Design and Simulation Study of a Variable Bus Lane System

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Abstract. This paper proposes a variable bus lane control strategy suitable for small and medium-sized cities to address the issue of road resource waste caused by fixed bus lanes and improve the utilization of road resources. By real-time detection of bus and non-bus traffic flow, bus speed, and passenger flow, and calculating the traffic flow ratio and road saturation, the strategy determines whether to activate the variable bus lane, displayed through variable signs. By fitting the changes in the ratio of bus to non-bus traffic flow and the average bus speed, the critical point for activating the bus lane is determined. This strategy is applicable to any time period and high-traffic areas in small and medium-sized cities, significantly improving road resource utilization and traffic efficiency. Through dynamic adjustment, it not only enhances the operating efficiency of buses but also improves the traffic speed of non-bus vehicles, providing an innovative and effective solution for traffic development in small and medium-sized cities.

Keywords: Variable bus lanes, setting conditions, critical points, variable signs

1 INTRODUCTION

Currently, due to the relatively lagging implementation of bus priority measures in China, the imbalance between urban transportation demand and the limited supply of transportation resources has become increasingly severe with the advancement of social development and urbanization. This has led to the inefficient use of road resources by conventional urban buses. To address this issue, this paper proposes a variable bus lane control strategy aimed at rectifying the uneven distribution of travel time and space for mixed traffic during different time periods on conventional bus lanes. This strategy is suitable for urban roads with non-fixed period bus lanes.

Scholars both domestically and internationally have conducted research on variable bus lanes. Viegas and colleagues from the University of Lisbon in Portugal first proposed the concept of variable bus lanes (IBL) and studied their impact on the operational efficiency of other social vehicles in 2004 [1][2]. Eichler and others evaluated the

G. Chen et al. (eds.), *Proceedings of the 2024 International Conference on Rail Transit and Transportation (ICRTT 2024)*, Advances in Engineering Research 254,
https://doi.org/10.2991/978-94-6463-610-9_6

variable bus lane system in 2006, finding that it had a minimal impact on buses but could reduce travel time for both buses and cars by about 20 minutes [3]. However, when the road is near or exceeds its capacity, setting up a variable bus lane is ineffective. Zyryanow and colleagues conducted a micro-simulation evaluation of IBL in 2012, assessing its advantages and limitations under different traffic conditions [4].

Domestically, Song Xianmin and others established average travel time models per vehicle and per person under different road conditions based on the operational characteristics of dynamic variable bus lanes. They used MATLAB for mathematical simulation to analyze the applicable conditions of dynamic bus lanes [5]. Dong Youbang and others found that intermittent bus lanes are more effective than fully dedicated bus lanes when vehicle density exceeds 20 veh/h and bus dispatch frequency is below 200 veh/h[6]. Zhao Chenxin established a critical model for setting intermittent bus lanes based on critical traffic volume conditions, determining the flow range for lane setting. However, this model did not consider the impact of periodic bus saturation on regular lanes[7].

In summary, although existing studies have explored the concept and small-scale trials of variable bus lanes, there is still a lack of in-depth research on the conditions for opening and closing these lanes, as well as traffic and passenger flow conditions. Therefore, this paper investigates the conditions for setting variable bus lanes by collecting data on traffic flow, passenger flow, and vehicle speed on Jianhua Road and Kaiyuan Road in Pingdingshan City. The aim is to improve the utilization of road resources in small and medium-sized cities, shorten residents' travel time, and lay the foundation for the implementation of variable bus lanes.

2 DEFINITION OF RELATED CONCEPTS OF VARIABLE BUS LANES

The variable bus lane system is defined as follows: during a predicted variable time period, one or more lanes are converted to bus-only lanes, while during other time periods, these lanes serve as mixed-use lanes. The key to the design of this variable bus lane system is determining the "variable time periods." By analyzing the real-time changes in bus speeds relative to the ratio of non-bus to bus traffic flow within the study area, the traffic flow ratio at which bus speeds significantly decrease is identified and used as the threshold for setting up the bus lanes. Automated detectors are used to sense whether the road traffic has reached this threshold to determine the variable time periods.

3 DESIGN PRINCIPLES OF VARIABLE BUS LANES

3.1 Design Approach

The design concept of this paper is illustrated in Figure 1.

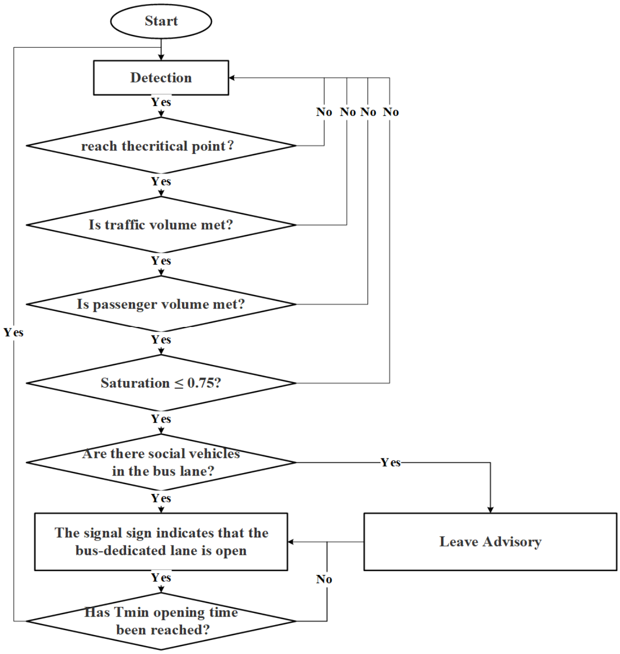

Fig. 1. Workflow diagram of detectors and variable message signs.

This project utilizes loop coil detectors for real-time, round-the-clock monitoring of road traffic flow and an intelligent card system to record passenger boarding and alighting data, achieving real-time monitoring of bus passenger flow. A set of two induction coils is embedded in the roadbed segment of the same lane, connected to a multi-channel vehicle detector. When a vehicle passes over the coils, changes in inductance are detected and transmitted to the vehicle detector for data collection and calculation.

The software performs fitting analysis on the collected data to find the critical point of the bus-to-non-bus traffic flow ratio. The signal controller calculates and determines whether the traffic flow data has reached this critical point and whether the conditions for activating the variable bus lane (traffic flow, passenger flow, and road saturation level reaching C-level service) are met. If these conditions are satisfied, variable information signs will prompt social vehicles to leave the bus lane, and the bus lane will be activated.

After the bus lane has been activated for a preset minimum duration, the system will recheck the current road traffic flow and passenger flow. If the conditions continue to be met, the bus lane activation will remain in effect.

3.2 Key Technologies

(1) Method for determining the setting conditions

When the proportion of bus traffic flow exceeds the proportion of lanes on the road, the traffic flow that causes a decrease in speed serves as the setting condition. When the bus passenger flow on the road exceeds the average passenger flow per lane, this serves as the passenger flow setting condition. When road saturation reaches a C-level service and congestion begins to occur, this serves as the saturation setting condition. The critical point is identified where there is a significant decrease in bus speed as the traffic flow ratio increases.

(2) Method for determining "T_{min}": "Tmin" refers to the ratio of the length of the set variable bus lane to the average speed of buses after the bus lane is activated.

4 DESIGN OF A VARIABLE BUS LANE SYSTEM

4.1 Traffic Flow-Based Method for Determining Variable Time Periods

Denote the bus traffic flow as QB, the non-bus traffic flow as Q1, the average speed of buses as VB, and the average speed of non-buses as V1. When the average speed of buses begins to decrease significantly, the ratio of non-bus traffic flow (Q1) to bus traffic flow (QB) serves as the critical value for activating the bus-only lane.

$$\frac{Q_1}{Q_B} \tag{1}$$

The variable bus lane is not limited to peak hours but is activated based on real-time traffic flow detection. When the ratio of bus traffic flow to non-bus traffic flow reaches or exceeds the critical value, the bus lane is activated. When the ratio falls below the critical value, the bus lane is deactivated and reverted to a mixed traffic lane. This method ensures the effective use of the bus lane through precise data monitoring and flexible control strategies, thereby improving the utilization efficiency of road resources.

4.2 Determination of the Critical Point

A continuous survey was conducted on the bus traffic volume, non-bus traffic volume, and bus speeds on Jian She Road and Kai Yuan Road from 6:30 AM to 9:00 PM, using manual counting and electromagnetic induction coil detection methods. This survey covered peak hours and other travel periods. The survey data shows that during the morning peak, the traffic volume on Jian She Road was 3146 vehicles per hour, with an average bus speed of only 14.46 km/h. On Kai Yuan Road, the morning peak traffic volume was 2553 vehicles per hour, with an average bus speed of only 13.48 km/h. Based on these data, a regression analysis of the traffic volume and average bus speeds on Jian She Road and Kai Yuan Road in Pingdingshan City was conducted, and regression curve graphs for the two roads were established, as shown in Figure 2.

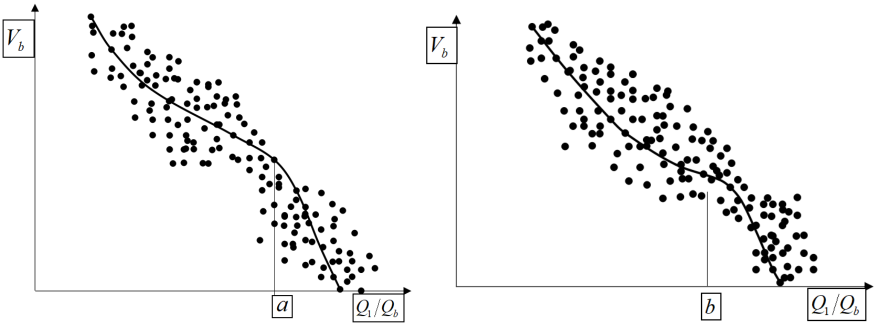

Fig. 2. Data fitting graph of Jianshe Road.

V_b:Average bus speed;Q_l:Non-bus traffic flow;Q_b:Bus traffic flow;

Construction Road Critical Point a: During the 7:10-7:15 period, speed significantly decreases, with a critical value of 8.53. Kaifang Road Critical Point b: During the 8:15-8:20 period, speed significantly decreases, with a critical value of 9.51, which is point b.

4.3 Setting of Loop Coils

The placement of the loop detectors on Kaifu Road is shown in Figure 3.

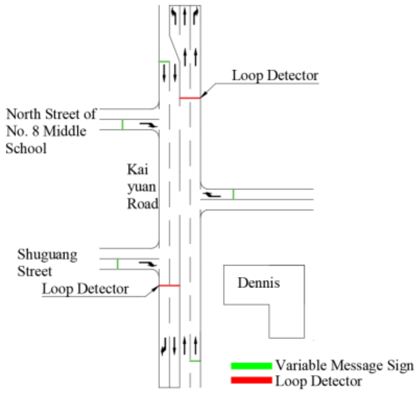

Fig. 3. Schematic diagram of detector placement locations on Kaiyuan Road.

The red line in the figure indicates the position of the loop detector. The loop detector should be placed 10 meters below the intersection of the traffic flow where the traffic flow converges, so as to ensure that the traffic flow converging from the branch road can be detected.

The placement position of the loop coil detector on Jianshe Road is shown in Figure 4.

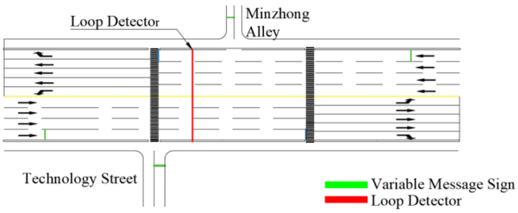

Fig. 4. Schematic Diagram of Detector Placement Locations on Jianshe Road.

The loop coils should be buried along the direction of the traffic flow, about 10 meters away from the merging point, to ensure that the traffic flow merging from Keji Street and Minzhong Lane into Jianshe Road can be detected.

4.4 Location of Variable Signs for Bus-Only Lanes

The sign of variable bus lane is an indicative sign, which needs to be adjusted through electronic screen projection due to its real-time changes. Its setting form is shown in Figure 5.

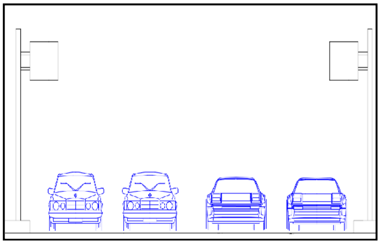

Fig. 5. Installation form of variable signs for bus-only lanes.

(1) location of variable signs on kaiyuan road

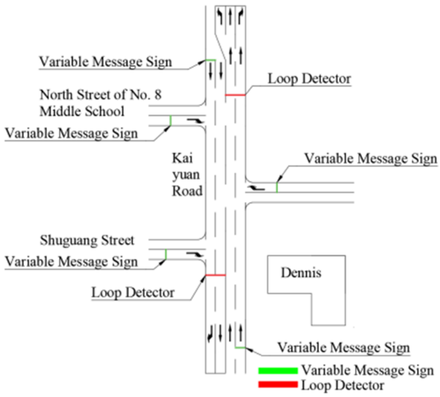

Fig. 6. Schematic diagram of variable Sign placement locations on kaiyuan Road.

To prevent vehicles from the branch road from preempting the bus lane after turning right and merging into the main road, a variable message sign (VMS) is set up 20 meters in front of the stop line of the branch road, so that drivers can get information about the bus lane on the main road in advance. The VMS on Kaiyuan Road and its branch roads is shown in Figure 6.

(2) Location of variable signs on Jianshe Road

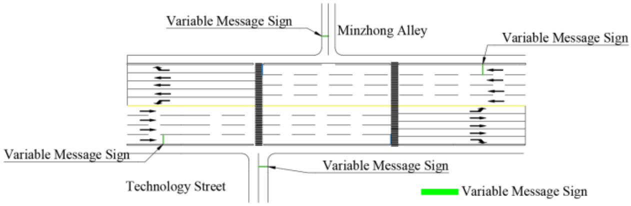

Fig. 7. Schematic Diagram of Variable Sign Placement Locations on Jianshe Road.

Similar to the setting principle of the variable message signs on Kaiyuan Road, variable message signs are set 20 meters before the stop line at the intersection of the branch road. The variable message sign on Kaiyuan Road is shown in Figure 7.

5 SIMULATION COMPARISON OF SCHEMES

5.1 Preparation of Basic Data

(1) Simulated road length (300m);

(2) Traffic flow on Kaiyuan Road and Jianshe Road;

(3) The proportion of social vehicles, buses, and non-motorized vehicles on Kaiyuan Road and Jianshe Road;

(4) Expected driving speeds of social vehicles, buses, and non-motorized vehicles.

5.2 Simulation Design

By summarizing the survey tables, we obtain the total traffic volume on Kaiyuan Road and Jianshe Road, as well as the proportion of various types of vehicles in the traffic flow. The data obtained through the survey is then input into Vissim for simulation.

(1) The simulation scenarios before and after the implementation of variable bus-only lanes on Jianshe Road are shown in Figure 8.

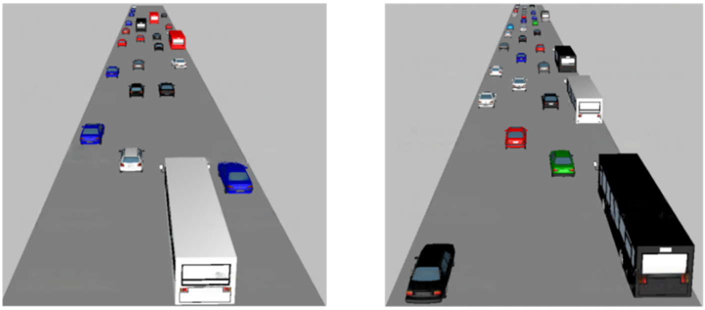

Fig. 8. Simulated effects before and after the setting of variable bus-only lanes on Jianshe Road.

On the left side of the figure is a simulation of the current condition of Jianshe Road before the setting of variable bus-only lanes, while the right side shows the simulation after the setting. The simulation images clearly demonstrate that due to the separated driving of vehicles, both social vehicles and public buses are able to operate normally without mutual interference, resulting in improved speed and efficiency for both social vehicles and public buses.

(2) The simulation results before and after setting variable bus-only lanes on Kaiyuan Road are shown in Figure 9.

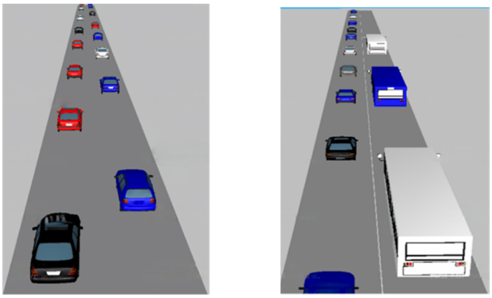

Fig. 9. Simulation results before and after the implementation of variable bus-only lanes on Kaiyuan Road.

The left image simulates the current situation on Kaifang Road without the variable bus lanes, while the right image simulates the current situation with the variable bus lanes. On Kaifang Road, mixed traffic of motor vehicles and non-motor vehicles significantly reduces the efficiency and speed of motor vehicles. After implementing the variable bus lanes, the speed and efficiency of buses have greatly improved. However, since Kaifang Road only has two lanes, social vehicles still mix with non-motor vehicles, meaning the driving environment has not improved and the road resources available to social vehicles are even less than before the implementation.

5.3 Analysis of Simulation Results

After setting up variable bus-only lanes, Vissim was used to simulate the speed changes before and after to determine the feasibility and scientific validity of the variable bus-only lanes.

(1) The simulation results of vehicle speed before and after setting variable bus-only lanes on Jianshe Road are shown in Figure 10.

Car;	21.74;
Bus;	20.58;
Bus;	17.25;
Car;	14.25;
Car;	26.28;
Car;	35.19;

Car;	38.76;
Car;	41.01;
Car;	42.26;
Bus;	31.59;
Bus;	30.57;
Bus;	32.65;

Fig. 10. Simulated data of vehicle speed before and after setting variable bus-only lanes on Jianshe Road.

The data on the left represents the situation before the implementation of the variable bus lanes. Data analysis shows that some vehicles' speeds exceeded the expected speed. The main reason is that at the beginning of the simulation, the traffic flow was light, allowing vehicles to move smoothly, resulting in higher-than-expected speeds for private vehicles. However, as more buses joined the traffic, the speed of private vehicles gradually decreased. When there were multiple buses on the road, the overall traffic speed significantly reduced, with the final actual speed being only half or less of the expected speed.

The data on the right represents the situation after the implementation of the variable bus lanes. Data filtering shows that the speeds of all vehicles approached the expected speed, with most vehicles even exceeding it. This indicates that setting up variable bus lanes on the construction section not only significantly improves the speed of buses but also enhances the speed of private vehicles, thereby increasing travel efficiency.

(2) The simulation results of vehicle speed before and after setting variable bus-only lanes on Kaiyuan Road are shown in Figure 11.

Bike;	17.10;
Car;	16.50;
Car;	15.66;
Car;	15.18;
Car;	14.31;
Car;	13.85;
Bike;	14.34;
Bus;	15.32;
Bike;	14.65;
Car;	19.95;

Bike;	16.83;
Bike;	18.93;
Bus;	32.15;
Bus;	28.51;
Bus;	28.73;
Bus;	35.52;
Car;	16.42;
Car;	16.50;
Car;	18.41;
Car;	16.62;

Fig. 11. Simulated data of vehicle speed before and after setting variable bus-only lanes on Kaiyuan Road.

The data on the left shows the vehicle speed before setting variable bus-only lanes, and the data on the right shows the vehicle speed after setting variable bus-only lanes. Through the data, we can see that after installing variable bus-only lanes, the speed of buses has been greatly improved. Most buses are able to reach or even exceed the expected speed of 30 km/h. However, the speed of social vehicles has not improved significantly. This is because Kaiyuan Road lacks bicycle lanes, and non-motorized vehicles will mix with social vehicles, resulting in a lower speed for social vehicles.

6 CONCLUSION

This article adopts the method of variable bus-only lanes. When the bus speed decreases significantly, the road service level reaches Level C, and both passenger flow and traffic volume conditions are met, the variable bus-only lanes are activated. The variable bus-only lanes can not only ensure the normal operation of social vehicles and the rational allocation of road resources during off-peak hours, but also achieve "bus priority" during peak hours. The results show that the implementation of variable bus-only lanes can not only improve the speed of buses but also enhance the utilization efficiency of road resources.

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