Optimisation of Bus Stop Layout Based on Time Distance Trajector

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Abstract. Under the background of arterial coordinated control, the location of a bus stop has a considerable influence on bus operations. In this study, the optimisation of the bus stop layout was investigated. Based on the time distance graph and green wave band, the distribution range of the travel trajectory of the bus flow on the road section was drawn. The travel trajectory distribution of two typical combinations of bus stop pairing layouts and intersections was analysed, and an ideal layout scheme with a staggered arrangement of a pairing layout and an intersection group was developed. For the reconstruction or new construction of a road, optimisation based on the local fine adjustment of the bus stop location, and the overall optimisation based on the ideal layout scheme were determined, respectively. The simulation results showed that the optimisation method based on the time distance trajectory had good manoeuvrability. The ideal layout scheme of bus stops could effectively reduce the bus delays and had a good optimisation effect. The deficiency was that the ideal layout scheme was restricted by the road condition and it had some limitations.

1. Introduction
Arterial coordinated control is a common signal control method for urban traffic; well-designed coordinated control allows vehicles to pass through multiple intersections continuously. Bus priority is set by setting the bus lanes and bus priority signals and assigning bus vehicles a higher priority. Doing so can improve the operation efficiency of public transit. In the background of arterial coordinated control, the bus is constrained to the intersection signal control and the bus stop; it is difficult to achieve continuous non-stop travel through multiple intersections, and there is an inconsistency between the bus operation and the green wave.

There are mutual influences and constraints between the bus stop layout and the green wave; when the bus stop is located at the upstream or downstream of the intersection, the impact on signal control is different.

A bus stop is placed upstream of the intersection: Lee, on the basis of the bus travel time prediction model, combined with the bus stop upstream of the intersection, proposed a bus priority signal control
method [1]. Kim, on the basis of the vehicle arrival time prediction model and the bus stop time model, established a bus signal priority control system for the bus stop upstream of the intersection [2]. Zheng established a theoretical model of bus delay, exploring the impact of the bus stops upstream of the intersection on bus delays, and proposed the optimal bus priority control strategy [3].

A bus stop is placed downstream of the intersection: Ludwick pointed out that it is more beneficial to assign the bus priority when the docking station is placed downstream of the intersection. When the bus stop is located at the upstream of the intersection, the uncertainty of the bus stop time affects the arrival time of the vehicle at the intersection, which makes the priority control of the bus difficult to realise [4]. Byrne et al. conducted a simulation test and analysis on the bus stops in the upstream and downstream of the intersection, and the results showed that the bus priority effect was better when the bus stop was placed in the downstream of the intersection [5]. Wang proposed the optimisation of the bus stop location under the bus priority control strategy: if the road conditions allow and the harbour bus stop is set up downstream of the intersection, the bus priority control effect is better [6, 7].

On the basis of the research background of the traffic arterial system, in this study, we considered the layout and the optimisation of bus stops on the arterial system. Satiennam proposed a bus priority control strategy for the upstream bus stop at the intersection with the two-lane arterial road as the research object through a model calculation and simulation analysis [8].

Based on arterial coordination control, this paper analyses the relationship between the signal control of the intersection and the layout of the bus station based on the time distance trajectory of the bus, and proposes a bus station layout optimization method.

2.  time distance trajectory

The time distance diagram is a two-dimensional diagram with time as the ordinate and distance as the abscissa, which is used to draw the running trajectory of the vehicle. In the graphical method of arterial coordinated control, the vertical axis represents the traffic light time controlled by signals, while the horizontal axis represents the multiple intersections along the line and their spacing. In the first quadrant of the time distance graph, a reasonable green wave band speed is selected for the coordinated control scheme design.

2.1. Trajectory of Transits

The integration of the coordinated green band and vehicle trajectory helps to analyse the bus traffic flow on the arterial system. Under the condition of bus lanes, the time and distance data of the bus vehicles travelling on the main line are collected, and the data points \((x = \text{distance}; y = \text{time})\) are connected into lines in the time distance graph to obtain the vehicle’s trajectory, as shown in Figure 1.

![Figure 1. Travel trajectory of transit vehicle at the time distance.](image-url)
Figure 1 shows that when the bus enters bus stop 2 for parking, its running trajectory is shown as a vertical line segment, and its length represents the bus stop time. When the bus leaves bus stop 2, it meets the red signal at the downstream intersection and waits for the red signal before entering the next green wave band. It can be seen from the trajectory that after the bus stops at bus stop 1 and bus stop 2, it cannot remain in the current green wave zone and is delayed to the next green wave zone.

2.2. Trajectory Distribution of Bus Flow on Road Section
On the time and distance trajectory map, the travel trajectory of a single bus is not representative. Therefore, it is necessary to analyse the overall travel trajectory distribution of the bus flow from a macro perspective. The data to be investigated to draw the trajectory of the bus traffic flow are the road conditions of the main lines, signal control scheme, speed distribution of the bus traffic flow, and the bus stop time distribution.

2.2.1 No bus stop on the road section. Starting from the green wave zone on the parking line at the upstream intersection, the bus flow trajectory has a smaller range of diffusion along the driving direction. The influence of signal control at the downstream intersection is divided into two parts.

When the minimum travel speed is lower than that of the green wave zone, the slower bus will move up to the outside of the green wave zone, meet the red light at the downstream intersection, and then continue driving at the beginning of the next green wave zone; that is, this part of the bus will be delayed to the next green wave zone. When the maximum travel speed is higher than that of the green wave zone, the faster bus will go down ahead of the current green wave zone and re-enter the current green wave zone after waiting for the shorter red light at the downstream intersection.

2.2.2 A bus stop on the road section. When there is a bus stop on the road section, the bus must stop at the station. The travel trajectory distribution range of the bus flow moves upward along the longitudinal time axis. The influence of signal control at the downstream intersection is divided into two parts.

The travel trajectory distribution of a bus has a stepped upshift at the bus stop: the length of time when the lower boundary moves up at the bus stop is the minimum stop time in the bus stop time distribution, and the upper boundary moves up at the bus stop. The length of time is the maximum stop time.

2.2.3 Bus stops are located in pairs on the road section. When there are two bus stops on the road section, the bus stops are usually located at the two ends of the road section; that is, the bus stops are arranged in pairs on the road section. The distribution of the trajectory of the bus flow moves axially twice in the longitudinal direction and is divided into two parts by the influence of the signal control at the downstream intersection. The trajectory distribution is shown in Figure 2.

![Figure 2. Travel trajectory distribution of two bus stops on a road section](image-url)
In Figure 2, the bus trajectory distribution is shifted up one step at each of the two bus stops and is affected by the difference in the bus speed and the signal control of the downstream intersection. The trajectory of the bus flow is also decomposed at the downstream intersection to the two parts of ‘delayed’ and ‘reserved’, as shown in the figure A’ B’ and B’ C’. Compared with the situation where there is only one bus stop on the road section, the proportion of ‘delayed’ here is relatively large.

3. Typical combination of bus stops and intersections
When considering multiple bus stops and intersections in the context of arterial coordination, different combination schemes result in different bus travel trajectories, and the representative combinations are as follows.

3.1. Intersection Group between Bus Stops
When there are two or more intersections (or pedestrian-controlled crosswalks) between the two bus stops, a typical combination of the upstream and downstream bus stops and the intersections between stations forms a bus trajectory distribution, as shown in Figure 3.

![Figure 3. Travel trajectory distribution of intersection group between bus stops](image)

In the example shown in Figure 3, there are three signal control intersections between bus stop 1 and bus stop 2, and the bus flow leaves bus stop 1 to enter the green wave band. Most buses can pass through the three intersections continuously, and a small number of slower buses are delayed at intersections 2 and 3 to the next green wave band. For the bus flow, this typical combination creates an effective local green wave between the two bus stops.

3.2. Combination of Paired Layout and Intersection Group
When considering more intersections and bus stops on the arterial system, we observed that the connection between the bus stops which were laid in pairs on the road section with the intersection group of bus stops formed another typical combination. The bus travel trajectory distribution is shown in Figure 4.
Figure 4. Travel trajectory distribution of a combination of pairing layout and intersection group

In Figure 4, bus stop 1 and bus stop 2 are arranged in pairs on the road section, and there are three consecutive intersections between bus stop 2 and bus stop 3. When the sum of the stop times of the bus at bus stop 1 and bus stop 2 is greater than the green time of the green wave band, the bus travel trajectory is delayed at intersection 2 to the next green wave band and is concentrated in the initial green light of the signal control.

3.3. Staggered Arrangement of Pairing Layout and Intersection Group
In the arterial system, the bus stop is used as the connection point, and the pair of layouts on the road section is intertwined with the intersections of the stations, which can form a very ideal bus stop layout scheme, as shown in Figure 5.

Figure 5. Staggered arrangement of pairing layout and intersection group

In the ideal layout of Figure 5, the bus can be docked in the paired route to make full use of the red light time outside the green band, and then transition to the next green band at the downstream intersection. The delay of the bus flow is mainly concentrated in the first intersection in the intersection of stations. As shown in the figure, the first intersection downstream of bus stop B2, and the other intersections in the local green wave have a very significant impact on the bus flow. The bus flow passes through the next pair of bus stops to enter the next local green wave.

4. Simulation experiments and results analysis
In order to verify the abovementioned bus stop layout optimisation method, the arterial simulation model was built in the VISSIM, and the current layout, optimised layout, and the ideal layout were, respectively, set up. The simulation experiment was run, and the bus delay was counted.
The simulation model was built in the background of Xiongchu Avenue in Wuhan. There were six control intersections and two crosswalk signal controls (#3 and #5) on the arterial system. A one-way green wave from west to east was set according to the road conditions and the traffic conditions. The common period of the signal control cycle was 90 s. The straight green time of the two key intersections (#2 and #6) was 35 s, and the straight green time of the other signal control was 50 s.

4.1. Bus Stop Layout Plan
The three bus stop layout schemes are shown in Figure 6. The current layout is the location of the bus stop under the existing road conditions. On the basis of the current layout, the bus stop upstream of intersection #6 is fine-modified, which is, moved from the upstream to the downstream of intersection #6, as shown by the arrow in Fig. 6, to obtain an optimised layout.

In order to verify the optimisation effect of the ideal layout, according to the road conditions and the location and the constraint relationship of the bus stop, an ideal layout for the intertwined connection between the paired layout and the intersection group is established, as shown in the bottom row of Figure 6.

In the ideal layout of Figure 6, the bus stop is arranged in pairs between intersections #1 and #2, #4 and #5, and #6 and #7, at intersections #2–#4 and #5 and #6, and three intersection groups are formed between #7 and #8.

4.2. Comparative Analysis of Bus Delays
The delay evaluation results of multiple simulation experiments were statistically analysed. The bus delays of the three bus stop layout schemes are shown in Figure 7.

Figure 7 shows that the bus delay of the optimised layout is reduced by 3.8% compared with the current layout, and the optimisation effect is not obvious. The bus delay of the ideal layout is reduced by 22% compared with the current layout, and the optimisation effect is very obvious. In addition, in the three bus stop layout schemes, there was no significant difference in the straight traffic flow of other vehicles.
5. Conclusion
Under the background of the coordinated control of the arterial system, the green wave band and the bus travel trajectory on the time distance map could be used to analyse the influence of the different positions of the bus stop on the bus operation. On the basis of an analysis of the different combinations of intersections on the arterial system and the location of the bus stop, the ideal layout scheme for the pairing of bus stops and the intersection of stations was proposed.

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