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Optimal Bus Scheduling Model based on Multi-objective Programming

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Abstract

The optimal scheduling of buses is not only a matter of people's well-being, but also of great significance to reducing my country's fiscal expenditure. This paper first establishes the net income evaluation function, and then obtains the threshold of human flow, and gives the definition of peak and peak. In addition, the two indicators of "relief of urban traffic congestion" and "public satisfaction" are comprehensively considered, and Multi-objective planning is carried out, and finally the optimal scheduling scheme of "transition period" under different conditions is obtained.

Keywords

Net Income Evaluation Model; Multiobjective Programming; SARIMA Model.

1. Introduction

With the upgrading of national consumption capacity, the lagging urban public transportation system has been unable to meet people's current needs. The bus scheduling optimization problem has always been the focus of research by scholars at home and abroad. Ma Weihong proposed that for the optimization of combined scheduling of full-distance trains and large-station express trains, it is necessary to excavate the essence and conduct clustering research on the stations with influencing factors such as station passenger flow, passenger flow structure, travel distance, and travel distance structure [1]. Sun Le pointed out that the waste of human resources and station resources in the traditional single-line bus scheduling method, and how to use the Internet of Things to put real-time intelligent public transportation into use is something that people need to consider [2]. Xiao Huaqiang proposed to use intelligent algorithms such as particle swarm algorithm and genetic algorithm to realize the corresponding prediction of bus time and people flow [3].

2. Net Income Evaluation Model

2.1. Model Establishment and Solution

Assuming that under normal circumstances, buses are dispatched every 15 minutes, a total of 8 buses are dispatched in a 2-hour period.

Assuming is that under normal circumstances, within 2 hours, x is the number of buses put into dispatch, and β is the growth rate of the number of passengers.

λ_1 is from the off-peak period to the peak period, each additional vehicle is dispatched, and the coefficient of influence on the growth rate of the number of passengers. λ_2 is from the peak period to the off-peak period, each additional vehicle is dispatched, and the increase rate of the number of passengers is affected by Influence coefficient.

Then the relationship between the growth rate of the number of passengers and the time can be obtained as shown below:

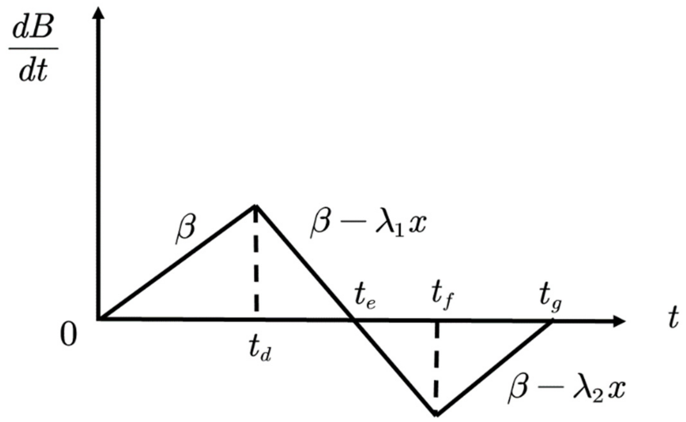

Fig 1. Graph of the fluctuation of growth rate over time

As can be seen from the above figure, t_d is the moment when the number of passengers increases the fastest, t is the moment when the number of passengers begins to decline, t_f is the moment when the number of passengers decreases the fastest, and t_g is the moment when the "transition period" ends, that is, the number of passengers begins to fluctuate. calm moments.

Let C_1 be the one-ticket fare for a single passenger, two RMB/person.

First, establish a model of net income from the low peak period to the peak period. Set $B(t)$ as passenger flow, from the figure above, when $t_d < t < t_e$, $B(t)$ is the area surrounded by the graph line and t.

Hence, the income function is

$$\begin{aligned} f &= C_1 B(t) \\ &= \frac{1}{2}\beta C_1 t_d^2 + C_1(t-t_d)\frac{\beta t_d + [-(\beta-\lambda_1 x)(t-t_e)]}{2} \end{aligned} \tag{1}$$

The cost function is

$$\begin{aligned} g &= hx(t) \\ &= C_2 x + C_3\frac{\beta t_d + (\beta-\lambda_1 x)(t-t_e)}{\beta-\lambda_1 x} \end{aligned} \tag{2}$$

From "net income = income – cost", net income can be gotten as $M = f - g$ $(M \text{ is related to the value of } \beta、C_1、t、t_d、\lambda_1、t_e、x)$.

Let β、C_1、t、t_d、λ_1、t_e is exogenous. by checking out the relevant literature[4], it can be found that $\beta = 50$, $C_1 = 2$, $t = 6$, $t_d = 5.5$, that is, at 5:30, the passenger growth rate reaches the fastest. At this point, take x as the maximum value when it is at the peak for a long time, which is 12 buses depart in 2 hours. (at this time, the influence of the number of buses put into dispatch on the growth rate of the number of passengers is at an average level. Substitute x into the net income equation, and the obtained threshold conforms to the daily law, that is, if the threshold is reasonable, it can be inferred that it meets the requirements).At this time, substitute the value of x、β、t_e、t_d into $\beta t_d = (\beta - \lambda_1 x)(t_e - t_d)$, it can be concluded that $\lambda_1 = -7$.

Once again, when $t_e = 7.5$ (at 7:30), the number of passengers starts to drop. by separating the constants from equation (2), we can get $C_2 = 10$, $C_3 = 5$. Because $C_2 x$ depends only on the number of buses put into dispatch, representing a fixed cost in bus operation, such as car depreciation, parking lot rental fees, bus driver wages, insurance premiums, etc. $C_3 \frac{\beta t_d + (\beta - \lambda_1 x)(t - t_e)}{\beta - \lambda_1 x}$ not only depends on the number of buses put into dispatch, but also depends on the bus running time, representing the variable costs in bus operation, such as bus fuel consumption, repair fee, maintenance fee, etc. After determining the values of all exogenous variables, it can be concluded that M is only related to x, so net income is

$$M(x) = \frac{1}{2}\beta C_1 t_d^2 - C_1(t - t_f)\frac{\beta t_d + (\beta - \lambda_2 x)(t_g - t)}{2} - C_2 x - C_3 \frac{\beta t_d + (\beta - \lambda_2 x)(t_g - t)}{\beta - \lambda_2 x} \tag{3}$$

It can be seen from the calculation that when the number of buses put into dispatch is 6, the net income is the largest, that is, a total of 14 buses are dispatched within 2 hours, and one bus is dispatched every 9 minutes, and the net income at this time is 834 yuan/hour.

In the same way, when entering the low peak period from the peak period, the corresponding net income model is established.

The income function is

$$\begin{aligned} f &= C_1 B(t) \\ &= \frac{1}{2}\beta C_1 t_d^2 - C_1(t - t_f)\frac{\beta t_d + (\beta - \lambda_2 x)(t_g - t)}{2} \end{aligned} \tag{4}$$

The cost function is

$$\begin{aligned} g &= hx(t) \\ &= C_2 x + C_3 \Delta t \\ &= C_2 x + C_3 \frac{\beta t_d - (\beta - \lambda_2 x)(t_g - t)}{\beta - \lambda_2 x} \end{aligned} \tag{5}$$

Similarly, at this time we take $\beta = 50$, $C_1 = 2$, $t = 11$, $t_g = 12$, $\lambda_2 = 9$, $t_f = 9.5$, $C_2 = 10$, $C_3 = 5$, so, it can be gotten

$$M(x) = \frac{1}{2}\beta C_1 t_d^2 - C_1(t - t_f)\frac{\beta t_d + (\beta - \lambda_2 x)(t_g - t)}{2} - C_2 x - C_3 \frac{\beta t_d + (\beta - \lambda_2 x)(t_g - t)}{\beta - \lambda_2 x} \tag{6}$$

It can be seen from the calculation that when the number of buses put into dispatch is -3, the net income is the largest, that is, a total of 5 buses are dispatched within 2 hours, and one bus is dispatched every 24 minutes, and the net income at this time is 697.5 yuan/hour.

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Observing the constitutive rules of equations (3) and (6), combined with the meaning represented by the area of image 1, it can be obtained, and the threshold should be taken $\frac{1}{2}\beta C_1 t_d^2$ do a trial calculation.

2.2. Conclusion of the Model

Since the net income is not only related to the flow of people, but also to the number of buses put into dispatch, so in the transition period between peak and low peak, if no bus dispatch is carried out, the net income is:

During the transition from the peak period to the low-peak period, when the number of buses put into dispatch is 0, that is, during the peak period, the net income per hour is 553 yuan;

In the conversion process from the low-peak period to the peak period, when the number of buses put into dispatch is 0, that is, during the low-peak period, the net income per hour is 177 yuan.

From the above model, it can be concluded that the nodes that define the passenger flow of "peak period" and "flat peak period" are the number of $\frac{1}{2}\beta t_a^2 = \frac{1}{2}\times 50\times 5.5^2 \approx 756$ people, the net income is 217.5 yuan per hour, which is the threshold is 217.5 yuan/hour, so the "peak period" is the time period when the difference between the total operating revenue and the total operating cost is not less than 217.5 yuan/hour.

In order to test the rationality of the threshold, we searched a group of Beijing Bus Line 2 (Haihutun→Muxiyuan Bridge North→Shazikou→Yongdingmennei→Tiantan West Gate→ Dashilan→Tiananmen Square East→Tiananmen East→Donghua). Gate→Beijing Obstetrics and Gynecology Hospital→Shangshaan intersection south→Kuanjie intersection south) The real data of the passenger flow on a certain day under normal circumstances [5].

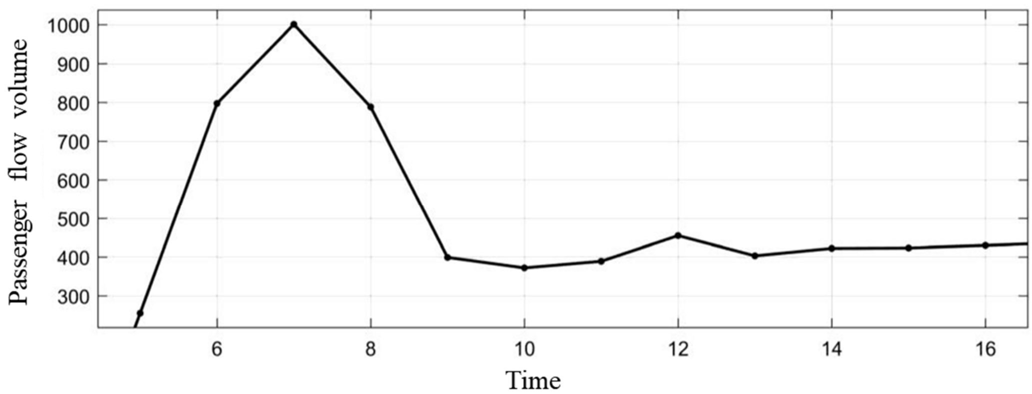

Fig 2. The change of passenger flow with unit hour time

By comparing the above data with the threshold calculated in the previous trial and the corresponding flow of people, it can be found that 6:00-8:00 is the peak period, which is in line with the work time of each unit and company and the time of students' class, 17:00 --19:00 is another peak time, which is the time when each unit leaves work and school, which is in line with the actual situation, and the net income is also more reasonable. Therefore, the threshold value obtained by trial calculation meets the requirement of rationality.

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3. Optimal Scheduling Scheme for "Transition Period"

3.1. Model Establishment and Solution

On the basis of Model 1, two variables f_1、 f_2 are introduced to represent the weight of the indicator of "satisfying the people" and the weight of the indicator of "relieving traffic congestion". Then the net income expression at this time can be obtained as

$$M = f_1 f - f_2 g \tag{7}$$

Eventually, when $f_1 = f_2 = 1$, the fluctuating graphs of net returns from "peak" to "flat" and from "flat" to "peak" can be obtained as follows:

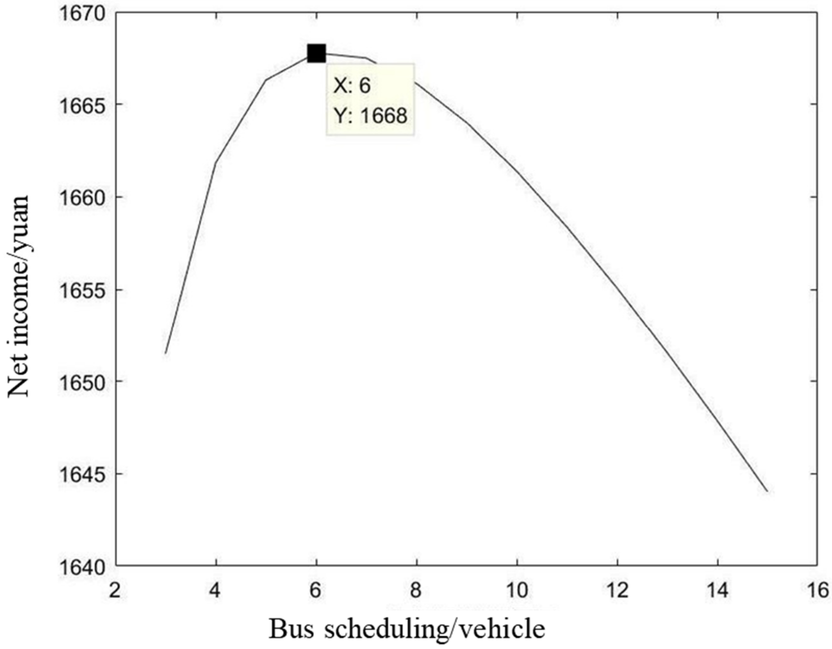

Fig 3. Changes in net income from peak period to peak period

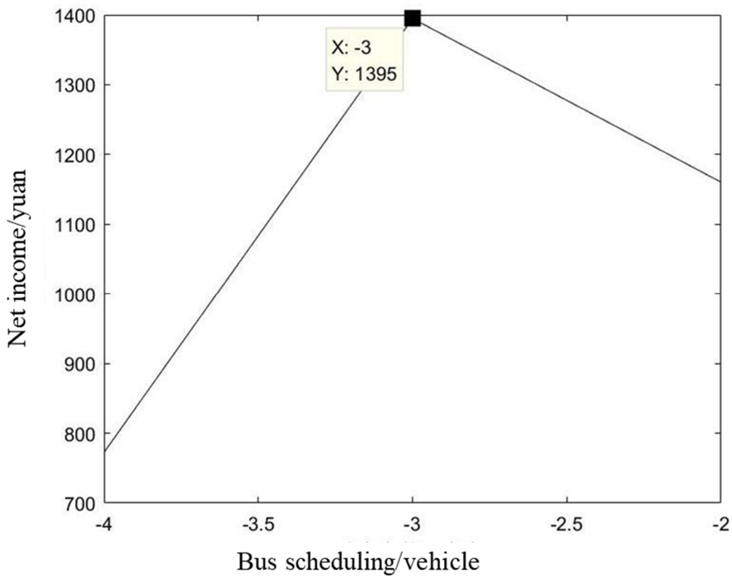

Fig 4. Changes in net income from peak to plateau

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As can be seen from the above figure, when the number of buses put into dispatch is 6, the net income is the largest. A total of 14 buses are dispatched within 2 hours, and one bus is dispatched every 9 minutes. At this time, the net income is 834 yuan/hour.

As can be seen from the above figure, when the number of buses put into dispatch is reduced by 3, the maximum net income is 697.5 yuan/hour. At this time, 5 buses will depart within 2 hours, and the departure time interval is 24 minutes.

In the same way, let f_1 and f_2 take different values, that is, under different indicators, the net income is maximized, and the optimal scheduling scheme for the transition period under different standards is obtained at this time.

3.2. Conclusion of the Model

The optimal scheduling scheme for the "transition period" is:

In the case that the bus company considers "satisfying passengers" more important, let $f_1 = 1.2$, $f_2 = 0.8$, the optimal scheduling scheme is obtained as follows:

When entering the flat peak period from the peak period, the departure frequency is 3 vehicles/hour, and the departure time interval is 20 minutes; from the flat peak period to the peak period, the departure frequency is about 8 vehicles/hour, and the departure time interval is about 8 vehicles/hour. for 7 minutes.

Let $f_1 = f_2 = 1$ when the bus company considers "satisfying passengers" and "relieving traffic congestion" as equally important [6].

The optimal scheduling scheme is obtained as follows: when entering the flat-peak period from the peak period, the departure frequency is 5 vehicles/2 hours, and the departure time interval is 24 minutes; from the flat-peak period to the peak period, the departure frequency is about 7 vehicles/hour, and the departure time The interval is 8.57 minutes.

Let $f_1 = 0.8$, $f_2 = 1.2$ when the bus company considers "relieving traffic congestion" to be more important.

The optimal scheduling scheme is obtained as follows: when entering the flat peak period from the peak period, the departure frequency is 2 vehicles/hour, and the departure time interval is 30 minutes; from the flat peak period to the peak period, the departure frequency is about 13 vehicles/2 hours, and the departure time The interval is 9.23 minutes.

3.3. Sensitivity Analysis of Parameters

Table 1. Sensitivity analysis of f_1 and f_2

From peak to plateau		2-hour departures	Departure time interval
$f_1 = 1.2$	$f_2 = 0.8$	6	20
$f_1 = 1$	$f_2 = 1$	5	24
$f_1 = 0.8$	$f_2 = 1.2$	4	30

Because f_1 represents the weight of the indicator of "satisfying the people", and f_2 represents the weight of the indicator of "relieving traffic congestion", it belongs to Multi-objective optimization, so assigning different weights to different objectives of the model will have an important impact on the results. The sensitivity analysis of f_1 and f_2 is as follows:

Table 2. Sensitivity analysis of f_1 and f_2

From plateau to peak		2-hour departures	Departure time interval
$f_1=1.2$	$f_2=0.8$	17	7
$f_1=1$	$f_2=1$	14	8.57
$f_1=0.8$	$f_2=1.2$	13	9.23

From the above sensitivity analysis of weights, it can be concluded that whether it is from the peak to the flat peak or from the flat peak to the peak, when the company pays more attention to "satisfying the people", the number of departures will increase and the frequency of departures will increase. This is for Reduce the waiting time of passengers and reduce congestion at the same time; when the company pays more attention to alleviating traffic congestion, the number of departures will be reduced, and the frequency of departures will be reduced, which is to reduce the number of buses, thereby alleviating urban congestion.

By observing the optimal number of departures and the interval between departures obtained under different standards, we can see that this is all feasible.

(The sensitivity analyses below are all conducted under the condition that satisfying the people is as important as easing traffic congestion)

Table 3. Sensitivity analysis of β

From peak to plateau	2-hour departures	Departure time interval
$\beta=40$	4	30
$\beta=50$	5	24
$\beta=60$	6	20

Table 4. Sensitivity analysis of β

From plateau to peak	2-hour departures	Departure time interval
$\beta=40$	14	8.57
$\beta=50$	14	8.57
$\beta=60$	14	8.57

Table 5. Sensitivity analysis of λ_1

From peak to plateau	2-hour departures	Departure time interval
$\lambda_1=-6$	5	24
$\lambda_1=-7$	5	24
$\lambda_1=-8$	5	24

From the sensitivity analysis of β , we can see that the number of departures is not sensitive about β from the peak period to the peak period. This is because in the peak period, the number of people is already large enough, so the change of β at this time is no longer the bus. The determinant of the number of departures, and from the peak period to the flat-peak period, the number of departures is more sensitive about β, because in the flat-peak period, the number

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of people is very small, so the change of β at this time can determine the number of bus departures and the frequency of departures.

Table 6. Sensitivity analysis of λ_1

From plateau to peak	2-hour departures	Departure time interval
$\lambda_1 = -6$	15	8
$\lambda_1 = -7$	14	8.57
$\lambda_1 = -8$	12	10

The result of this sensitivity analysis is obviously the impact of each bus dispatched on the final result when entering the peak period, so when λ_1 changes, it will only affect the optimal value entering the peak period, but has no effect on the effective value entering the flat peak period. Influence, and when the absolute value of λ_1 is larger, it means that the passenger capacity or performance is better, and the number of vehicles that need to be sent will be less.

Table 7. Sensitivity analysis of λ_2

From peak to plateau	2-hour departures	Departure time interval
$\lambda_2 = 8$	6	20
$\lambda_2 = 9$	5	24
$\lambda_2 = 10$	4	30

Table 8. Sensitivity analysis of λ_2

From plateau to peak	2-hour departures	Departure time interval
$\lambda_2 = 8$	14	8.57
$\lambda_2 = 9$	14	8.57
$\lambda_2 = 10$	14	8.57

Same as λ_1, λ_2 is the impact of each bus dispatched on the final result after entering the peak period. So, when λ_2 changes, it will only affect the optimal value entering the flat peak period, but has no effect on the effective value entering the peak period. And the larger the absolute value of λ_2, the better the passenger capacity or performance, and the less the number of vehicles that need to be sent.

4. Conclusion

According to the existing problems of bus operation and the research content of this paper, the following optimization schemes can be adopted:

1. In the bus operation management, increase the evaluation and control of the passenger experience, investigate and predict the travel rules of passengers, and formulate a reasonable coupling scheme of bus supply and demand balance.

2. Optimize the departure frequency of the whole train. In the transition period from peak to flat peak, the frequency of departure should be appropriately reduced on the basis of ensuring reasonable waiting time for passengers. For example, it can be reduced from the original one every 15 minutes to every One train departs every 24 minutes to reduce costs and increase net income; during the transition period from low-peak to flat-peak, the frequency of trains should be appropriately increased on the basis of ensuring smooth urban traffic, for example, one train can be departed every 15 minutes from the original Increase to one train every 8 minutes, increasing gross revenue and increasing net revenue.

3. Combination of various service methods. During peak hours, there are many express trains at major stations, and reasonable arrangements are made for empty cars to return, shuttle buses, etc., to increase the flexibility of scheduling. If there is a big difference in the passenger flow of a single line and one direction, the station-hopping dispatch is adopted. If the passenger flow distribution of a single line and two directions is asymmetric and the passenger flow of a certain section is large, the shuttle bus dispatch is adopted.

4. Combination of large and small models. Buses with large passenger capacity are arranged on routes with large traffic flow, many stations, long length, and long one-way time-consuming, and vice versa. This saves costs and improves operational efficiency.

In view of the complexity of bus scheduling, there is still a long way to go to completely solve a series of problems in bus operation. Beneficial and highly economical development.

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