Design and Simulation of Urban Variable-route Bus

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Abstract. As a new mode of public transport service, variable-route bus service can further improve the service quality of urban public transit system, and will become an important part of integrated urban comprehensive public transit system. Therefore, this paper studies the operation scheduling model of variable-route bus, aiming at improving the service level of public transport and reducing the operating cost. Based on the theoretical research, the service area maximum width of variable-route bus is obtained according to the relationship between the system slack time and the travel time. Then a two-stage vehicle scheduling model which comprehensively considers the reservation demand and the dynamic real-time demand is proposed. The operation mode conversion model of variable-route bus and the conventional bus are further established, which provides powerful guarantee for the application of variable-route bus service. Finally, by designing simulation experiment, the comparison of relevant operation service parameters between variable-route bus and conventional bus is conducted. This paper aims to study the influence of variable-route bus to operation and scheduling, and provides a theoretical basis for the promotion and application of variable-route bus in China.

1. Introduction

With the development of China's economy, the rapid growth of urban population, the gradual expansion of urban scale, Urban space gradually expands to the suburbs, newly-built residential, commercial, office, industrial areas in new city district far from the city centre. In new city district, land development density is relatively low, development zones are relatively discrete, travel demand points are scattered, and the bus route is relatively long. In these conditions, conventional bus usually costs a high cost, which can give rise to waste of public transport resources. As a new hybrid bus system, variable-route bus combines the low cost-effectiveness of conventional bus with the high flexibility of responsive public transport system, and has well applicability in low-travel demand density areas such as new city district and suburbs.

Foreign scholars research on flexible public transport service system has been carried out for more than 30 years, basically formed a set of variable-route bus operation and scheduling theory methods, and accumulated a large number of variable-route bus service practice experience. Quadrifoglio et al.[1] introduced the operating principle of Mobility Allowance Shuttle Transit(MAST), and studied the relevant system parameters, a mixed integer programming model of the static schedule problem of
vehicle is established. Domestic research on variable-route bus system started late, the current research is mainly on foreign advanced concepts and design, operation and other key theories to introduce and summarize[2]. But few researches have been made on the key theories of the variable-route busation with China's national conditions. Lin Yeqian et al.[3] established the scheduling optimization model of variable-route bus service system, and designed the relevant genetic algorithm to solve this model. Qiu Feng et al.[4] established a two-stage scheduling model of variable-route bus, and solved it by heuristic simulated annealing algorithm. Gao xuming[5] studied the system parameter of demand response transit system, and establishes the demand response transit scheduling model. The above research results provide an important reference for this paper.

Based on the above analysis, this paper studies the key technologies of variable-route bus, including the research of service area, variable-route bus and conventional bus mode conversion, and apply the research results to Pingdingshan City No.9 bus route. Finally, the operation of variable-route bus system is simulated by design simulation experiment, and the parameters of variable-route operation service and conventional bus operation service are compared.

2. Study on the service area of variable route bus

2.1. service area form

The service area length is $L$, the non-linear factor of the base line is 0, the length of the fixed route is $L$, the width of the service area is $W$, then the maximum distance that the bus can deviate is $W/2$, which is shown in Figure 1.

![Fixed station interval and different service widths.](image)

2.2. the slack time

In order to improve the reliability of variable-route bus operations, the bus should have a fixed departure time and slack time at each station. The fixed route includes the starting station, terminus and $S - 2$ fixed stations, The Numbers are $i_1, i_2, ..., i_s$, $j_1, j_2, ..., j_s$, for each adjacent fixed station, the fixed route length of station interval is recorded as $L_{ij}$, the system given an initial time is $ST$, the slack time assigned to each adjacent station are $ST_{ij}$.

For the form of service area, the distance between adjacent fixed stations is the same and the width of service area is different, because the station interval is the same, the allocation of the slack time is proportional to the width of the service area for each fixed station interval. Make the service area width of the $i$’th fixed station interval to be $W_i$, then the slack time of each station interval as:

$$ST_{ij} = \frac{W_i}{\sum W_i} ST$$  \hspace{1cm} (1)
2.2.1. System initial slack time
Initial slack time is the maximum slack time pre-set by the system, the requirements of passengers outside fixed station must meet the constraints of the maximum slack time. The initial slack time can be expressed as the difference between the scheduled travel time for one bus and the time that vehicles take to travel along the fixed route. Let scheduled travel time between each round of the system be $T_H$, the average vehicle operating speed be $v$, the system initial slack time is:

$$ST = T_H - \frac{L}{v}$$ \hspace{1cm} (2)

The initial slack time for each fixed station interval as:

$$ST_y = \frac{T_H - \frac{L}{v}}{S - 1} = T_{H_y} - \frac{L_y}{v}$$ \hspace{1cm} (3)

2.2.2. Operation consumption slack time
The vehicle in operation according to the needs of demand response station passengers, that consumed a certain amount of the slack time. Operation consumption slack time can be expressed as the difference value between the actual travel time of the vehicle and the time vehicles travel only along the fixed route, therefore, the slack time consumed by operation mainly depends on the actual travel time of the vehicle. Since the actual travel time is determined by the passenger travel demand and the generated path, it can be considered to instead by the expected amount, which expressed as $E(T_R)$, . When $E(T_R) \leq T_H$, the system is stable.

Assuming that passenger demand in the service area is evenly distributed, based on the results of existing research[6], the actual travel time of the vehicle is:

$$E(T_{H_y}) = \frac{L_y}{v} + \frac{1}{6v} + \rho_y \cdot T_{H_y} \cdot L_y \cdot t_s \cdot W + \frac{\rho_y \cdot T_{H_y} \cdot L_y \cdot W^2}{3v}$$ \hspace{1cm} (4)

where $K_y$ is the number of demand response station, $D_y$ is The actual operating distance, $t_s$ is the parking time at each demand response station, $t_o$ is get on and off time per passenger, $b$ is door opening and closing time, usually 3 to 4s, $\rho_y$ is passenger travel demand density at fixed station interval( per / km² / h).

The actual travel time minus the straight travel time along the reference fixed route in the case of no outside demand is the consumption slack time in service area:

$$E(ST_y) = E(T_{H_y}) - \frac{L_y}{v} = \frac{1}{6v} + \rho_y \cdot T_{H_y} \cdot L_y \cdot t_s \cdot W + \frac{\rho_y \cdot T_{H_y} \cdot L_y \cdot W^2}{3v}$$ \hspace{1cm} (5)

When the vehicle is traveling at a known uniform speed, the reference route length and departure time are pre-set, and the passenger demand density in the service area is known, the width of the service area $W$ can be obtained by determining the system slack time.

2.3. Variable-route bus service area width design
Based on the actual slack time is less than the system initial slack time, a quadratic inequality about the width of the service region is obtained:

$$W = \frac{-1 - 6v \rho_y T_{H_y} L_y t_s + \sqrt{(1 + 6v \rho_y T_{H_y} L_y t_s)^2 + 48v \rho_y T_{H_y} L_y E(ST_y)}}{4 \rho_y T_{H_y} L_y}$$ \hspace{1cm} (6)
When the system's scheduled travel time is determined, the system has pre-set the vehicle's slack time, which is the maximum slack time, the vehicle can obtain, therefore, the vehicle travel time cannot exceed the maximum slack time given by the system, that means \( 0 \leq E(ST_{ij}) \leq ST_{ij} \).

To find the maximum distance that the vehicle can deviate from the reference route, set \( E(ST_{ij}) = ST_{ij} \), get the calculation formula for the maximum service area width:

\[
W = \frac{-1 - 6v \rho(T_{ij}^c - t_s^c) + \sqrt{(1 + 6v \rho(T_{ij}^c - t_s^c))^2 + 48v \rho(T_{ij}^c - t_s^c)(T_{ij}^c - L_{ij}^c)/v}}{4 \rho(T_{ij}^c - t_s^c)}
\]  

(7)

It is observed that the maximum service area width is related to vehicle travel speed, system schedule travel time, passenger travel density in service area, route length, etc. If the values of these parameters are already known, you can get the maximum width of the service area.

3. Operating mode scheduling mode

3.1. Two-stage vehicle scheduling model

The two-stage vehicle scheduling model for the variable-route type is shown as the figure, the stage of I scheduling model optimizes system cost with lowest, vehicle scheduling model processes booking requirements to determine the initial travel path of the bus vehicle, the stage of II Scheduling model deals with real-time travel needs to continuously correct the travel path of bus vehicles.

![Diagram](image)

Figure 2. Fixed station interval and different service widths.

3.2. Operating mode transformation model

This design solves the choice of operation mode by constructing the utility function of the two modes of conventional bus and variable-route bus.

Utility function of variable-route bus:

\[
C_1 = \omega_1 \sum_{i \in N, n \in N} (t_{p(i)} - t_{v(i)}) k_i + \omega_2 \sum_{j \in S} [(T_{s(j)} - A_{s(j)} n_j)] + \omega_3 \left[ \sum_{j \in S} \sum_{n \in N} \frac{k_{j,n}d_{j,n}}{v} - \alpha_n \sum_{i \in N} k_i m_i \right]
\]  

(8)
Where $\omega_1$, $\omega_2$, $\omega_3$ are the utility function coefficient, $t_{p(i)}$ is boarding time for passenger $i$ who get on outside the station, $t_{r(i)}$ is passenger's request time, $T_{s(j)}$ is the departure time of the $j$th station, $A_{s(j)}$ is the arrive time of $j$th station, $n_j$ — is passengers which destination is not on the $j$th station when the bus arrives at the $j$th station, $k_{,j,u}$ is a coefficient, if the route from station $j$ to demand response station $u$ is feasible, $k_{,j,u}=1$, otherwise $k_{,j,u}=0$. $d_{,j,u}$ is the distance from station $j$ to demand response station $u$, $v$ is the bus speed, $\alpha_m$ is conversion factor which translate economic cost into time cost, $m_i$ is bus fare, $S_i$ is the set of all fixed stations, $k_i$ is travel demand of passenger $i$, if the travel demand is satisfied $k_i=1$, otherwise $k_i=0$.

It can be seen that the difference of the utility of the two modes of operation is mainly caused by the change of three parameters $\omega_1$, $\sum_{j}[(T_{s(j)} - A_{s(j)} n_j)]$, $v$, and the change can be expressed as:

$$C_2 = \omega_1 \sum_{i \in \{1,2\}} (t_{p(i)} + t_{r(i)}) k_i + \omega_2 \sum_{j}[(T_{s(j)} - A_{s(j)} n_j)] + \omega_3 \sum_{j \in S_i} \sum_{u \in u_{j,s}} k_{,j,u} d_{,j,u} - \alpha m \sum_{i \in N} k_i m_i$$

When $C_1 \leq C_2$, choose variable-route service. When $C_1 > C_2$, choose conventional bus service.

### 4. Variable route design and simulation of No.9 bus in Pingdingshan City

Combined with the investigation results of the regular bus operation of No.9 bus in Pingdingshan City and the operation and scheduling situation of other routes in Pingdingshan City, this design plan is to set variable bus routes between the XinKuang Cross and Guanshang Station.

#### 4.1. Simulation of No.9 bus in Pingdingshan City

The simulation mainly compares the travel time, load ratio, speed, stop delay and other indicators of conventional bus service and variable-route bus service. Build random travel demand codes within the service area with Matlab, and then the path was planned according to the travel demand generated by Matlab. Finally, Vissim simulates the planned route and compares it with the conventional bus operation and service conditions.

#### 4.2. Set simulation parameters

The simulation of the variable-routes bus mainly includes three parts: bus routes, bus stations (includes fixed station, demand response station) schedules.

The stop time of each fixed station is determined according to the amount of passengers on and off, if there is no demand to get on and off, the station can be ignored, but the fixed station cannot be ignored.

The simulation time is 2400s, during which there are a total of 5 vehicles.

#### 4.3. Simulation data analysis

In the simulation of conventional bus operation and variable route bus operation of No.9 bus in Pingdingshan City, a total of 5 detectors are embedded at each fixed station, travel time of conventional and variable-route bus is shown in Table 1.
Table 1. Travel time simulation data

| Detector number | Vehicle number | Travel time | Delay(second) |
|-----------------|---------------|-------------|---------------|
|                 |               | Conventional| Variable      | Conventional| Variable  |
| 1               | 1             | 415.8       | 898.0         | 45.1        | 84.9      |
| 1               | 2             | 403.5       | 883.5         | 47.4        | 89.6      |
| 1               | 3             | 417.4       | 902.1         | 44.2        | 83.8      |
| 1               | 4             | 399.7       | 879.9         | 48.2        | 91.2      |
| 1               | 5             | 415.8       | 897.3         | 46.8        | 88.8      |

Comparing with conventional bus, it can be found that due to the increase in service area, the number of passengers on the variable-route service is higher and the vehicle load rate is higher. It increased travel time, reduced average route speed and increased delay due to the increase of the slack time, route adjustment, stops and travel time. Demand-responsive transportation system can bring convenience to the residents of the new city district and suburbs with lower bus coverage, but will have a certain impact on speed, delays and travel time.

5. Conclusion

In order to improve the operational efficiency of public transportation, this paper carried out a study on the service area of variable-route bus system, the scheduling of variable-route bus system and the transformation of operation mode. the main findings are as follows: (1) The service area of variable-route bus system is studied, the width of system service area is obtained by determination of the operation slack time. (2) A two-stage vehicle scheduling model is designed to take into account of the appointment demand and dynamic real-time demand. It expanded the number of bus service and effectively improved the service level and attractiveness of public transportation services in the new city district and suburbs. (3) Matlab is used to generate random points in the service area to simulate residents' travel demands, according to the scheduling model, the operating route under the predicted condition of travel demand is calculated, finally, Vissim simulates the operation of this route for comparative analysis.

This paper aims to study the impact of variable-route bus on operational efficiency, which provides a theoretical basis for the promotion and application of variable-route bus operation service in China.

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References

[1] Quadrifoglio L, Yin K, Lu W. (2014) Performance Measures for Multi-vehicle Allowance Shuttle Transit (MAST) System. Public Transit, 5: 28-35.
[2] Pan Shuliang, Yu Jie, Lu Xiaolin, Zou Nan. (2014) A Review of Flexible Transit Service. Urban transport of china, 12(2): 62-68.
[3] Lin Yeqian, Li Wenquan, Qiu Feng, Ding Yuling. (2012) An optimal model for flex-route transit scheduling problem, Traffic information and safety , 30(5):14-18.
[4] Qiu Feng, Li Wenquan, Shen Jinxing. (2014) Two-stage model for flex-route transit scheduling, 44(05):1078-1084.
[5] Gao Xuming. (2015) Research on dispatching system of demand-responsive connector with on-demand stations. Southeast University.
[6] Baha W. Alshalafah. (2009) Designand scheduling offlex-route transit service. University of Toronto.