WEP Warwick Evans Publishing

Transactions on Engineering and Technology Research
ISSN: 2960-1797, eISSN: 2960-2246 | Volume 1
AMMEE 2023

Study on Optimization of Departure Interval of Pure Electric Bus in Airport Area

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Abstract. As a zero-emission, pollution-free and pure green public transport, pure electric bus has received more and more attention from society and enterprises. At present, most urban public transport lines in China have basically realized pure electric bus. With the popularization of pure electric bus, the operation and management of pure electric bus in specific areas are required. How to reasonably set the departure time interval, configure the number of vehicles and reduce the charging cost while meeting the travel needs of passengers and the enterprise cost as low as possible has become a hot issue in the research of pure electric bus operation management. In this paper, from the perspective of system cost, a pure electric bus departure interval optimization model is constructed, which considers the comprehensive cost of passengers and enterprises to be minimum. The load factor constraint and departure interval are considered as the main constraints, and the optimal departure interval is obtained.

Keywords: Airport area; pure electric; departure interval.

1. Introduction

All Compared with conventional bus routes, airport routes have fewer stations and longer routes, which have a greater impact on the driving range of pure electric bus vehicles. Due to the limitations of charging time and charging equipment, the departure interval and schedule formulation of pure electric bus schedules cannot be formulated according to conventional buses. In the future, to continue to promote the application of new energy vehicles in the field of public transport and achieve the scale of pure electric public transport vehicles, there must be a reasonable driving plan as a support. In view of the uncertainty and irregularity of the pure electric bus in the area where the airport is located, there are not many researches on the optimization of the pure electric bus schedule for specific areas in China. At present, the rapid promotion of pure electric bus in various fields, it is not completely appropriate to apply the optimization method of the pure electric bus schedule to the pure electric bus in specific scenarios. Therefore, it is of practical significance to study the optimization of pure electric bus schedule in specific scenarios.

Zhao[1] takes large-scale public transport network as the research object and establishes an optimization model of comprehensive departure interval, public transport network and timetable. Dong et al. [2] established a bus schedule optimization model considering the minimum passenger waiting time and maximum benefit as optimization objectives. Rojas et al. [3] studied that under the background of regional public transportation network, the highest passenger transfer rate and the lowest vehicle cost were the optimization objectives, and established a multi-objective optimization model to effectively solve the problem of timetable optimization and vehicle scheduling. Ceder[4] took the problem of bus schedule preparation as a multi-objective optimization problem, and built a bus schedule optimization model by assuming that passenger arrival follows uniform distribution and half of departure interval time is passenger waiting time.

2. Analysis of Departure Interval of Pure Electric Bus

2.1 Pure Vehicle Performance

2.1.1 Charging mode

The vehicle slow charging uses relatively constant and small current to charge the vehicle, which has little damage to the vehicle battery, but the charging time is slow; The vehicle fast charge uses high current to charge the vehicle, which has great damage to the vehicle battery, and can be filled in 1 hour; Battery replacement mode, short operation time, free charging time. The advantages and disadvantages of the three charging methods are shown in Table 1.

Table 1 Comparison of Charging Modes

Charging mode	Full vehicle slow charge	Full vehicle fast charge	Replace the battery
Damage to battery	lesser	larger	lesser
Battery life impact	longer	shorter	longer
Charge/change time	6-8hours	0.5-1hour	15 minutes
Charging cost	lower	higher	lower，be charged in non-peak demand
Facility cost	lower	higher	lower

2.1.2 Driving range

Driving range refers to the maximum distance that a vehicle can travel continuously when its battery is fully charged. The driving range constraint of pure electric vehicles is an important constraint condition for the optimization of pure electric bus schedule. The ear-driving range of electric vehicles is generally calculated as follows:

$$S=1000C_0D_0\omega/E_0m \tag{1}$$

In the formula, S represents the mileage (km) of pure electric bus; C0 indicates the amount of power stored in the battery; D0 indicates the battery discharge depth; E0 indicates the specific energy consumption of the electric vehicle; m stands for pure electric vehicle mass (kg).

2.2 Battery Performance

The performance index of electric bus power battery determines the vehicle characteristics of pure electric bus. Battery performance indicators mainly include battery capacity, charge state, and discharge depth.

The discharge depth is the ratio between the used power and the rated power; The state of charge is the ratio between the remaining power and the rated power; Battery capacity The battery capacity currently used on the market is generally 200-350kWh[5].

3. Model Building

Considering the charging cost and operating cost of the enterprise, and aiming at the minimum comprehensive cost of the enterprise and passengers, an optimization model of the departure interval of pure electric buses was constructed under the condition of satisfying the full load rate, driving distance and the maximum and minimum departure interval.

As the input of the pure electric bus timetable optimization model, the research problem is how to set the departure interval reasonably so as to minimize the comprehensive cost of passengers and enterprises.

3.1 Model Assumption

In the optimization model of departure interval in this paper, it is assumed that the charging vehicle can be charged after entering the charging field. All pure electric vehicles use the same model; All vehicles on the line run in the order of departure.

3.2 Optimization Objective

Aiming at the minimum comprehensive total cost of passengers and enterprises, the model is established as follows:

$$M=\min(\alpha_1 M_1+\alpha_2 M_2) \tag{2}$$

α_1 and α_2 are the weights of the total cost of passenger travel and the cost of enterprise, $\omega_1+\omega_2=1$.

$$M_1=w_1+w_2+w_3 \tag{3}$$

$$w_1=c_1\sum_i^n(n_i t_0+\varphi\sigma_i h) \tag{4}$$

$$w_2=c_2\sum_i^n(\epsilon d_{i,i+1}v_{i,i+1}) \tag{5}$$

$$w_3=c_3\theta(p_i-p_0)l \tag{6}$$

$$M_2=C_0+u_0 lf \tag{7}$$

The total passenger travel cost is the sum of transfer time cost w1, ride time cost w2 and congestion cost w3, where c represents the cost coefficient, φ is the penalty coefficient, ni is the number of people waiting for buses at station i, h is the decision variable, and θ is the congestion degree. Vehicle fixed cost C0 is related to vehicle maintenance cost, depreciation cost and maintenance cost. u0lf is the cost of vehicle electricity and is related to the frequency of departure.

3.3 Constraint Condition

The model should meet the following constraints:

$$\sum_i^n ni\,/C_{ax}f \tag{8}$$

$$n_{in}\le 120lf/v\le n_{ax} \tag{9}$$

$$h_{in}\le \mathrm{h}\le h_{ax} \tag{10}$$

Where, formula (8) is the constraint of vehicle load factor, which is related to bus frequency, vehicle capacity Cax and passenger number; Formula (9) is the scale constraint of public transport vehicles, which is related to departure frequency, speed and line length; Formula (10) is the time interval constraint, and the departure interval meets the maximum and minimum departure time interval.

3.4 Example Analysis

In this paper, the background of the example is Shunyi area of Beijing, and the route is selected as a pure electric bus line in Shunyi area. The total length of the line is 15km, with a total of 16 stations, station 8 is a transfer station, and the one-way running time of the whole line is 40min. The line runs from 6:30-18:30. 6:30-18:30 is divided into five periods, as shown in Table 2.

Table 2 6:30-18:30 Time Division

Serial number	Period division	Duration (h)
1	6:30-8:30	2
2	8:30-11:30	3
3	11:30-14:30	3
4	14:30-16:30	2
5	16:30-18:30	2

Route design speed and station spacing, as well as planned travel time are shown in Fig.1.

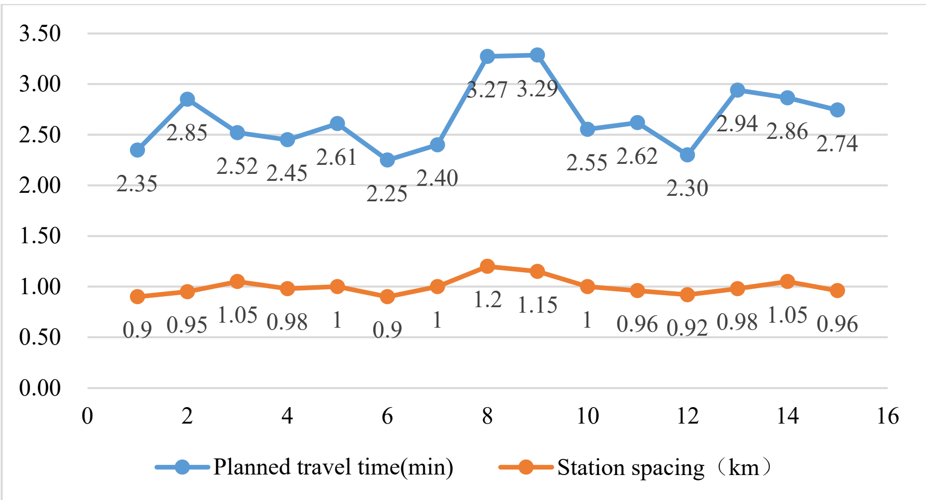

Fig. 1 The relationship diagram of each station and station spacing and planned travel time

Taking 2022 as an example, the relevant indicators of the line are: the passenger time value of 0.216 yuan /min, the rated passenger number of 40 people, the maximum and minimum load rate of 1.2 and 1.6, the vehicle purchase cost of 1.1 million yuan, the maximum and minimum departure interval of 10min and 60min, and the penalty coefficient of 0.5. The passenger flow of each period is shown in Fig. 2.

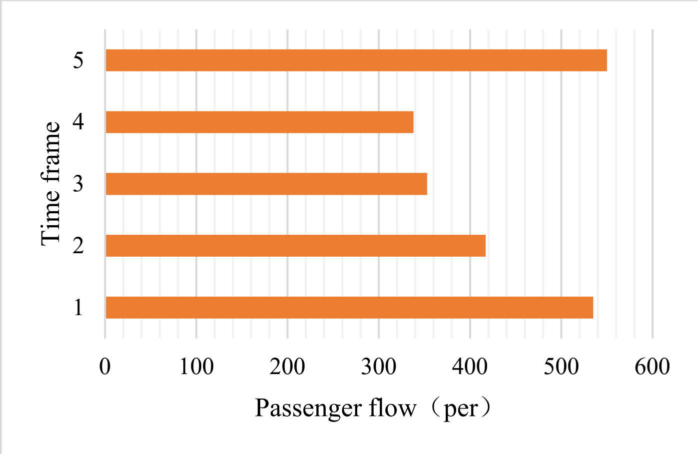

Fig. 2 Passenger flow during each period

The model belongs to nonlinear programming model, and LINGO software is used to solve it. The optimal solution is shown in Fig. 3 (a), and the departure interval before optimization is shown in Fig. 3 (b).

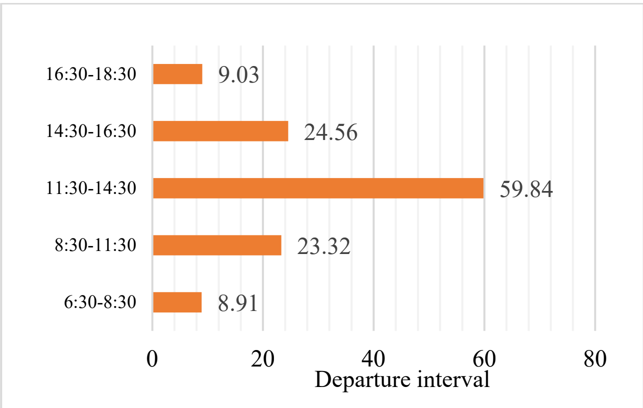

Fig. 3(a) Optimized line departure interval

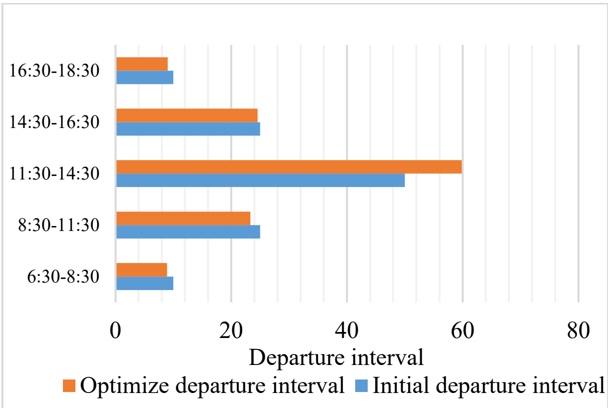

Fig. 3(b) Optimize the comparison of before and after departure intervals

Compared with before optimization, the combined cost of enterprise and passenger decreased by 2.02%.

4. Summary

On the basis of the existing research results, this paper makes an in-depth study of the pure electric bus timetable optimization method. Through the comparison and analysis of vehicle fast charge, vehicle slow charge and battery replacement three charging modes, this paper adopts the vehicle fast charge mode; By analyzing the running characteristics of the vehicle and the performance of the battery, the running characteristics of the pure electric bus are obtained. Considering passenger cost and enterprise operating cost, an optimization model of pure electric bus departure interval is established. The model takes into account the cost of passengers' waiting time, ride cost, congestion cost, and enterprise operation cost, and obtains the optimal departure interval. Taking a bus line in the airport area as an example, the optimal solution is obtained by optimization algorithm, and the comprehensive cost is reduced by 2.02% compared with that before optimization.

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