15:00	15:30:00	15:45:00	259.5
Optimized departure time in off-peak hour	14:50:00	15:01:00	15:20:00	15:37:30	217.5
Original departure time in peak hour	17:15:00	17:30:00	17:45:00	18:00:00	396.5
Optimized departure time in peak hour	17:09:30	17:29:00	17:41:00	17:54:30	279

Table 6. Departure time under different number of departures

Number of bus departures	3		4		5		6	
	Before	After	Before	After	Before	After	Before	After
Departure time	17:20:00	17:11:00	17:15:00	17:05:30	17:12:00	17:09:00	17:10:00	17:09:30
	17:40:00	17:29:00	17:30:00	17:22:00	17:24:00	17:21:00	17:20:00	17:14:30
	18:00:00	17:41:00	17:45:00	17:39:00	17:36:00	17:33:30	17:30:00	17:27:00
	—	—	18:00:00	17:58:00	17:48:00	17:38:30	17:40:00	17:37:00
	—	—	—	—	18:00:00	17:57:00	17:50:00	17:38:30
Waiting time	506.5	316.5	396.5	279	306.5	249	256.5	206
Time fluctuation	90		117.5		57.5		50.5	
Optimization range	37.5%		29.6%		18.8%		19.7%	

Table 7. Comparison of total waiting time at different departure times

Number of bus departures	Total waiting time of passengers (μ)	Utilization rate of transport capacity	Difference with ideal utilization degree(ν)	Comprehensive target value		
				$\mu = 0.3$ $\nu = 0.7$	$\mu = 0.5$ $\nu = 0.5$	$\mu = 0.7$ $\nu = 0.5$
3	316.5	0.481	0.379	0.452	0.608	0.765
4	279	0.361	0.499	0.898	0.330	0.762
5	249	0.289	0.571	0.537	0.495	0.452
6	206	0.241	0.619	0.7	0.5	0.3

(2) Departure frequency changed

Take the peak hours with better optimization effect as an example, analyze the difference between the equal time interval departure mode and the non-equal time interval departure mode under different departure frequencies under the constraints. According to the parameters set in the model, the departure time interval of No. 472 bus in the study period is 10-20 minutes, so the number of bus departures in an hour can be 3-6. Table 6 reflects the passenger time departure time and waiting time calculated by the genetic algorithm and the departure time with equal time interval under different departure numbers. When the number of departures is 3, the total waiting time is reduced by 90 minutes, and the optimization range is 37.5%; When the number of departures is 4, the total waiting time is reduced by 117.5 minutes, and the optimization range is 29.6%; When the number of departures is 5, the total waiting time is reduced by 57.5 minutes, and the optimization range is 18.8%; When the number of departures is 6, the total waiting time is reduced by 50.5 minutes, and the optimization range is 19.7%.

Analyze different departure frequencies and compare the

comprehensive target values of the total waiting time of passengers and the utilization rate of transport capacity under different weights. The weight of passenger waiting time is μ and the weight of difference with ideal utilization degree(0.86) is ν . The minimum value of the target function is better, as shown in the Table 7. When the number of departures is fewer, the total waiting time of passengers is longer, and at the mean time, the utilization rate of transport capacity is higher. When the number of departures increases, the total waiting time of passengers is shorter, but the utilization rate of transport capacity is lower. The Figure3 shows the relationship between the total waiting time of passengers with different departure numbers and the utilization rate of transport capacity. If the public transport operation enterprises only value the interests of passengers, the scheme with the number of departures of 6 is selected; If the public transport operation enterprises only focus on the interests of the enterprises, choose the scheme with the number of departures of 3; If the interests of the two are equally important, you can choose the scheme with a departure number of 4.

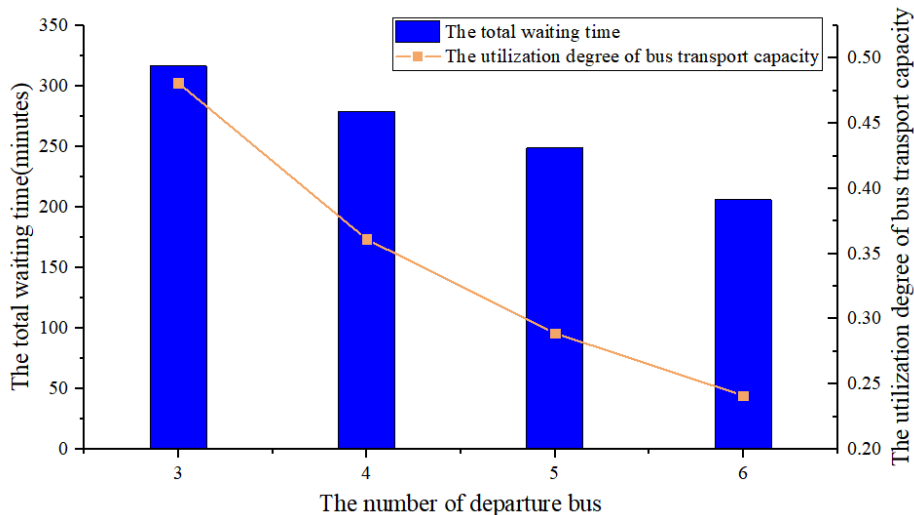


Figure 3. Relationship between total waiting time of passengers and utilization rate of bus transport capacity

5. Conclusion

This paper proposes a bus timetable optimization model, which uses the actual survey data to optimize the existing timetable. By comparing and analyzing the results, it can be confirmed that the use of the uneven departure time interval pattern table is more suitable for bus stops with time-varying passenger flow characteristics. The timetable optimization model provides an idea for the public transport operation enterprises to determine the dynamic departure timetable to a certain extent. However, this method only considers the passenger flow of the departure station, not the passenger flow of the whole line. Therefore, this method is only suitable for the case of large passenger flow of the departure station, and has limitations in solving the optimization of the general line schedule.

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