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The Optimal Design of Bus Lines

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Abstract: With the rapid development of urban transportation in China, public transportation has also become an important way for people to travel. Having a good travel condition has been more and more necessary for the public .How to optimize public transport has become an important issue that we now need to solve.Therefore, it is imperative to establish a scientific route optimization method.

Key words: public transportation; line optimization and resource allocation; mathematical model

1.Introduction

With the enhancement of China's economic strength, people's living standards continue to improve. The number of cars continues to increase, urban traffic pressure is increasing, which has seriously affected the development of the city and the people's production level. To solve the problem of urban traffic, the key is to establish the city public transportation's dominant position in the city traffic system. The prioritized development of public transportation is the inevitable requirement of urban healthy and sustainable development, Is an important aspect to build a resource-saving and environment-friendly society.

For the optimization of vehicle scheduling for public transportation, the main goal of its optimization must be clear, and this goal can be represented by the parameters in the model. Our goal is to achieve the greatest satisfaction of passengers and business. This paper establishes a static scheduling optimization model for line,through the nonlinear constraints to obtain the optimal solution, and then optimize the bus lines.

2.Definition and relationship of model parameters

1) l_i: Full-line passengers are divided into l periods, l_i represents the i-th period;

2) T_i :The time interval of the i-th period;

3) n_i :The number of departures in the i-th period, a total number of departures for the line all day is n, obviously, $n=\sum_{i=1}^{l} n_i$;

4) t_i :The time interval of departures for the i-th period.(min), $t_i = \frac{T_i}{n_i}$, the unknown parameter that the objective function depends on;

5) $t_{i\max}$:The largest departure interval for the buses in the i-th period. To ensure the benefit of the passengers,bus industry has a specified value;

6) h_i :The maximum waiting time for passengers in the i-th period, it is determined according to the investigation or experience;

7) q :The number of passengers per car;

8) $r_{\min}$:Minimum vehicle loading rate, the minimum vehicle loading rate that the enterprise must reach to maintain the minimum benefit operation;

9) $r_{\max}$:Maximum vehicle loading rate, the maximum vehicle loading rate provided by the enterprise to ensure the level of service;

10) h_r :the upper limit of the full load rate that passengers can accept,then the critical value that passengers feel crowded and dissatisfied is $q \bullet h_r$;

11) m_j :The j-th station, the line has m stations in total;

12) γ :The cost of traveling for each bus(yuan);

13) ρ :The fare（yuan）；

14) $P_{i,j}$:The number of arriving passengers at the j-th station in the i- th period，$p_{i,j} = T_i \bullet \lambda_{i,j}$;

15) $P^{'}$:The total number of passengers who are dissatisfied with the waiting of the buses all day; $P^{'} = \sum_{i=1}^{l} \sum_{j=1}^{m} \left(P_{i,j} \bullet \frac{t_i - h_i}{t_i} \right)$;

16) $y_{i,j}$:The number of passengers from the j-1 to the j-th station on the buses in the i-th period;

17) $x_{i,j}$:The number of passengers arriving at the j-th station in the i-th period; $x_{i,j} = \alpha \bullet y_{i,j}$, so the increase of the number of passengers at the j-th station in the

i-th period is $P_{i,j}-x_{i,j}$, the number of passengers of J section is $P_{i,j}-x_{i,j}+y_{i,j}$;

18) $q^{'}$:The total number of passengers on the line that are dissatisfied with the crowds on the buses all day, $q^{'}=\sum_{j=1}^{m}\sum_{i=1}^{l}(p_{i,j}-x_{i,j}+y_{i,j}-n_i \bullet q \bullet h_r)$;

19) r_i :The average load factor in the i-th period， $r_i=\frac{\sum_{j=1}^{m}(p_{i,j}-x_{i,j}+y_{i,j})}{n_i \bullet q}$;

20) $\delta_{i,j}$:The parking time of the vehicle at the i-th, j-th station， $\delta_{i,j}=\theta \bullet \max[P_{i,j},x_{i,j}]$.

3.Establishment and Solution of Starting Frequency Optimization Model

In this paper we select three objective functions:The ratio of efficiency and cost of bus enterprises is the largest; the ratio of passengers who are dissatisfied with the waiting of the buses is the smallest; the percentage of persons who feel crowded on the bus is the smallest. We use $\omega_1,\omega_2,\omega_3$ to describe these three goals and give each of these three goals a non-negative weighting factor η_1,η_2,η_3 to convert a multi-objective function into a single objective function，the specific expression is as follows:

1． The ratio of efficiency and cost of bus enterprises——The ratio of net profit and operating cost of public transportation enterprises：

$$\omega_1=\frac{\rho \bullet p-\gamma \bullet n}{\lambda \bullet n} \bullet 100\%$$

2． the ratio of passengers who are dissatisfied with the waiting of the buses

$$\omega_2=\frac{p^{'}}{p} \bullet 100\%$$

3 .The crowded degree（%）

$$\omega_3=\frac{q^{'}}{p} \bullet 100\%$$

Through the above analysis, we set up three objectivefunctions $\max \omega_1,\min \omega_2,\min \omega_3$,using the introduced weighting factor η_1,η_2,η_3 , the three objective functions can be transformed into a single objective function:

$$\max W=\max(\eta_1 . \omega_1-\eta_2 \bullet \omega_2-\eta_3 \bullet \omega_3)$$

W is a comprehensive indicator of the satisfaction of passengers and enterprises，

$\max W$ shows that the optimization goal is to make the degree of comprehensive satisfaction of passengers and enterprises the highest.

Constraints

The feasible solution of the model should considers the possibility that the company will maintain its minimum efficiency and the lower limit of the service level specified by the industry. Therefore, the following constraints are established:

1.Company operating income can maintain the normal operating expenses of the line, that is the average full load rate of the vehicle can not be lower than the limit of the minimum full load rate. The formula is:

$$r_i = \frac{\sum_{j=1}^{m}(P_{i,j} - x_{i,j} + y_{i,j})}{q \bullet n_i} \geq r_{\min}$$

$$\Rightarrow n_i = \frac{T_i}{t_i} \leq \frac{\sum_{j=1}^{m}(P_{i,j} - x_{i,j} + y_{i,j})}{q \bullet r_{\min}} \Rightarrow t_i \geq \frac{T_i \bullet q \bullet r_{\min}}{\sum_{j=1}^{m}(P_{i,j} - x_{i,j} + y_{i,j})}$$

2.To ensure the benefit of passengers, departure time interval should not be longer than the bus industry's largest bus departure interval,The formula is:

$$t_i \leq t_{i\max}$$

3.In order to provide a higher level of service, passengers shouldn't be behind and do not need to wait for the next car, so the maximum number of passengers required for any period should be larger than the number of passengers in all stations within that period,And the departure time interval t_i in the i-th period should not be less than the maximum value of $\delta_{i,j}$ of the station's docking time in the i-th period of j-th station,The formula is:

$$n_i \bullet q \bullet r_{\max} \geq \sum_{j=1}^{m}(P_{i,j} - x_{i,j} + y_{i,j})$$

$$t_i \geq \max\left\{\delta_{i,j}\right\}, \quad \mathrm{j} = 1, 2, 3 \cdots m;$$

$$\Rightarrow n_i = \frac{T_i}{t_i} \geq \frac{\sum_{j=1}^{m}\left(p_{i,j} - x_{i,j} + y_{i,j}\right)}{q \bullet r_{\max}}$$

$$t_i \geq \max\left\{\delta_{i,j}\right\}, \quad \mathrm{j=1,2,3 \cdots m;}$$

$$\Rightarrow \max\left\{\delta_{i,j}\right\} \leq t_i \leq \frac{T_i \bullet q \bullet r_{\max}}{\sum_{j=1}^{m}\left(p_{i,j} - x_{i,j} + y_{i,j}\right)}, \; j = 1, 2, 3 \cdots m$$

Based on the above several constraints:

$$\max\left\{\frac{T_i \bullet q \bullet r_{\min}}{\sum_{j=1}^{m}\left(p_{i,j}-x_{i,,j}+y_{i,j}\right)}, \max\left\{\delta_{i,j}\right\}\right\} \le t_i \le \min\left\{\frac{T_i \bullet q \bullet r_{\max}}{\sum_{j=1}^{m}\left(P_{i,j}-x_{i,j}+y_{i,j}\right)}, t_{i\max}\right\}$$

$i=1,2,3\cdots\cdots l;\ j=1,2,3\cdots\cdots m$。

From the above formula,it can be obtained that the starting frequency optimization model is as follows:

$$\max W=\max(\eta_1 \bullet \frac{\rho \bullet p-\gamma \bullet n}{\gamma \bullet n} \bullet 100\% - \eta_2 \bullet \frac{p'}{p} \bullet 100\% - \eta_3 \bullet \frac{q'}{p} \bullet 100\%)$$

$$S.T. \max\left\{\frac{T_i \bullet q \bullet r_{\min}}{\sum_{j=1}^{m}\left(p_{i,j}-x_{i,,j}+y_{i,j}\right)}, \max\left\{\delta_{i,j}\right\}\right\} \le t_i \le \min\left\{\frac{T_i \bullet q \bullet r_{\max}}{\sum_{j=1}^{m}\left(P_{i,j}-x_{i,j}+y_{i,j}\right)}, t_{i\max}\right\}$$

$i=1,2,3\cdots\cdots l;\ j=1,2,3\cdots\cdots m$。

Because there are l periods,this model can be decomposed into l sub-models, followed by solving l optimal, then solve l optimal t_i

4.Conclusion

In the model, we combine the benefit of passengers and enterprises. We build the objective function based on the comprehensive indicators of the two, it is a very typical nonlinear optimization problem.A multi-objective optimization model of bus line departure frequency is established, which considers the benefit of passengers and enterprises.The model is widely used,this model can be applied when the study involves a problem that need to satisfy the two goals .It can be applied in industry, agriculture, transportation, commercial and other industries.

5.References

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