Optimisation of Bus Routes in Small and Medium-sized Cities: The Case of No. 7 Bus Route in Jiaozuo City

Hanbo Wei, Chengming Zhu*

College of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, Henan China, 454003

(*zhuchengming@hpu.edu.cn)

Abstract. Urban traffic problems affect urban development and comfort. The development of public transport and the improvement of transport efficiency are the key, but the optimization of bus routes in small and medium-sized cities is overly dependent on experience and lacks scientific basis, which affects the overall efficiency. In order to make better use of the existing road network and bus enterprise resources, this paper chooses to optimize the No. 7 bus route in Jiaozuo City. In this paper, the basic characteristics of bus routes such as uplink and downlink peak and peak running time, line length and non-linear coefficient are analyzed, and then 9 indicators are selected by AHP method to comprehensively evaluate its current situation. Finally, through summary and analysis, the non-linear coefficient, departure frequency, platform and line efficiency of the line were optimized, so that the optimized non-linear coefficient met the recommended value, the departure frequency was more suitable for the peak and peak passenger flow, the safety of the platform was improved, and the line efficiency was increased by about 19.6%.

Keywords: urban public transport; bus route optimisation; station adjustment; hierarchical analysis

1 INTRODUCTION

The optimisation of bus routes has long received extensive attention from scholars in the field of transportation at home and abroad.PopovaOlga[1] et al. study optimisation methods for public transport in cold regions.A simulated annealing algorithm combined with a Monte Carlo simulation framework is proposed by Sadrani[2] et al. for solving practical problems under stochastic journey times, but is less applicable to small and medium-sized cities.Ma[3] et al. propose a time-dependent schedule optimisation model for varying passenger demand and travel times between stops, which requires a large amount of historical data.Gkiotsalits[4] modelled bus scheduling time control for the problem of trip time and passenger demand perturbation, and the method is able to react according to passenger demand.Fernandez[5] et al. developed a high-capacity bus stop layout and design system, which adopts a combined mathematical method, which can provide decision makers with simulated decision re-

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sults.Pattnaik[6] et al. proposed the use of genetic algorithms to design the bus line network, the model with the objective of minimising the total sum of bus passenger travel costs and operating costs, to generate the line selection set, and then through the genetic algorithm for the preferred selection.

This paper focuses on how to optimise bus routes in a cheaper and more practical way by relying on the existing road network in small and medium-sized cities. Through the preliminary investigation, this paper selects nine indicators that have a greater impact on the efficiency of the line for detailed investigation, and uses hierarchical analysis to evaluate the actual operation of the line. In the selection of optimisation objectives, this paper selects four aspects that are obvious to passengers and feasible for optimisation, which are station platform, non-linear coefficient, line efficiency and frequency of departure. The optimised bus routes are better able to meet passengers' travel needs on holidays and weekdays, reduce air pollution and resource wastage, lower the operating costs of the bus company, and improve the line operating efficiency and passenger satisfaction.

2 ANALYSIS OF THE CURRENT SITUATION OF BUS ROUTE 7 IN JIAOZUO CITY

2.1 Overview of Bus Routes

Bus 7 runs through Jiaozuo city east and west, is an important trunk line connecting Jiaozuo city and suburbs, the starting station is the Shenzhou Road car park, the terminal is Wanfang Aluminium Factory, the line is 27 kilometres long one-way, the upper line set up a total of 42 stops, the lower line set up a total of 41 stops.

At present, Jiaozuo City 7 Road is equipped with Yutong E10 model, 10.5 metres long, with a 15-minute departure interval. The route not only passes through Jiaozuo No.2 Hospital, Jiaozuo Maternal and Child Health Hospital, railway station and other areas in the centre of Jiaozuo City, but also connects to industrial areas such as Carbon Factory and Wanfang Aluminium Factory. The route direction is shown in Figure 1.

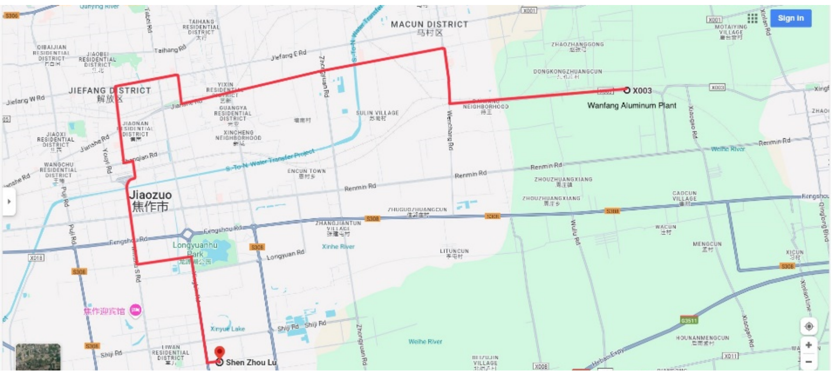

Fig. 1. Jiaozuo City 7 bus route direction.

2.2 Line Basic Characteristics

Table 1. Basic characteristics of the line

route name	Number of uplink stations	Number of downstream stations	Line length	Length of bus lanes	Percentage of bus lanes	departure frequency	fares
7-way	42	41	27	0.775	2.87 per cent	15min	1-2.5

The basic characteristics of the routes of Jiaozuo City 7 are shown in Table 1.

2.3 Line Length Analysis

Jiaozuo City 7 line road length of 27 kilometres, from the length of the analysis belongs to the trunk line, although the line covers a wide range but the length of the line is too long will also cause a series of problems, such as: passenger waiting time is long, poor ride experience, travel time reliability is unstable and so on affecting the operational efficiency of the line.

2.4 Analysis of Line Non-Linear Coefficients

The non-linear coefficient is the ratio of the actual distance between the first and last stops of a bus route to the straight-line distance in space, reflecting the degree of circuitousness of the bus route[7]. According to the relevant provisions of the non-linear coefficient of the formula should be

$$\mu \leq \left[\frac{1}{d}\right]_{max} = 1.6 \tag{1}$$

In the formula:

L--Length of the bus route (km).

d--Spatial straight-line distance (km) between the line's start and end stations.

The results of the calculation of the downstream non-linear coefficients on the 7 roads are shown in Table 2.

Table 2. Non-linear coefficients

bus route	Actual route length between first and last stops of bus routes (kilometres)	Spatial straight-line distance between first and last stations (kilometres)	Non-linear coefficient
7 up train	27	12.9	2.09
7 down train	27	12.9	2.09

The analysis of Table 2 shows that the non-linear coefficient of Jiaozuo City's No. 7 bus line is too large, and the overall diversions distance of the line is too long, which may lead to the low operational efficiency of the line, and the travelling time of the passengers is prolonged, which affects the passenger travelling satisfaction.

3 EVALUATION OF THE CURRENT SITUATION OF BUS ROUTE 7 IN JIAOZUO CITY

This chapter uses the AHP method to assess the current status of the existing bus transport system. The method allows the calculation of the weights of specific evaluation indicators for conventional bus operations and combines them with the evaluation grading criteria to finally arrive at the overall evaluation level of the system.

3.1 Calculation of Indicator Weights

This paper constructs a bus route evaluation index system that contains three levels: the target level, the criterion level and the index level. The objective layer is the optimisation of bus line efficiency; the criterion layer includes service level indicators, operational efficiency indicators and economic and social benefit indicators. The service level indicators include peak hour departure frequency, average running speed and interval offset; the operational efficiency indicators include non-linear coefficient, peak full load rate and bus swipe ratio; and the economic and social benefit indicators include safe travelling intervals, bus fare rate and 10,000 passenger seats. The peak hour departure frequency is selected to better alleviate the pressure of passenger flow and improve the service quality; the interval offset is selected to improve the safety and passenger experience; the non-linear coefficient and the peak load factor are selected to optimise the route design and save the operating cost; the bus fare rate and the number of 10,000 passenger seats are selected to promote the popularity of public transport and support the sustainable development.

In this paper, the judgement matrix is constructed by pairwise comparison method and 1~9 comparison scale, and the following judgement matrix is given by expert evaluation method.

Table 3. Judgement matrix for the guideline layer

normative	Service level indicators（x_1）	Operational efficiency indicators（x_2）	Economic and social indicators（x_3）
Service level indicators（x_1）	1	3	4
Operational efficiency indicators（x_2）	0.33	1	2
Economic and social indicators（x_3）	0.25	0.5	1

Table 4. Judgement matrix for level of service indicators

normative	Peak hour headway intervals（x_{11}）	Average running speed（x_{12}）	Travelling interval deviation（x_{13}）

Peak hour headway intervals（x_{11}）	1	3	5
Average running speed（x_{12}）	0.33	1	4
Travelling interval deviation（x_{13}）	0.2	0.25	1

Table 5. Judgement matrix for operational efficiency indicators

normative	Non-linear coefficient（x_{21}）	peak filling rate（x_{22}）	Public transport swipe ratio (x_{23})
Non-linear coefficient（x_{21}）	1	2	9
peak filling rate（x_{22}）	0.5	1	5
Public transport swipe ratio (x_{23})	0.11	0.2	1

Table 6. Judgement matrix for economic and social indicators

normative	Safe Driving Intervals（x_{31}）	Public transport rates（x_{32}）	Number of seats per 10,000 passengers（x_{33}）
Safe Driving Intervals（x_{31}）	1	8	9
Public transport rates（x_{32}）	0.125	1	2
Number of seats per 10,000 passengers（x_{33}）	0.11	0.5	1

In order to facilitate the analysis of this paper adopts four levels of division standards, and the various levels were assigned 1, 2, 3, 4 as shown in Table 7. According to the judgment matrix of table 3 to table 6 to calculate the weight vector and then carry out the hierarchical single sorting and consistency test and the hierarchical total sorting and consistency test to finally get the Jiaozuo city 7 road comprehensive level evaluation table as shown in table 8.

Table 7. Evaluation level of indicators of operational characteristics of bus routes.

rating	Performance Description	quantitative value
I	superior	1
II	very much	2
III	middle	3
IV	differ from	4

Table 8. Jiaozuo City 7 road comprehensive level evaluation table

Evaluation indicators	calculated value	weighting	rating	quantitative value
Peak hour headway (min)	15	0.385995537	IV	4
Average operating speed (km/h)	21.89	0.177138213	II	4
Travelling interval deviation (min)	11.36	0.060090977	III	3
Non-linear coefficient	2.07	0.147339961	III	3
peak filling rate	11.83 per cent	0.076330927	IV	4
Public transport swipe ratio	72.17 per cent	0.01581672	II	2
Safe driving intervals (10,000 km/trip)	125	0.109880197	I	1
Public transport rates	8%	0.017071878	I	1
Number of seats per 10,000 persons (seats per 10,000 persons)	131.33	0.01033559	IV	4

The formula for calculating the overall evaluation score for bus routes is shown below.

$$F = \sum_{i=1}^{9} \omega_i \times f_i \tag{2}$$

In the formula:

F-- the overall evaluation score of the level of operation of the conventional public transport system.$1 < F < 4$.

ω_i,f_i --No.i quantitative values of the weights and evaluation levels of the indicators.

According to formula (2), the comprehensive evaluation score of Jiaozuo City Bus Route 7 is calculated to be 3.38, the overall score is not too satisfactory, and the operation needs to be improved.

4 OPTIMISING RESULTS

4.1 Station Optimisation

The optimisation of the stops is mainly to improve the safety of pedestrians crossing the street. The downstream stop of Wanda Plaza is located at the upstream of the pedestrian crossing, and when pedestrians cross the intersection from the front of the parked buses, their sight distance is easily blocked by the parked vehicles. It is desirable to adjust the bus stop to the downstream of the pedestrian crossing and there is a large open space nearby, which is more feasible. Before and after optimisation are shown in Figure 2 and Figure 3.

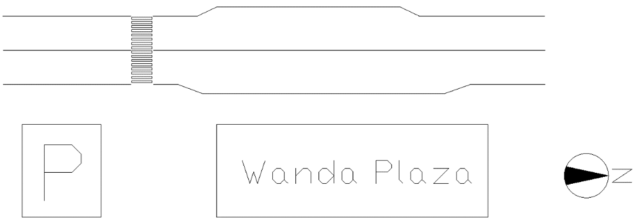

Fig. 2. Schematic diagram before optimization.

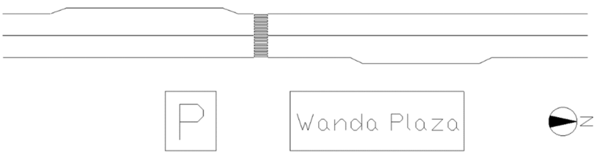

Fig. 3. Schematic diagram after optimization.

4.2 Optimisation of Non-Linear Coefficients

At present, the non-linear coefficient of 7 road up and down is 2.09, which exceeds the requirement of the "Urban Road Traffic Planning and Design Code" that the non-linear coefficient of bus arterials should not be greater than 1.60[8]. Therefore, in the case of meeting the travelling needs of passengers can be in the East Second Ring Junction Station and the railway station (east) (road) will be divided into three lines 7, from south to north named 71, 72 and 73, 71 road from the suburbs to the city, 72 road without vehicles, through the other vehicles through the line of interchange, 73 road from the suburbs to the city.The line schematic is shown in Figure 4.

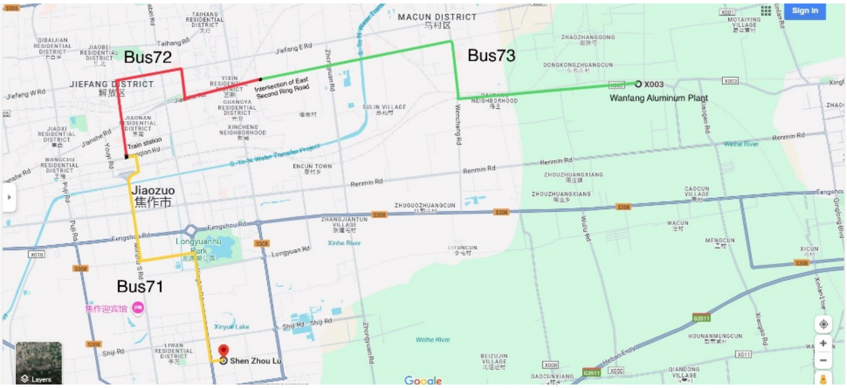

Fig. 4. Schematic Route Map of Routes 71, 72 and 73.

The revised non-linear coefficients of the routes are 1.46 for Route 71 and 1.19 for Route 73, which are in line with the requirements of the Urban Comprehensive Transport System Planning Standards. In terms of route length, route 71 has a mileage of 8.3 kilometres and a turnaround time of about 37 minutes, while route 73 has a mileage of 11.5 kilometres and a turnaround time of about 45 minutes, which is more reasonable.

It can be seen that after the optimisation of the non-linear coefficients, the frequency of each route has changed, and the interval between departures has become a bit longer compared to the previous one, which is able to meet the needs of residents along the route to make the operational efficiency of public transport improved.

4.3 Line Efficiency Optimisation

For transport modes with welfare nature such as public transport, the main objective is to maximise social benefits. Considering the economic and social benefits of bus route optimisation, the bus route optimisation model is obtained as shown in equation (3)[9].

$$\max E_R = \frac{\sum OD_{kh} L_{kh} \beta_{kh}}{\sum q_{ij} l_{ij}} \tag{3}$$

In the formula:

E_R--routesR the efficiency of the routes.

OD_{kh}--Transportation nodesk andh OD flows between them.

L_{kh}--Transportation nodesk andh distance between them.

β_{kh}--Transportation nodesk andh non-linear coefficients between them; the

l_{ij}--Adjacent sitesi andj distance between them; the

q_{ij}--Adjacent sitesi andj cross-sectional flow between them.

The current line efficiency of Route 7 is calculated to be 6.53. In order to further improve the efficiency of the bus route, the terminal location of the route is appropriately changed, and the schematic before and after the change is shown in Figure 5.

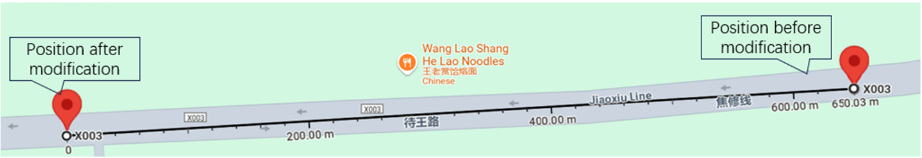

Fig. 5. Schematic diagram before and after the change of terminal location.

The changed location is located near Dongkongzhuang police workstation of Mazhun Branch, which is about 650 metres away from the original location. Assuming that the amount of OD (origin-destination) between each station remains the same after the optimisation, the route is re-evaluated in this paper. With the optimised route design, the efficiency of the route is significantly improved. Specifically, the optimised line efficiency reaches 7.81, which is an increase of about 19.6% compared to the original line efficiency.

4.4 Optimisation of Departure Frequency

Method 1 is to consider the maximum daily passenger flow section.

$$F_{1j} = \max\left(\frac{P_{mdj}}{d_{oj}}, F_{mj}\right), j = 1,2,\cdots,q \tag{4}$$

$$P_{md} = \max_{i\epsilon s} \sum_{j=1}^{q} P_{ij} = \sum_{j=1}^{q} P_{ij} \tag{5}$$

$$P_{mdj} = P_{i*j} \tag{6}$$

In the formula:

F_{1j}--Time slotsj the frequency of departures.

P_{mdj}--Time periodj The maximum daily passenger flow section during thei* passenger flow in the time periodP_{i*j}.

d_{oj}-- time slotj Desired passenger capacity.

F_{mj}--Time periodj the theoretically set minimum departure frequency (3 for peak hours and 2 for off-peak hours).

P_{md}--The total number of passengers in the statistically obtained maximum daily passenger flow section.

Method 2 is to consider the hourly maximum passenger flow section.

$$F_{2j} = \max\left(\frac{P_{mj}}{d_{oj}}, F_{mj}\right), j = 1,2,\cdots,q \tag{7}$$

$$P_{mj} = \max_{i \in S} P_{ij} \tag{8}$$

In the formula:

F_{2j}--Time slotsj the frequency of departures.

P_{mj}--Time periodj the maximum number of passengers at the cross section during the time period.

P_{ij}--Time periodj withini the number of passengers at the cross section.

Other symbols have the same meaning as before.

Based on the operation data of the whole day, we used two methods to calculate the departure frequency respectively. Firstly, we set the desired carrying capacity to 29 passengers from the perspective of passenger satisfaction. Then, the specific departure frequency was derived using the above calculation method. Through the calculation of these two methods, we were able to better assess the impact of different departure frequencies on passenger satisfaction and find the optimal departure frequency scheme. The calculation results are shown in Table 9, which demonstrates in detail the departure frequencies under different methods and their corresponding carrying capacity and passenger satisfaction.

Table 9. Departure frequencies and intervals based on the maximum passenger flow profile method of the station survey

the twelve two hour divisions of the day	P_{mdj}	F(Vehicles/h)	H(min)
06:00-07:00	35	2.00	30
07:00-08:00	42	2.00	30
08:00-09:00	61	2.10	28
09:00-10:00	64	2.21	27
10:00-11:00	44	1.52	30
11:00-12:00	62	2.14	28
12:00-13:00	61	2.10	28
13:00-14:00	66	2.28	26
14:00-15:00	39	1.34	30
15:00-16:00	63	2.17	27
16:00-17:00	62	2.14	28
17:00-18:00	58	2.00	30
the twelve two hour divisions of the day	P_{mdj}	F(Vehicles/h)	H(min)
06:00-07:00	35	2.00	30
07:00-08:00	62	2.14	28
08:00-09:00	61	3.00	20
09:00-10:00	64	2.21	27
10:00-11:00	49	1.69	35
11:00-12:00	65	2.24	26
12:00-13:00	61	2.10	28
13:00-14:00	66	2.28	26
14:00-15:00	57	1.97	30
15:00-16:00	67	2.31	25
16:00-17:00	62	2.14	28
17:00-18:00	58	2.00	30

5 CONCLUSION

This paper takes the 7 bus line in Jiaozuo City as the research object, firstly, through the investigation and analysis of the data on the length of the line, up and down travel speed, the stay time at each station and the peak passenger distribution, we get the conclusions that the 7 bus line is too long, the peak fullness rate is low, and the distribution of the passenger flow is not even. Specifically, the length of the No. 7 bus route is long, which leads to longer passenger travelling time during peak hours and affects the travelling efficiency. In addition, there are differences in the upward and downward journey speeds of the route, with slower travelling speeds on some sections of the route, further exacerbating passenger travel times. The distribution of passenger flow during peak hours is uneven, and some stops have higher passenger flow, which affects passengers' travelling experience.

Then AHP method is used to select 9 indicators to evaluate the status quo of Road 7, and finally the departure frequency, station, line efficiency and non-linear coefficient of Jiaozuo City's Road 7 bus route are optimised respectively, and the departure frequency of buses is transformed from the original fixed frequency to the frequency adjusted according to different time periods. In terms of platforms, the focus on adjusting the platform of Wanda Plaza Station, so that it is located in the downstream of the pedestrian crossing, to avoid stopping vehicles on the pedestrian's sight distance obstacles to improve the safety of pedestrians crossing the street. In terms of line efficiency, the adjustment of Wanfang Aluminium Factory Station to the vicinity of Dongkongzhuang Police Workstation of Mazhou Sub-bureau, which is about 650 metres away from the original location, has increased the overall line efficiency from 6.53 to 7.81, an increase of about 19.6%. In terms of non-linear coefficients the entire line is divided into three, making it consistent with meeting the requirements of the Urban Comprehensive Transport System Planning Standards.

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