

Train Timetable Optimization for Metro Lines Connecting to Airport

Jinwei Lu ^a, Yun Bai ^b and Jiajie Li ^c

MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology,
Beijing Jiaotong University, Beijing 100044, China

^a16120860@bjtu.edu.cn, ^byunbai@bjtu.edu.cn, ^c15120834@bjtu.edu.cn

Abstract. Due to the advantages of huge capacity and reliable service, metro plays an important role in transporting airport passengers. It is known that train timetable has a direct impact on passenger waiting time which affects the service level of airport express. This paper first analyzes the behavior characteristics of passengers arriving at the airport express, and obtains the distribution of passenger flow throughout the day. Afterward, an optimization model on train timetable is established to minimize the total passenger waiting time at stations in airport express. GA algorithm is adopted to solve the proposed model. The results on Beijing metro airport express show that the proposed model reduces the passenger waiting time over 10%, compared to the fixed-headway timetable and the actual timetable.

Keywords: Airport express, Timetable optimization, Passenger waiting time, Genetic algorithm.

1. Introduction

Because of large capacity and reliable service, metro plays a crucial part in transporting airport passengers. The metro lines connecting to airport can be divided into sharing type and dedicated type [1]. Sharing type focuses on urban traffic and airport traffic. The dedicated type, also called airport express, is exclusively used by air passengers, escorts and airport staff. Considering the characteristics of airport passenger flow of the two types, this paper mainly analyzes the airport express.

Research on airport express mainly focused on two aspects, one is the passengers' characteristic, the other is to improve the service level of airport express. In the first aspect, Bianco L. et al. [2] indicated that the time of passengers arrived in advance is mainly related to passengers' estimation of the travel time to the airport. Considering different time, cost and comfort needs of passengers, Nie.et al. [3] established the generalized time function to forecast the passenger flow. Xing.et al. [4] mainly focused on the effect of aircraft's departure time on passengers. In the other aspect, airport express timetable design is an important evaluation index for passengers' service level [5]. In the early stage, the most common way to optimize the timetable based on passenger flow is the equally spaced operation diagram of time segment [6]. Then, smart card and AFC system enabled us to obtain detailed travel data. And timetable optimization under dynamic passenger flow thrived [7].

For daily commuter routes, the timetable optimized based on AFC historical data can well serve ordinary passengers of commuter lines. However, for the passenger flow of airport station, the applicability is not good. Therefore, this paper decides to depict the air passengers by describing the impact of deadline limit on passengers, and establishes a mathematical model as well as GA algorithm to optimize the airport express timetable.

2. Analysis of Departing Passenger Flow

Arriving at airport before the departure time is a rigid requirement for passengers, and most passengers who chose to take the plane will book tickets online in advance. Therefore, according to the departure time of a flight, the time of going to the airport can be predicted to some extent. According to the practical statistical data, Bianco L [2] indicated that the peak time of passengers arrived in advance is mainly related to passengers' estimation of the travel time to the airport. The longer travel time estimated the longer time arrived in advance. And passengers arrived at the airport between 15 minutes and 2 hours before the flight leaves.

Passenger flow is determined by the flight passengers' number and the proportion of passengers who chose to take the airport express. Since the air passenger needs to arrive at the airport before the departure time of the passenger's flight, which is an event with a deadline. And according to the literature [4], the passengers flow can be described by the heavy tail distribution. What's more, since the air passengers will pay a high price if they are late, this paper assumes that passengers will plan their travel in advance. And because of the difference in walking speed, it is assumed that passengers' walking speed follow the normal distribution. The passenger flow of each station in the airport express can be described by the following model:

$$A(t) = \sum_{t_0=0}^{T_0} (A_{t_0}(t) - A_{t_0}(t-1)) * Q_{t_0} \quad (1)$$

$$A_{t_0}(t) = a - \left[a * \operatorname{erf} \left[\frac{\ln(t_0-t')-u}{\partial\sqrt{2}} \right] \right] \quad (2)$$

$$\partial = kt_0^3 - k_1t_0^2 + k_2t_0 - k_3 \quad (3)$$

$$u = w_1t_0^4 - w_2t_0^3 + w_3t_0^2 - w_4t_0 - w_5 \quad (4)$$

$$A^m(t) = \left(\frac{u_m * A(t)}{M'} \right) * \left[\left(\frac{m-\bar{m}}{\Sigma m} \right) - \left(\frac{t_m^j - \bar{t}_m^j}{\Sigma t_m^j} \right) + 1 \right] \quad (5)$$

t_0 : departure time of the flight; t' :time before the flight takes off; Q_{t_0} :number of people in airport express at t ; \bar{m} :the average station number; \bar{t}_m^j : average travel time of each station; u_m : the conversion station number in entire network which can transfer 1 or 2 times to airport express through m station; M' : total number of network stations.

Passengers going to the airport usually transfer by the subway or other means of transportation to the metro stations. Therefore, it is assumed that the arrival time of passengers is related to the arrival time of other transfer lines. The arrival time of passengers can be revise through the timetable of other lines, which can be described by the following formula:

$$A_m(t_m) = \sum_t^m A_m(t) \quad (6)$$

3. Timetable Optimization Model and Solution Method

The main objective of this paper is to improve the passenger service level, taking the minimum passenger waiting time as the optimization objective and the departure time of each train at each station as the decision variables, the model is as follows:

$$\min f = \min \sum_{m=1}^{M-1} \sum_{i=1}^N \sum_{t=F_{i-1}^m+1}^{F_i^m} (F_i^m - t) A_m(t_m) \quad (7)$$

$$F_i^m - F_{i-1}^m \geq d_{\min}; F_i^m - F_{i-1}^m \leq d_{\max} \quad (8)$$

$$F_i^m - F_i^{m-1} \geq a_{\min}^{m,m-1}; F_i^m - F_i^{m-1} \leq a_{\max}^{m,m-1} \quad (9)$$

F_i^m :the departure time of i train at station m; $d_{\min}, (d_{\max})$:min (max) departure interval between front and rear vehicles; $a_{\min}, (a_{\max})$:the min (max) stop time between front and rear stations; i:train

number; m : station number; N : total train numbers; M : maximum station number; $A_m(t_m)$: number of passengers at time t_m in m station; t_m : schedule of connecting lines at station m .

The above model is simple, but the solution space is large. Therefore, combined with the characteristics of this problem, an improved genetic algorithm is adopted in this paper. In the encoding process, as the ASCII encoding range is insufficient, this paper improves the ASCII encoding. Each gene location corresponds to the departure time of the train at the hub station in the study period, in other words, Chromosome length is the number of train departments during the study period. Therefore, during initialization, each gene has been set as the initial solution within a reasonable range, that is, the feasible solution. Compared with the traditional coding method, when calculating the initial solution, scopes of the program is greatly reduced and the computational efficiency of the program is improved.

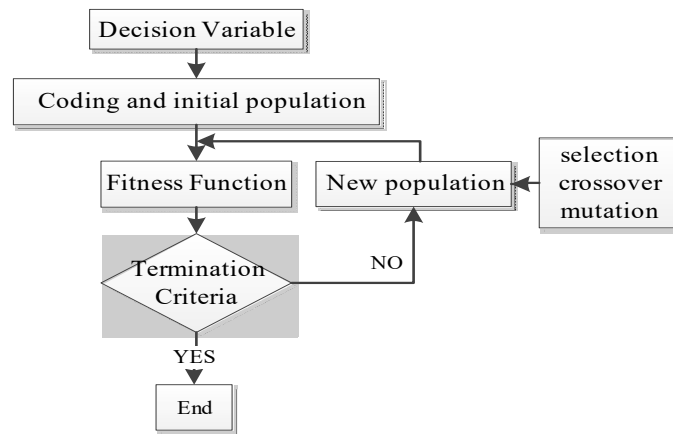


Fig. 1 The genetic algorithm framework

4. Case Study

This paper selects Beijing airport express for case analysis, and compared with the actual timetable. The passenger flow data are the flight timetable and airport express timetable of capital airport on a certain day in 2018.

Before optimizing the initial timetable, it is necessary to verify all-day passenger flow. The transfer stations of the airport express in this case are Dongzhimen and Sanyuanqiao stations. The line that can be transferred through Dongzhimen is line 13 and line 2. What's more, the line that can be transferred through Sanyuanqiao to the airport express is line 10. The relevant parameter Settings of this case are shown in table 2. The verification results are shown in figure 2 and 3 below, whose average error is within 15%.

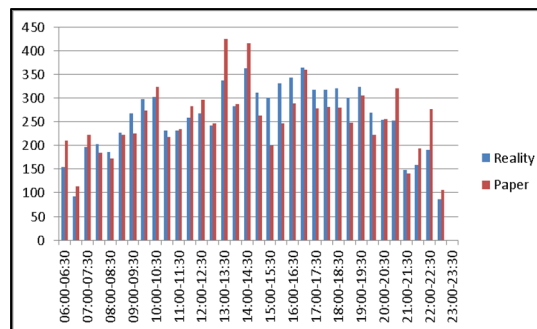


Fig. 2 Dongzhimen passenger flow validation

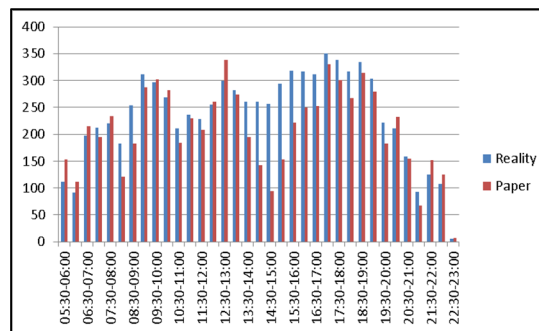


Fig. 3 Sanyuanqiao passenger flow validation

Table 1. Verification of passenger flow model

Station	Average error	Passengers number		Error
		Reality	Paper	
Dongzhimen	9.70%	8721	8761	3%
Sanyuanqiao	11.30%	8249	8275	1.2%

Table 2. Parameters

period	population size	iterations	trains
16:00-17:00	300	1000	23

Table 3. Optimization Results

comparison	Passengers' waiting time		Optimization
	Before	After	
equal-headway	14860	13168	3%
reality	14797		1.2%

To verify the model, this case selected the time period from 16:00 to 17:00. Results show that the total waiting time of passengers can be effectively reduced compared with the parallel train diagram and the actual situation. The comparison and optimization results are 11.39% and 11.01% respectively, which verify the effectiveness of the model and algorithm in this paper.

5. Conclusion

This paper first analyzes the passenger flow on the airport express, and uses heavy tail distribution to describe the passenger flow. Then, the rule of passenger flow proposed in this paper is verified by actual data, whose average error is within 15%. Besides, this paper also concludes that under certain conditions, the closer to the departure time the more people will arrive at the airport. A departure time optimization model aiming at the minimum total passengers' waiting time is established, and the improved genetic algorithm is used to solve the model. The case shows that the proposed model can reduce the total waiting time of passengers over 10% compared with equal-headway timetable and actual timetable.

The timetable optimization problem of one-way airport express was studied, and a solution to the problem of optimizing the train timetable to the airport direction was proposed. However, due to the limitation of time, this paper did not consider the optimization of train timetables in both directions. The next step is to consider the optimization of train timetables in the other direction, so as to study the optimization of bi-direction timetables with different passenger flow in both directions.

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