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Optimization of bus stops layout under the conditions of coordinated control

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Abstract

Arterial coordinated control and transit signal priority are effective ways to alleviate traffic congestion. Transit vehicles must enter the bus stops for passenger boarding and alighting. The research of transit signal priority should consider the impact of bus stop locations under the condition of arterial coordinated control. The objective of this paper is to analyze and optimize the bus stops layout under the conditions of coordinated control. The restrictions of relocated bus stops on public transportation planning were explained, and the impact of relocated bus stop on bus trajectory and arterial coordinated control was analyzed. The simulated optimization method was applied to optimizing bus stops layout when compared with the mathematical optimization method. Then, the arterial simulation model with ten signal controls and eight bus stops was built, and typical layouts of bus stops were planned. One bus stop at one link was defined as "single" layout, near- and far-side bus stops at the same link was defined as "pairing" layout. Single layout for some bus stops and pairing layout for others defined as "mixed" layout. Simulation experiments of each layout at the same coordinated control and traffic volume were carried out, and performance index such as delay was evaluated. The simulation result shown that delay of all bus stops at pairing layout was less than all at single or mixed layout. Furthermore, the ideal layout module composed with three bus stops at some segments was proposed, and suggestion of relocated bus stops based on ideal layout module was presented.

Keywords: bus stops layout; simulated optimization; coordinated control; transit signal priority

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1. Introduction

Arterial coordinated control refers to timing plan design during inter-coordination at multiple intersections on an artery so as to enable vehicles moving under regulated speed to continuously pass through multiple intersections on the artery with as minimal interruption as possible. Practical experiences have shown arterial coordinated control is an effective signal control strategy as well as basis and supplement for regional control.

Transit signal priority refers to providing convenient control measures for buses passing through signal intersections, and also refers to providing a priority for buses at signal control intersections compared with the other vehicles. Based on continuous signal coordination at adjacent intersections, signal priority can be realized through on/off time of green lights at corresponding phases, through changing phase sequence and other methods.

Buses must enter the bus stops for passenger to board and alight, a particularity of bus traffic flow running when transit signal priority is implemented under the background of arterial coordinated control. Therefore under the arterial coordinated control, some interactions effects and restrictions may possibly exist between different schemes of bus stop layout and coordinated control schemes. Therefore it is necessary to deeply research on the adjustment of bus stop positions and optimal bus stop schemes to alleviate conflicts between arterial coordinated control and bus signal priority to some extent.

As research on transit priority become deeper and deeper, more and more scholars have started to include bus stops into research scopes, and have conducted analyses and research of different levels according to different research scopes.

Byrne et al. (2005) made simulation tests and analyses of upstream and downstream bus stops at single-point intersections, and the results showed transit priority presented much better effects in downstream bus stops at intersections. Long et al. (2008) considered impacts of upstream bus stops upon downstream intersections in transit priority strategy in 2008, and predicted time intervals from buses leaving bus stops to reaching stop lines. Ma et al. (2011) considered impacts of downstream bus stops upon transit signal priority in signal control strategy, put forward a signal priority system based on intersections and bus stops, and set up mathematical models taking the minimum time table deviation and minimum social vehicles delay as targets. Lee et al. (2013) considered layout conditions of near-and far-side bus stops, and put forward prediction models of online bus journey time.

Relevant research of Ludwick et al. (1976) indicated setting up bus stops at downstream intersections would be much better for exerting transit priority benefits; the reason was when buses stopped in upstream intersections, uncertain stopping time would impact time of buses reaching intersections, thus it would be more difficult to realize priority control. Wu et al. (2008) made a simulated analysis and took bus delay as evaluation index, comparing advantages and disadvantages of different setting modes in adjacent bus stops on the coordinated artery. The research results showed bus delay could be reduced through optimization of bus stop layout under a certain signal timing scheme.

Based on research of isolated intersections, Ma et al. (2010) took intersection groups as research targets in 2009, and put forward a coordinated control method of transit priority taking the minimum delayed deviation for vehicles passing through intersection groups as control targets. Ma et al. (2013) t took coordinated intersection groups between two bus stops on the artery as research targets, set up delay models and invalid priority time models, and set up linear programming models taking the minimum journey time and invalid priority time as targets so as to obtain the optimal priority strategy and duration.

In transit priority research at the arterial level, as for near-side bus stops on the artery, Kim et al. (2005) adopted weighted least square regression models to estimate standing time of buses and predict a time window for bus arrivals, and furthermore comprehensively considered the time window to implement signal priority in priority strategy. Satiennam et al. (2005) considered impacts of near-side bus stops on a two-lane artery, estimated green loss time during bus stopping, and selected proper priority strategy after buses left.

Impacts of bus stop positions have been considered in previously relevant research and multiple research results have been made. However there is neither sufficient research on multiple bus stops at the arterial level nor detailed optimization research on layout schemes of bus stop positions.

2. Problem Description and Method Selection

2.1. Problem Description

Layout positions of a single bus stop in a segment can be divided into: upstream segment, middle segment, and downstream segment. Positions of multiple bus stops in the same segment are multiple combinations of single bus stop layout, such as combination between upstream and downstream positions, or combination between upstream and middle positions. Layout schemes of multiple bus stops in multiple segments can have more combinations. Under the arterial coordination background, the known road conditions are multiple intersections, segments, and bus stop positions on the artery.

The problems researched in this paper can be described in the following: take arterial coordination as background, based on the unchanged and existing coordination control strategy, optimize layout schemes of bus stops on artery, seek an optimal layout scheme of bus stops to minimize running time or delayed time of bus traffic flow on artery.

2.2. Selection of Optimization Methods

There are multiple optimization methods of layout schemes. The common methods based on mathematical models need to set up corresponding optimization models according to hypothesis, and then solve by various methods. Quality of mathematical models depends upon presumption and hypothesis, complexity of models, and difficulty level of mathematical solutions. In case of easy presumption and hypothesis, the built mathematical models cannot show complex traffic conditions; meanwhile complex presumption and hypothesis limit universality of models. Furthermore, it is difficult to make mathematical solutions in complex mathematical models. Usually the optimal solution to the models cannot be found out.

Microscopic traffic simulation is an analysis tool of testing and optimizing various traffic planning and design schemes as well as describing traffic running processes in complex roads. The optimization methods based on simulation experiments are widely applied in traffic systems: road-network models built in micro-simulation simulator, building simulation experiment platforms for repeated trials, observing change law of indexes such as delay or queue through changing single or multiple factors in road-network models, making quantitative analyses under various influential factors.

The optimization methods based on simulation experiments also have disadvantages, namely, a local optimal solution instead of a global optimal solution is obtained during an optimized analysis. The reason is all states of combinations cannot be fully enumerated during analyzing states of combinations of influential factors, and an optimal solution may be missed, thus the optimal solution cannot be judged as the global one.

Select optimization methods of simulation experiments as trials in view of special layout optimization of bus stops as well as difficult modeling based on optimization methods of mathematical models.

3. Simulation Optimization of Bus Stop Layout

Enumerate typical schemes of bus stop layout during simulation optimization research on bus stop layout. Conduct simulation experiments in the same road-network model and output evaluation indexes such as bus delay. Seek the optimal scheme of bus stop layout through analyzing and comparing relations between different layout schemes and delayed indexes.

Based on the completion of building simulated road-network models, simulation optimization of bus stop layout has two steps: firstly make position adjustment of bus stops in internal segment, such as layouts in upstream, middle or downstream segment; secondly make position adjustment of bus stops in upstream and downstream intersections, namely position adjustment between segments.

3.1. Build Simulation Models of Optimized Bus Stop Layout

In order to enumerate schemes of bus stop layout in a much more detailed way, take the following place as research background: partial segments in Xiongchu Avenue, Hongshan District, Wuhan City, Hubei Province, China;

build 8 signal control areas and 8 arterial simulation models of bus stops. Figure 1 shows the specific positions of the researched areas in Wuhan City.

Fig. 1. Sketch Map of Specific Positions of the Researched Areas in Wuhan City

Figure 2 shows arterial models built in VISSIM. Arterial road is about 3860m long; set up 6 signal control intersections and 2 pedestrian crossing signals, for a total of 8 signal control areas. Set up a one-way green wave from west to east according to road and traffic conditions, with a green wave band speed of 50km/h. Common period in signal control scheme lasts 90s, in which straight moving green lights last 35s in Xiongchu Avenue-Luoshi Road intersections (#2) and Xiongchu Avenue-Zhuodaoquan Road intersections (#6); the rest of the straight moving green lights under signal control last 50s.

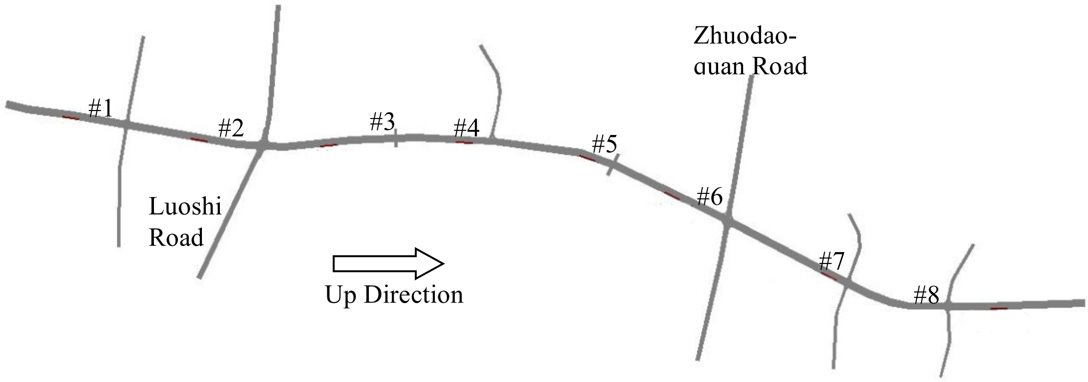

Fig. 2. Arterial Simulation Models Built in VISSIM

According to the investigated traffic flow during off-peak times, set up corresponding quantity of flow and flow direction in road-network models. Adopt OD form to input path selection which can guarantee vehicles will not disappear due to frequent path selections during vehicle running, and keep smaller rates of changing lanes to guarantee accuracy of flow direction and quantity of flow.

Set up 8 bus stops on the artery running from west to east, as shown in Figure 2. Refer to bus routes actually operated on the artery. Set up 4 bus routes in simulation models after classification and combination. Set up different departure frequency in road-network models, and total departure frequency in bus traffic flow to be about 2.14 vehicles/min. Bus stopping time is subject to normal distribution.

Set up special bus transit roads in simulation models. Only adjust bus stop positions and do not change arterial coordination signal control schemes at the same time. Therefore adjustment of bus stop positions slightly impacts social traffic flow. Simulation evaluation results show quite small changes in delayed social traffic flow. The subsequent research and analysis targets mainly focus on changes in delayed bus traffic flow.

3.2. Adjustment of Bus Stop Positions within Segments

In view of various limitations on bus stops within intersection scope, such as queue in entrance lane, interweaving, and overflow limitations on exit lane etc. Adjust bus stop positions within segments under the scope of the allowed road conditions.

- Layout schemes

Set up 5 typical combination schemes in bus stops, as shown in Table 1.

Table 1 Collection of Layout Schemes of Bus Stops within Segments

<table>
<tr><th>NO.</th><th>SEG.1</th><th>SEG.2</th><th>SEG.3</th><th>SEG.4</th><th>SEG.5</th><th>SEG.6</th><th>SEG.7</th><th>SEG.8</th><th>SEG.9</th></tr>
<tr><td>A-01</td><td align="left">▬</td><td align="left">▬</td><td align="left">▬</td><td align="left">▬</td><td align="left">▬</td><td align="left">▬</td><td align="left">▬</td><td align="left">▬</td><td></td></tr>
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</table>

In Table 1, "▬" in the Table stands for bus stop positions; running direction of bus traffic flow is from Segment 1 to Segment 9. "▬" leftwards in the Table stands for bus stop layout in the upstream segment, rightwards in the downstream segment. Layout schemes No. A-01 ~ A-03 successively stands for the schemes of bus stops in upstream, middle and downstream. Layout schemes No. A-10 and A-11 stand for two schemes of staggered bus stop layouts in upstream and downstream.

- Simulation analysis

In the arterial simulation models of VISSIM, keep the other parameters unchanged and only change 8 bus station positions, and operate 5 random seeds in each layout scheme.

Record total delay of bus traffic flow from Segment 1 to Segment 9, which includes signal control delay time and delay time of in/out bus stop. Calculate average value of delayed buses under 5 random seeds for contrastive analysis. Collect bus delay comparisons of 5 layout schemes of Type A, as shown in Figure 3.

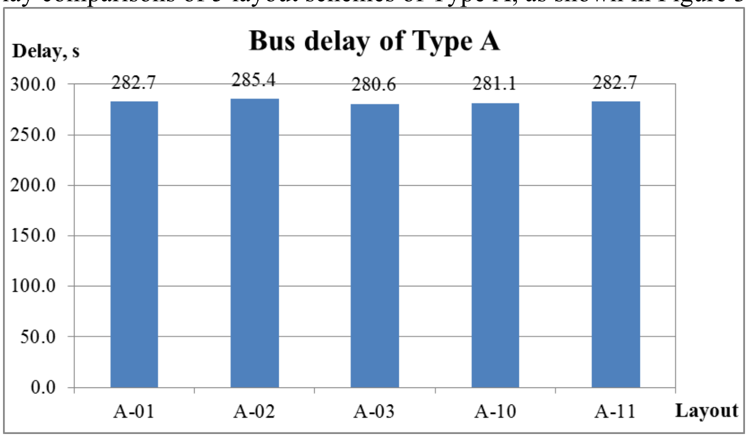

Fig. 3. Comparison Diagram of Bus Delay of Layout Schemes of Type A

Figure 3 shows closely approximate bus delay under several bus stop layout schemes. No obvious differences are seen in different layout schemes.

In reason analysis, only changes of bus stop positions are considered in arterial simulation models, excluding time changes from bus passenger walking to bus stops after adjustment of bus stop positions as well as changes in passenger arrival distribution. Relevant setting is time distribution of bus stopping in station. Due to pedestrian simulation uninvolved in road-network models, it is unable to accurately describe changes of stopping time distribution possibly caused by adjustment of bus stop positions.

In the case of neglecting inconformity between changes of passenger arrival distribution and bus stopping time, adjustment of bus stop positions within segments will slightly impact total delay of bus traffic flow.

3.3. Adjustment of Bus Stop Positions within Segments

Adjustment of bus stop positions within segments is made in upstream and downstream intersections of bus stops.

- Layout schemes

In order to fully enumerate layout combinations of bus stops, layout schemes are divided into “pairing” layout and “mixed” layout.

Pairing layout: it refers to layout of 2 bus stops in the upstream and downstream of the same segment. 8 bus stops are distributed in 9 segments, decide whether to separately set up bus stops by front and end segments (Segment 1 and Segment 9); then divide layout schemes into sub-type B0 (no bus stops) and sub-type B1 (separate bus stops); a total of 26 layout schemes as shown in Table 2.

Table 2. Collection of Pairing Layout Schemes of Bus Stops between Segments

NO.	SEG.1	SEG.2	SEG.3	SEG.4	SEG.5	SEG.6	SEG.7	SEG.8	SEG.9
B0-0		— —		— —		— —		— —	
B0-1		— —	— —		— —			— —	
B0-2		— —	— —			— —		— —	
B0-3		— —		— —	— —			— —	
B0-4		— —		— —			— —	— —	
B0-5		— —			— —	— —		— —	
B0-6		— —			— —		— —	— —	
B1-0	—		— —		— —		— —		—
B1-1	—	— —	— —			— —			—
B1-2	—	— —			— —	— —			—
B1-3	—	— —			— —			— —	—
B1-4	—			— —	— —	— —			—
B1-5	—			— —	— —			— —	—
B1-6	—			— —			— —	— —	—
B1-7	—	— —		— —		— —			—
B1-8	—	— —		— —			— —		—
B1-9	—	— —			— —		— —		—
B1-10	—		— —	— —		— —			—
B1-11	—		— —	— —			— —		—
B1-12	—			— —	— —		— —		—
B1-13	—		— —		— —	— —			—
B1-14	—		— —			— —	— —		—
B1-15	—			— —		— —	— —		—
B1-16	—		— —		— —			— —	—
B1-17	—		— —			— —		— —	—
B1-18	—			— —		— —		— —	—

Table 2 shows layout schemes of No B0-0 ~ B0-6 are B0 without bus stops in front and end segments, a total of 7 layout schemes in which B0-0 is uniform layout. Layout schemes of No B0-0 ~ B0-18 are B1 with bus stops in front and end segments, a total of 19 layout schemes in which B1-0 is a special uniform layout excluding bus stops in front and end segments.

In the 26 pairing layout schemes, except B1 front and end segments, 0 or 2 bus stops exist in the rest of the segments; the condition of 1 bus stop does not exist.

Mixed layout: Compared with pairing layout, it refers to the condition that 0 or 2 pairs of bus stops exist in segments and the fact that 1 bus stop exists in segments, and the pairing is mixed with separately set position. According to 1 and 2 pair(s) of bus stops, there is C1 (1 pairing layout) and C2 (2 pairing layouts), a total of 12 layout schemes as shown in Table 3.

Table 3 Collection of Mixed Layout Schemes of Bus Stops between Segments

NO.	SEG.1	SEG.2	SEG.3	SEG.4	SEG.5	SEG.6	SEG.7	SEG.8	SEG.9
C1-1		— —		—	—	—	—	—	—
C1-2	—		— —		—	—	—	—	—
C1-3	—	—		— —		—	—	—	—
C1-4	—	—	—		— —		—	—	—
C1-5	—	—	—	—		— —		—	—
C1-6	—	—	—	—	—		— —		—
C1-7	—	—	—	—	—	—		— —	
C2-1		— —		— —		—	—	—	—
C2-2	—		— —		— —		—	—	—
C2-3	—	—		— —		— —		—	—
C2-4	—	—	—		— —		— —		—
C2-5	—	—	—	—		— —		— —	

Table 3 shows schemes of No.C1-1 ~ C1-7 are C1 with 1 pair of bus stops, a total of 7 layout schemes. The segments with pairing layouts in the Table are filled with light color background. Schemes of No.C2-1 ~ C2-5 are C2 with 2 pairs of bus stops, a total of 5 layout schemes.

- Simulation analysis

In simulation models, set up bus stop positions according to layout schemes. Operate simulation experiments and record total delay of bus traffic flow. Calculate average value of total delay under 5 different random seeds. Collect bus delay of different layout schemes and draw delayed comparison diagrams by type.

Pairing layout: in pairing layout schemes of bus stops, Figure 4 and Figure 5 show delayed bus comparisons of B0 and B1.

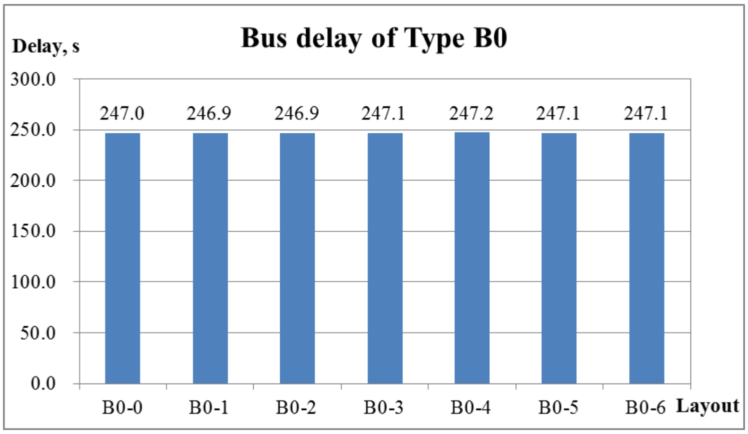

Fig. 4. Comparison Diagrams of Delayed Buses in B0 Layout Schemes

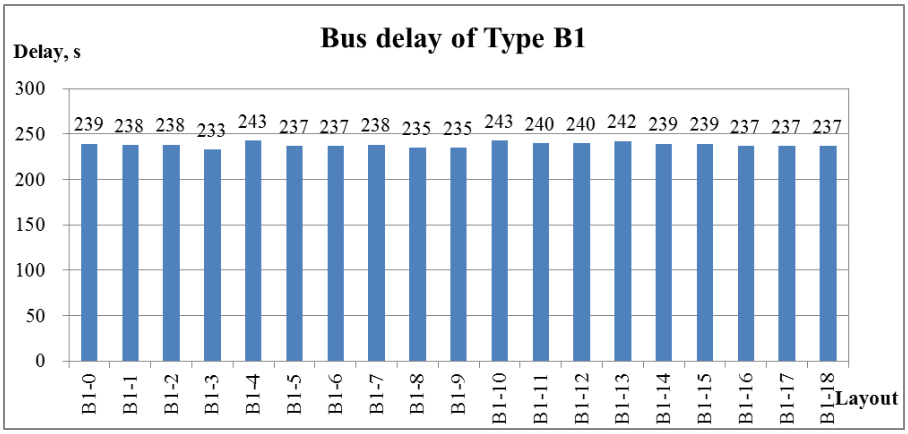

Fig. 5. Comparison Diagrams of Delayed Buses in B1 Layout Schemes

Figure 4 and Figure 5 show the bus delay is approximate in the two layout schemes. No obvious differences are seen in different layout schemes of the same type.

No obvious differences exist in bus delay between layout schemes of the same type comparing Type A, Type B0 and Type B1, but big changes exist in average delay of different types. In order to further analyze delay correlations of different types, calculate average value of bus delay of various layout schemes by type, and collect average value of bus delay of the three layout schemes, as shown in Figure 6.

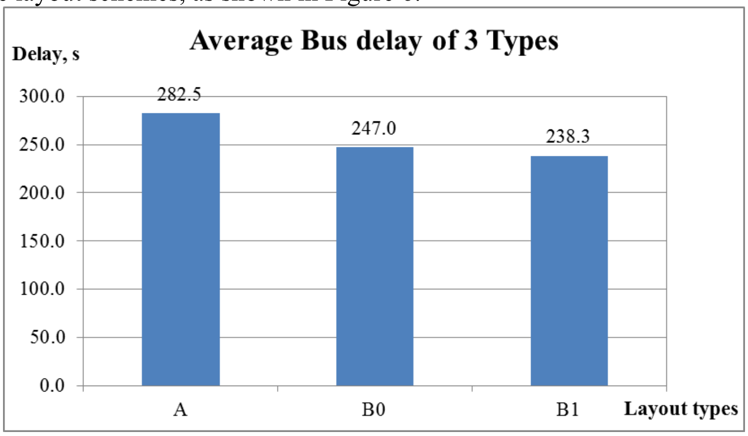

Fig. 6. Comparison Diagram of Average Value of Bus Delay of Layout Schemes of Type A, B0 and B1

Figure 6 shows average value of bus delay is much bigger in layout scheme of Type A, meanwhile average value of bus delay is much smaller in pairing layout schemes of Type B0 and B1. In sub-types of pairing layouts, comparing no bus stops in front and end segments of Type B0 with separate bus stops in front and end segments of Type B1, average value of bus delay in B0 layout scheme is slightly bigger than that of in B1 layout scheme, but with no obvious differences.

Through the above comparisons, pairing layout schemes are more advantageous than those of separate bus stops in each segment. The reason is that multiple intersections and segments exist between two bus stops in the pairing layouts, as shown in the regions between Bus Stop 2 and Bus Stop 3 in Figure 7. As there is no bus stop in the regions, a section of local green wave may be easily formed during bus running traffic flow, thus total bus delay is reduced.

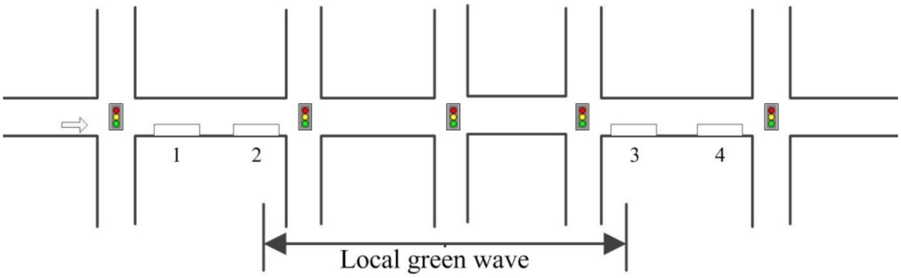

Fig. 7. Sketch Maps of Two Pairs of Bus Stops in Pairing Layouts

Mixed layout: in mixed layout schemes of bus stops, Figure 8 and Figure 9 show bus delay comparisons of sub-type C1 and C2.

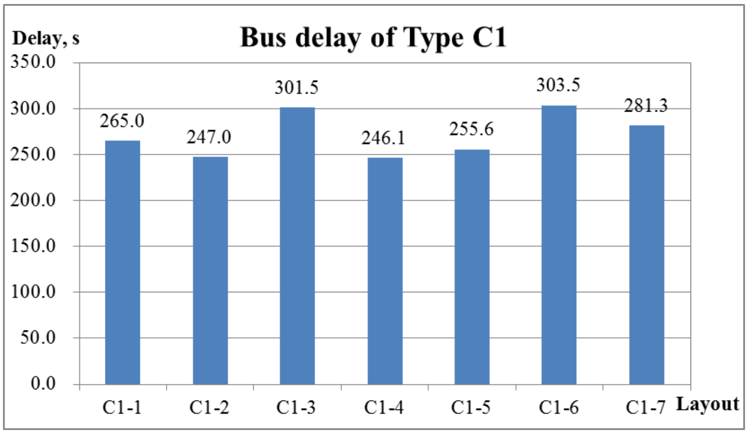

Fig. 8. Comparison Diagrams of Delayed Buses in C1 Layout Schemes

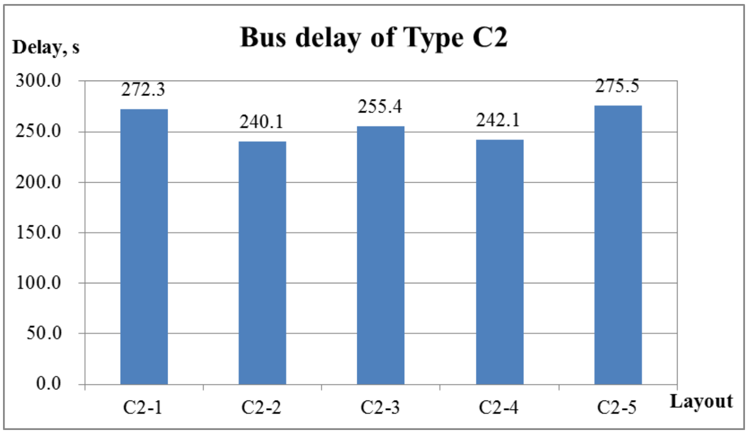

Fig. 9. Comparison Diagrams of Delayed Buses in C2 Layout Schemes

Figure 8 and Figure 9 show bigger changes in bus delay of the two layout schemes, thus detailed reasons of bigger bus delay should be deeply analyzed.

In sub-type C1, layout schemes of C1-3 and C1-6 have the biggest delay, and bus delay has surpassed 300s, higher than the average value of bus delay of 282.5s in Type A layout scheme. Subdivide the delay in each signal control area and bus station on the artery, and find out that bus delay mainly occurs in 2 key intersections with shorter green light time: Xiongchu Avenue-Luoshi Road intersections (#2) and Xiongchu Avenue-Zhuodaoquan South Road intersections (#6).

In C1-3 layout scheme, pairing layout of bus stops only exists in Segment 4, with the benefit of smaller delay at intersection #3 and #5. But the delay is much bigger at intersection #2 and #6, causing bigger total delay on the artery.

In C1-6 layout scheme, pairing layout of bus stops only exists in Segment 7. But as greet light time is shorter at intersection #6, ideally local green wave is not formed between intersection #5 and intersection #6, causing much bigger delay of bus traffic flow at intersection #6 and much bigger total delay on the artery.

In sub-type C2, layout schemes of C2-1 and C2-5 have bigger delay. But delay mainly occurs in two key intersections of #2 and #6. In layout scheme of bus stops, the two intersections are not effectively integrated into corresponding local green wave. From another point of view, the two intersections are the first intersections of local green wave as shown in Figure 7. Shorter green light time limits the local green wave bandwidth and causes bigger delay of bus traffic flow.

The above analysis shows it is needed to fully consider the relationships between key intersections of shorter green light time and bus stop layout under mixed layout. Detailed methods include: try to avoid taking key intersections as starting intersections of local green wave, but take key intersections as subsequent intersections of local green wave.

4. General Conclusion Based on Simulation Optimization

Based on simulation experiments and data analysis, further conclude, refine and summarize general conclusion: ideal modules of bus stop layout.

4.1. Ideal Modules of Bus Stop Layout

Based on previous simulation analysis, expand layout scheme in Figure 7 to obtain ideal modules of bus stop layout formed by several upstream intersections based on pairing layout, as shown in Figure 10.

The ideal modules have 2 parts: ① n signal control intersections exist between bus stop b and b+1; ② set up subsequent bus stop b+1 and b+2 in the upstream and downstream of the same segment; no signal control exists between the two bus stops.

For the ideal modules, set up a local green wave between SC#(k) and SC#(k+n-1) to guarantee the delay only occurs in SC#(k) when buses leave the upstream bus stop b. Buses can enjoy green wave signals with arterial coordination during running between SC#(k+1) and SC#(k+n-1).

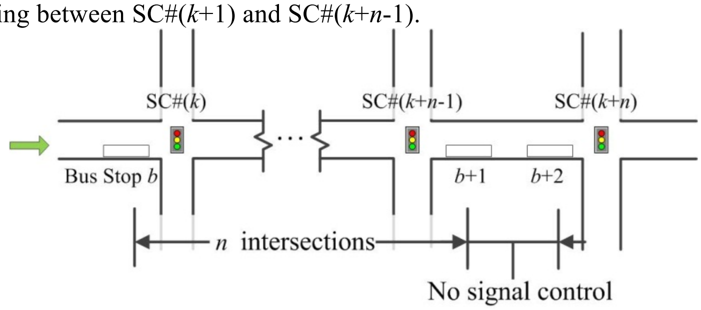

Fig. 10. Sketch Maps of Ideal Modules of Bus Stop Layout

In addition, the pairing layout of bus stops in segments can enable buses to fully use “red wave band” time to stop in b+1 and b+2 stations and thus effectively reduce waste time of green light due to bus stopping.

Take ideal modules in Figure 10 as basis, combine multiple ideal modules according to overlapped front and end of bus stops so as to obtain bus stop layout on artery as shown in Figure 11.

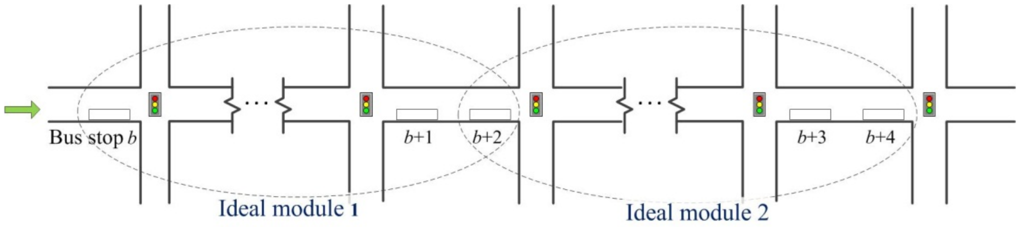

Fig. 11. Sketch Maps of Combinations of Multiple Ideal Modules on Artery

In the bus stop layout on the artery as shown in Figure 11, bus traffic flow delay mainly occurs in the first signal control intersection of each ideal module so as to effectively reduce total delay of bus traffic flow on the artery.

Only adjust bus stop position in the optimal bus stop layout scheme so as to make running bus traffic flow integrate into arterial coordinated control in a much more reasonable way; meanwhile no negative impacts will be made on social traffic flow as the existing arterial coordinated control parameters need no adjustment.

4.2. Effects and Significances of Ideal Modules

Refer to ideal modules of bus stop layout under the existing road conditions. Within the allowed scope of public transport planning, locally and slightly adjust bus stop positions to form layout modes of ideal modules.

As for the ideal modules in bus stop layout, spatially realize effective integration between arterial coordination and transit priority signals. Therefore fully recognize effects and values of the ideal modules in public transport system planning. During bus stop layout in arterial traffic lines, refer to layout modes of the ideal modules. In the sources of public transportation system planning, realize integration between arterial coordination and transit priority.

In industry norms and local norms or local standards and national standards related to bus stop layout, focus on the optimization of layout schemes of bus stops on the artery; especially the optimization of bus stop layout under arterial coordination, take the ideal modules of bus stop layout as reference basis.

5. Conclusion and future research

Schemes of bus stop layout on the artery have close interactions with arterial coordinated signal control. Proper layout schemes can effectively reduce running time and delay of bus traffic flow; therefore optimal schemes of bus stop layout are research topics with practical significances.

Different from traditional optimization methods, the simulation experiment methods refer to obtaining experimental data through numerous simulation experiments, summarize general conclusion based on data analysis. The paper takes actual roads as background to make simulation experiments and data analysis, and concludes ideal modules of bus stop layout: on the one hand, prove optimization methods of simulation experiments are feasible; on the other hand, confirm the effects and significances of the ideal modules.

As gaps exist between simulation experiments and actual traffic running, take actual roads and traffic conditions as basis in further subsequent research to expect conclusions with practical significances.

Acknowledgements

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References

Byrne N., Koonce P., Bertini R L., et al., 2005. Using Hardware-In-The-Loop Simulation to Evaluate Signal Control Strategies for Transit Signal Priority. Transportation Research Record 1925, 227-234.

Kim S., Kim W., Rilett L. R., 2005. Calibration of Micro-Simulation Models Using Non-Parametric Statistical Techniques. Transportation Research Record 1935, 111-119.

Kim W., 2004. An Improved Bus Signal Priority System for Networks with Nearside Bus Stops. Texas U.S.: Texas A&M University.

Kim W., Rilett L. R., 2005. Improved Transit Signal Priority System for Networks with Nearside Bus Stops. Transportation Research Record 1925, 205-214.

Lee J., Shalaby A. Rule-Based Transit Signal Priority Control Method Using a Real-Time Transit Travel Time Prediction Model. Canadian Journal of Civil Engineering 40, 68-75.

Long K., Luo X., Liu Y., 2008. Bus priority control strategies for intersections with near-side stops. Journal of Changsha Communications University 24, 52-57.

Ludwick J. S., 1976. Bus Priority System: Simulation and Analysis. Final Report Prepared for the U.S. Department of Transportation. Washington DC: U.S. Department of Transportation, 1976.

Ma W., Ni W., Head L., et al., 2013. Effective Coordinated Optimization Model for Transit Priority Control Under Arterial Progression. Transportation Research Record 2356, 71-83.

Ma W., Xie H., 2011. Bus Signal Priority Strategy for Isolated Intersection with Far-side Bus Stop. Journal of Tongji University(Natural Science) 39, 524-528.

Ma W., Yang X., Liu Y., 2010. Development and Evaluation of a Coordinated and Conditional Bus Priority Approach. Transportation Research Record 2145, 49-58.

Satiennam T., Fukuda A., Muroi T., et al., 2005. An Enhanced Public Transportation Priority System for Two-Lane Arterials with Nearside Bus Stops. In Tokyo, Japan: the Eastern Asia Society for Transportation Studies.

Wu Z., MA W., YANG X., 2008. Optimal Location of Adjacent Bus Stops on Condition of Bus Signal Priority. Journal of Highway and Transportation Research and Development 25, 146-150.