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Research Article

Performance of the Priority Control Strategies for Bus Rapid Transit: Comparative Study from Scenario Microsimulation Using VISSIM

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Bus rapid transit (BRT) has a great potential to improve the service level of transit system and has been implemented in many Chinese cities. However, the priority it can provide to buses has not been explored fully. Therefore, this study mainly investigated two advanced control strategies (signal priority using advanced detection and transit speed control). Signal priority using advanced detection is a strategy which detects one cycle ahead of buses' arrival in order to adapt a more flexible control algorithm to provide signal priority for buses. Another is transit speed control, which provides priority at intersections for buses by controlling the speed of them and predicting their arrival at certain intersection. These two advanced strategies were modeled and evaluated using simulation software VISSIM and presented better performance than other three scenarios (base case, exclusive bus lane, and conventional transit signal priority). Only the eastbound direction would be researched as its traffic flow and bus volume are much larger than those of the other direction. Data used in this model was collected in Yingtan City. It is also shown that both the operation of BRT and the efficiency of private traffic can be much improved by applying the two strategies proposed above.

1. Introduction

Bus rapid transit (BRT) is a high-quality bus-based transit system that delivers fast, comfortable, and economical urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service [1, 2]. Compared with the traditional rapid transit system (such as rapid rail transit), BRT system requires lower initial capital investment and shorter implementation time and provides more flexible routes. Compared to normal bus transit (NBT), it has larger capacity, better passenger facilities such as exclusive bus lanes, fare collection system, real-time information system, and modern bus stations. It also combines advantages such as the flexibility of conventional buses and the operational efficiency of rail transit [3, 4]. As a promising alternative, BRT has existed for almost 40 years, while it has not been introduced into China until the late 20th century. Cai and Xu discussed BRT application forms and the urgency of popularizing BRT in China [5]. To accommodate to increasing travel demand, many cities such as Beijing, Hangzhou, Changzhou, and Jinan have developed BRT system; also many other cities including the city of Yingtan mentioned in this study are planning to implement BRT system.

However, priorities that BRT systems in China provide for buses are not fully exploited. Mostly, exclusive bus lanes and conventional transit signal priority are implemented, which limits the efficiency of BRT [6, 7]. Moreover, heterogeneous traffic conditions (prevailing in Chinese cities) will limit the efficiency of the implementation of exclusive bus lanes [8]. Thus, deeper research is needed to further investigate control strategies that can be integrated with BRT. To this end, this study tries to improve BRT efficiency using advanced traffic control strategies.

Transit signal priority (TSP) has been pervasively implemented worldwide, which includes passive, active, and adaptive priority treatment [9]. Passive TSP strategy does not require any detector or request activation. It provides transit vehicles with signal priority by timing signal plan favoring these vehicles. In general, when transit operations are predictable with stable routes and arrival schedules, passive priority strategies can be an efficient form of TSP [10].

Active TSP needs the implementation of detection and responds to priority requests generated by transit vehicles. Green extension strategy and early green strategy are two well developed and widely used active TSP strategies. Active TSP also can be implemented as unconditional and conditional. Unconditional TSP provides priority for each transit vehicle that sends a request. Conditional TSP offers priority for vehicles only under certain conditions. Previous studies have shown that the net impact of active TSP in terms of delay can be positive or negative, depending on factors such as signal timings, travel demand, and TSP strategy parameters [11]. Also the location of bus-only lane can impact the performance of TSP strategy. Simulation study showed that curb bus-only lane arrangement appeared to have an advantage over median bus-only lanes arrangement in improving overall intersection performance if green extension and early green were deployed [12].

Adaptive TSP considers the tradeoffs between transit and traffic delay and optimizes signal timing plan dynamically through real-time detection. However, currently there is a lack of comprehensive documentation of the effectiveness of such transit priority measures over a wide range of traffic levels, network configuration, technology sophistication and bus volume, and transit frequency and characteristics [13].

Many researchers agreed that TSP can work better under certain conditions such as phase length limitation [14, 15]. But, in this case, conditional TSP strategies may ignore some transit priority calls due to this limitation and thus fail to provide signal priority to every bus and increase bus delay. To address this problem, Wadjas and Furth proposed a new TSP strategy using advanced detection to provide signal priority for light rail trains [16]. Instead of relying on detection only a few seconds in advance of the stop line, they developed a control algorithm in which trains are detected two to three cycles in advance of their arrival at intersection. Then through active modification of signal timing plan in advance, all buses can receive preference treatment.

Other than signal control, speed control strategies also can offer priority to buses. Wang et al. proposed a transit speed control strategy to dynamically control the operating speed of transit to make sure that it can arrive at intersections within certain time range so that preference treatment can be obtained [17]. They also recommended a near-side bus stop design at each intersection to accommodate to dwelling buses. This type of design requires buses to drive at a particular speed and arrive at bus stops right in front of intersections during red interval. After serving on-offs during the red interval and when the signal turns green, buses can drive through intersections without being delayed (dwell time does not count as control delay).

To offer priority to bus, there are also many other alternative operation plans like dynamic scheduling and deadheading strategies. However, considering the feasibility of these strategies in China and the maneuverability in simulation, these strategies were not taken into account. Therefore, to evaluate these two advanced control strategies and to find out whether they really work, we modeled these two strategies using VISSIM in our study together with other three scenarios (base case, bus lane, and conventional TSP) as comparison. We hope to figure out the genuinely effective strategies, so that the efficiency of BRT could be improved by a large margin.

This paper is organized as follows. In Section 2, the Yingtan city and the model preparation of Shengli avenue are briefly introduced. In Section 3, two proposed control strategies and other three conventional ones are explained. In Section 4, simulation results of those five scenarios are evaluated and analyzed. Finally, summary and recommendations are made.

2. Simulation Preparation

In order to analyze potential of the proposed strategies, a behavior-based microscopic simulation software VISSIM was used in this study. With simulation software, we can model these scenarios and analyze their advantages and disadvantages using a set of indicators.

Indicators used to evaluate proposed strategies' influences on transport system generally include three sets: (1) impacts on bus efficiency and reliability (bus delays, travel speed, and travel time consistency), (2) impacts on private traffic (automobile delays and travel speed), and (3) overall impacts on whole network (person delay) [18]. Indicators adopted here include the following:

(i) bus delay and travel speed,

(ii) bus reliability,

(iii) automobile delay and travel speed,

(iv) average person delay.

Using VISSIM simulation software, we modeled Shengli avenue, which is an important corridor in the downtown area of Yingtan. Located in the northeast of Jiangxi province, Yingtan serves as the transportation junction from central to southern China. In 2009, the population of downtown area in Yingtan has reached the number of 208,000, GDP per person has exceeded 20,000 RMB, and the number of automobiles was 34,310. The area modeled in this study is a traffic arterial crossing through the downtown area of Yingtan from east to west, along which many commercial and entertaining buildings were constructed, such as Xinhua bookstore, central square, and no.1 primary school of Yingtan (as is shown in Figure 1).

Shengli avenue is a four-lane dual carriageway with three signalized intersections including Zhanjiang, Jiaotong, and Zhengda, and each lane has a width of 3.5 meters. Eastbound bus volume during peak hour is 60 vehicles per hour, and passenger volume of maximum section is 3000 persons per hour. Yingtan is at the middle of a rapid developing period, during which travel demand is increasing dramatically. To relieve traffic congestion, Yingtan has planned to provide priority to public transit and recently is about to install a BRT lane along Shengli avenue (shown in Figure 2).

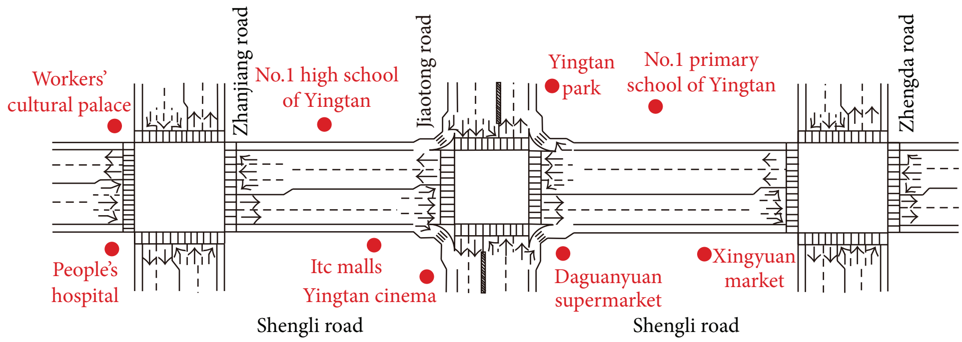


Figure 1: Current intersections and land use along Shengli road.

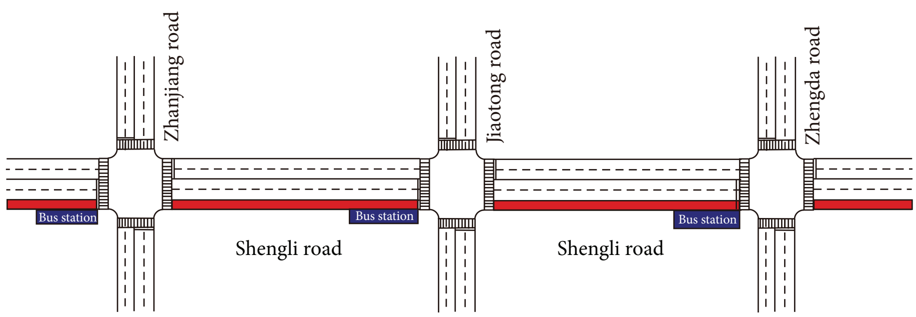


Figure 2: The exclusive lane and bus stops of BRT planned on Eastbound Shengli road.

Besides the implementation of BRT lane, Yingtan also has prepared to install a bus stop in front of stop line at each intersection along this arterial. There are mainly two reasons: one is to facilitate passengers to transfer from one route to another; the other is to make use of the period of red signal to load and unload riders. Thus, the objective of these strategies mentioned in this study may have a slight difference from normal situation as normally priority strategies' objective is to provide green signal for buses at intersections to allow them to pass without stop or delay. On the other hand, in this study, because the bus stops are installed in front of stop lines at intersections, priority strategies are trying to provide red signal for buses to allow them to have sufficient time to load and unload passengers and then drive through intersections during green signal. The capacity of bus stop is calculated using a microscopic model presented by Fernández (2010) [19].

With the help of data provided by the final report on urban transit planning of Yingtan (2011–2020) [20], we modeled Shengli avenue in VISSIM. As the microscopic simulation software VISSIM is driving behavior based [21], parameters concerning driving model are essential for model validation. To establish a behavior model of Chinese driver, this study adopts the parameters adjustment done by Berkhout in his work of parameter calibrating using Chinese driving behavior model [22]. Based on this, we calibrate and validate the model by comparing the observed automobile travel speed to the simulated automobile travel speed from the VISSIM model.

3. Simulation Scenarios

This study employed five simulation scenarios including (1) base case, (2) adding exclusive bus lane, (3) conventional active transit signal priority, (4) transit signal priority using advanced detection, and (5) transit speed control. By modeling these five scenarios in VISSIM, we tried to analyze the impacts of two proposed priority strategies (modeled as scenarios (4) and (5)) on public transit as well as on private traffic. For the reason that the traffic flow and bus volume from eastbound direction are much larger than those from the other one, all of the following scenarios only provide priority for eastbound direction for the convenience of comparison.

3.1. Scenario (1): Base Case. The first scenario modeled in VISSIM is the current situation of traffic network along Shengli Avenue. This scenario serves as the base case and is used to analyze the impacts that these following treatments would bring to this corridor. In this scenario buses are not given any priority in any form.

3.2. Scenario (2): Adding Exclusive Bus Lane. On the basis of scenario (1), scenario (2) adds an eastbound exclusive bus lane on the outer side of the corridor. For our study, only focused on one direction, westbound exclusive bus lane is not installed and priority strategies are not provided for buses driving this direction.

3.3. Scenario (3): Conventional Active Signal Priority. Active priority strategies provide priority treatment to a specific transit vehicle following detection and subsequent priority request activation. Traditionally, this kind of strategies relies on detection only a few seconds' distance of travel in front of the stop line. There are two kinds of active strategies implemented in Scenario (3), which are green extension strategy and early green strategy. A green extension strategy extends the green time for the TSP movement when a TSP-equipped vehicle is approaching. This strategy only applies when the signal is green for the approaching buses. An early green strategy shortens the green time of preceding phases to expedite the return to green (i.e., red truncation) for the movement where a TSP-equipped vehicle has been detected. This strategy only applies when the signal is red for the approaching bus vehicle [9].

In simulation model of this scenario, we provide bus with priority by adding a separate lane and adopting TSP strategy described above. Also, two detectors are used for this scenario, one is installed 30 meters in front of the stop line and the other is installed right after the stop line. The first detector generates priority request and second detector is used to determine when the green extension should end.

3.4. Scenario (4): Active Signal Priority Using Advanced Detection. This priority strategy was proposed by Wadjas and Furth [16]. Through advanced detection and prediction, this strategy algorithm could begin to adjust signal timing ahead of the arrival of bus; thus there would be more room for signal timing adjusting than simple active signal priority (i.e., scenario (3)). Better flexibility for adjusting leads to less amount of adjustment for each phase, and because of this, the impacts on private traffic would be negligible. Brief process of this strategy is shown in Figure 3.

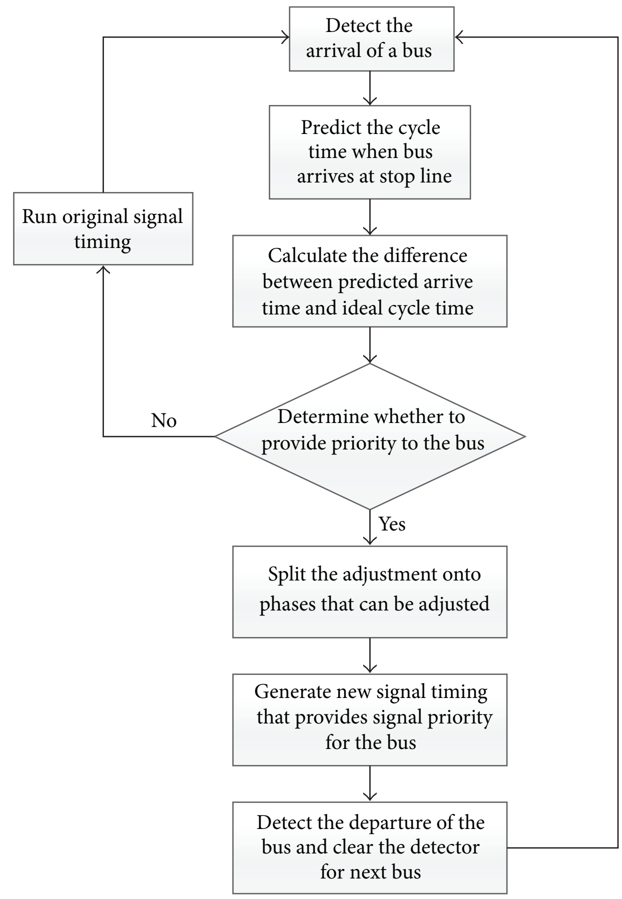


Figure 3: Brief algorithm of active signal priority using advanced detection.

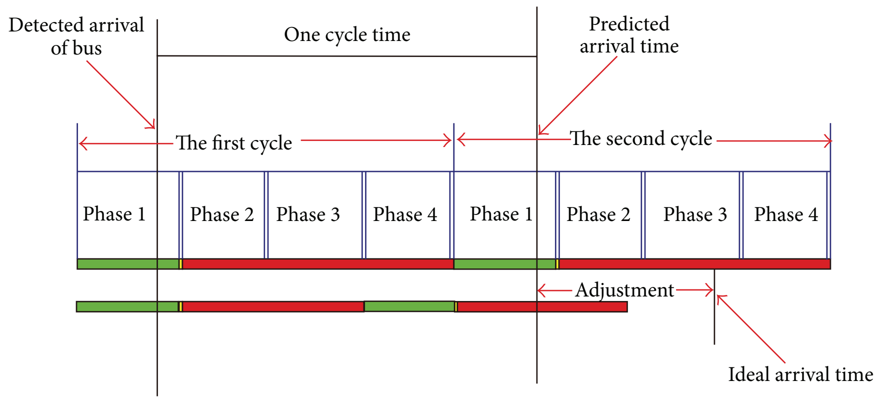
There are mainly two differences in scenario (4) compared with the original one proposed by Wadjas and Furth [16].

(i) Prediction window is cancelled. Because of the advanced detection used in original strategy, prediction was needed to estimate how much time certain vehicle would need to drive from the detection to stop line. In original strategy, Wadjas proposed a twenty-second long prediction window as many factors would fluctuate transit travel time. However, in scenario (4), these factors do not exist or are too slight to impact bus travel time; implementation of exclusive bus lane protects buses from private traffic. There is no other intersection between detector and its corresponding intersection and bus stops are constructed right in front of the stop line, so dwell time would not fluctuate travel time. Moreover, simulation results show that the standard deviation in this scenario is 2.6 seconds, which proves that bus travel time is very reliable. For these reasons, priority strategy used in scenario (4) cancels prediction window.

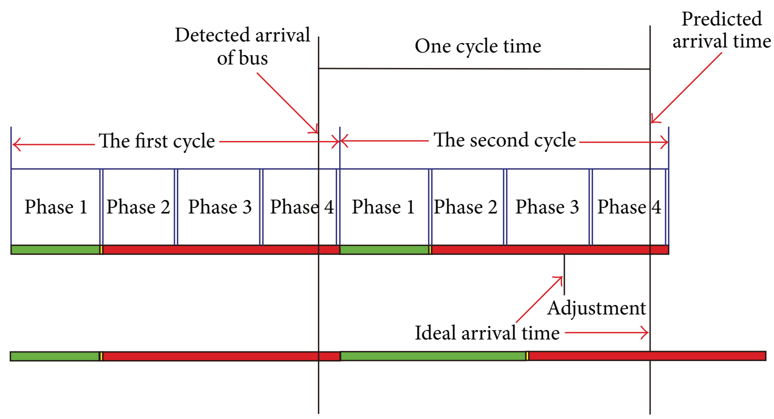
(ii) Bus serving signal at intersections is different. Original algorithm allows (if it succeeds) buses to obtain green signal at intersections, while in this scenario, as we have discussed, bus serving signal is red at intersections. Together with the bus stops installed in front of the stop lines, this design allows buses to load or unload passengers during period of red signal and then drive through this intersection when it gets green. Target (ideal) arrival time is 20-second red remaining time, which equals the minimum predicted dwell time.

Apart from those two points mentioned above, strategy used in scenario (4) remains the same as original. Figure 4 is an illustration of this algorithm.

As shown in Figure 4, the difference between the predicted arrival time and the desired arrival time is the amount of adjustment. This difference could be eliminated through adjusting signal timing. Because of the advanced detection, the amount of adjustment could be split to those phases among the advance; for example, in Figure 4(a) (compression situation), the adjustable phases could be phases 2, 3, 4, 1, and 2 (phases between the detect time and the desired arrival time). As we can see, adjustment of each phase is much less because the split and impact to the private traffic would be negligible. Similar thing happens in Figure 4(b) (extension situation). In this scenario, all the three signalized intersections along the Shengli Avenue would implement this



(a) Compression Situation



(b) Extension Situation

FIGURE 4: Illustrations of Adjustment between the Predicted and Target Arrival Time.

strategy, and each corresponding detector is installed at one cycle's distance of travel ahead of the stop line.

3.5. Scenario (5): Transit Speed Control. This strategy is initially proposed by Wang et al. [17], coauthor of this paper. Through guiding and controlling the travel speed, this strategy provides priority for buses at intersections and makes their arrivals at certain intersection predictable. Moreover, there was a theoretical analysis proposed by Wang proving that transit speed control can decrease bus delay. Their analysis is briefly shown below.

Assume that there is an arterial that has n intersections and m out of them is installed with near-side bus stops. Considering the base case, in which no bus speed control is adopted and bus stops are installed in the middle of road segment, the travel time of bus running through this arterial can be calculated as follows:

$$\text{total}_1 = \sum_{i=1}^{n+1} \frac{s_i}{v_i} + \sum_{i=1}^{n} p_i R_i + \sum_{i=1}^{m} T_i, \qquad (1)$$

where

S_i is the length of road segment i,

v_i is the speed in segment i,

p_i is the possibility of a bus stops at intersection i,

R_i is the stop time of a bus stops at intersection i, and

T_i is the dwell time.

We can see that total travel time in this case consists of three parts: travel time in the road segment, delay at intersection, and dwell time at bus stops. Statistically, $p_i = 0.5$ and $R_i = C_{i2}/2$, where C_{i2} is the red signal time at intersection i.

Considering another case, where transit speed control is adopted and bus stops are installed near intersections, the total travel time can be calculated using the following formula:

$$\text{total}_2 = \sum_{i=1}^{n+1} \frac{s_i}{v_i} + \sum_{i=1}^{m} \max\left(T_i, C_{i2}\right), \qquad (2)$$

where C_{i2} is the red signal time at intersection i.

Assume that the time decrease because of acceleration is approximately equal to the time increase because of deceleration, and $T_i \leq C_{i2}$. We have

$$\text{total}_2 \approx \sum_{i=1}^{n+1} \frac{s_i}{v_i} + \sum_{i=1}^{m} C_{i2}. \qquad (3)$$

So by comparing formulations (1) and (3), we can know the time saved by this strategy if there are k buses running through this arterial as follows:

$$\Delta = k * (\text{total}_1 - \text{total}_2) = k * \left(\frac{1}{4} \sum_{i=1}^{n} C_{i2} + \sum_{i=1}^{m} T_i - \sum_{i=1}^{m} C_{i2} \right). \tag{4}$$

They also did a numerical estimation according to formula (4) to demonstrate how much time this strategy can save. If there are 100 buses, the arterial consists of 10 intersections and 7 of them are installed with near-side bus stops, and dwell time and signal cycle time are 50 s and 60 s, respectively, then $\Delta = 2.22$ h, which means that the total time saved by this strategy is more than two hours.

However, in this scenario, the strategy is no longer real-time because VISSIM is unable to simulate the real-time speed control.

In order to simulate speed control strategy, we adopt a simplified strategy. Simplification is as follows.

(i) Equalize signal cycle of three intersections along the corridor.

(ii) Make the dispatch interval of buses multiples of the equalized cycle.

(iii) Calculate the desired speed at each portion of road to allow buses to obtain desired signal.

Desired speed is calculated as follows.

Assume that a certain bus departs stop at T_1 time with a speed of V. This bus needs to travel a distance of S to arrive at next intersection or stop; then it will take the bus $T = S/V$ to drive through this portion of road. When it arrives at next intersection, this cycle has run a time of $T_2 = (T_1 + T)\%C$ (symbol % is used here for calculating residue), so the desired speed in this portion of road would be as follows:

$$V_{\text{opt}} = \frac{S}{T - [T_d - (C - T_2)]}, \tag{5}$$

where S is the distance to travel to the next intersection or stop, C is the equalized cycle time, and T_d is bus dwell time.

If $T_d - (C - T_2) > 0$, bus needs to accelerate; otherwise, bus needs to decelerate.

Also, bus cannot accelerate or decelerate too much because of safety and efficiency issues. So Wang has already proposed a speed interval: [15, 40] km/h. If calculated speed exceeds this interval, speed control is cancelled and this bus runs at its original speed.

Here is a demonstration of calculation with numbers to show how the previous equation can be used in real implementation case.

Assume that signal starts at time 00:00:00 and its cycle time is $C = 100$ s. At time 00:30:00 (T_1), a bus dispatched from terminal and detected by detector associated with the first intersection that it will encounter. This bus travels at speed of $V = 30$ km/h and there is a distance of $S = 1$ km between his current position and the intersection. Then it will take this bus $T = 1/30 * 3600 = 120$ s to travel to the intersection. And when it arrives at the intersection, the current signal cycle has run a time of $T_2 = (T_1 + T)\%C = (30*60+120)\%100 = 20$ s. Dwell time for this bus is predicted as 30 s. So, recommended speed for this bus would be as follows:

$$\begin{aligned} V_{\text{opt}} &= \frac{S}{T - [T_d - (C - T_2)]} \\ &= \frac{1}{120 - [30 - (100 - 20)]} * 3600 = 21.2 \text{ km/h}. \end{aligned} \tag{6}$$

All these seemingly meaningless numbers (like 60, 3600) in equations above are used for unit converting.

Because 21.2 km/h lies in the speed interval [15, 40] km/h, which was proposed by Wang et al. (2003), it would be recommended as the desire speed in this segment of road.

In simulation model, buses are running on a separate lane and guided by the speed control algorithm described above.

4. Simulation Results

The VISSIM evaluation function makes it possible to the level-of-services for different scenarios. In this section, based on the results of VISSIM models, we evaluate how each priority strategy will impact public transit efficiency and operation of private traffic. Evaluation is going to be analyzed in two categories: buses and automobiles. In the end, we also proposed an indicator of average person delay.

4.1. Throughput. Throughput is the ratio of number or trips generated to number of trips completed in each case. Throughput of five scenarios is shown in Table 1.

When the situation is saturated, some parameters should be considered again, such as the speed of vehicles.

4.2. Buses. Indicators used in this section to evaluate bus efficiency are delays of buses at intersections, bus travel speed, and bus reliability.

4.2.1. Delay and Travel Speed. Delay can be calculated as the time difference between the simulated travel time and the ideal travel time (where vehicle would neither be interrupted by other traffic nor by signals). Delays of buses at three intersections and their average in five scenarios are listed in Table 2, and average travel speed is shown in Table 3.

We can see that compared to scenario (1), delays of buses at intersections in scenario (2) have been decreased dramatically from 46.3 s averagely to 36.2 s and bus travel speed in scenario (2) has been improved from 13.9 km/h to 18.4 km/h, which means that implementation of exclusive bus lanes can improve bus efficiency. However, when adding priority strategies (especially in scenarios (4) and (5)), bus efficiency improvements can achieve a much higher level (average bus delay decreased from 46.3 s to 11.3 s and 9.6 s and bus travel speed increased from 13.9 km/h to 23.8 km/h and 21.0 km/h). These results demonstrate that exclusive bus lanes integrated with priority strategies can improve bus efficiency much more than merely implementing exclusive bus lanes. The reason why the improvement

Table 1: Throughput of five scenarios.

Scenario	1	2	3	4	5
Throughput	0.953	0.978	0.978	0.974	0.969

Table 2: Bus delays (s) in five scenarios along Eastbound Shengli road.

Scenario section	1	2	3	4	5
Zhanjiang road-Shengli road	36.0	29.9	27.4	11.3	10.3
Jiaotong road-Shengli road	47.0	41.8	30.8	11.4	9.5
Zhengda road-Shengli road	56.0	36.8	27.2	11.2	9.1
Average value	46.3	36.2	28.5	11.3	9.6

Table 3: Average bus travel speeds (km/h) in five scenarios along Eastbound Shengli road.

Scenario	1	2	3	4	5
Average speed	21	23.8	19.5	18.4	13.9

of bus efficiency in scenario (3) is less evident than in scenarios (4) and (5) is that active signal priority strategy used in scenario (3) is limited and cannot provide full priority to every detected bus as strategies used in scenarios (4) and (5) do.

4.2.2. Reliability. Another important indicator to evaluate bus operation is bus reliability. Bus reliability represents the ability for bus vehicles to arrive at stops according to timetable. Improvement of this indicator can make public transit appeals more to passengers.

To measure bus reliability, we have to know whether the bus arrived at and left the stops solidly. In this paper, the standard deviation of the time that a bus needed to travel from the beginning of Shengli avenue to the end was defined as the quantitative measurement of "bus reliability."

Simulation results of this indicator are listed in Figure 5 and Table 4.

As shown in Figure 5, this study uses the time that a bus needed to travel from the beginning of Shengli avenue to the end to measure the reliability of buses. The use of travel time to reflect the reliability due to this evaluation data can be directly and easily measured in VISSIM. The fluctuation of these curves in figure above shows the reliability of buses.

We can see that only the curves of scenario (4) and (5) show an excellence of bus reliability, while other three scenarios demonstrate rather fluctuated curves meaning that bus travel time in these scenarios has no satisfactory consistency. These data demonstrate that the implementation of exclusive bus lane and traditional active signal priority contribute little to the improvement of bus reliability. On the other hand, buses have been much more reliable because of strategies like transit signal priority using advanced detection and transit speed control.

4.3. Automobiles. Indicators used in this section to evaluate automobile operation are delays of automobiles at intersections and automobile travel speed. Delays and

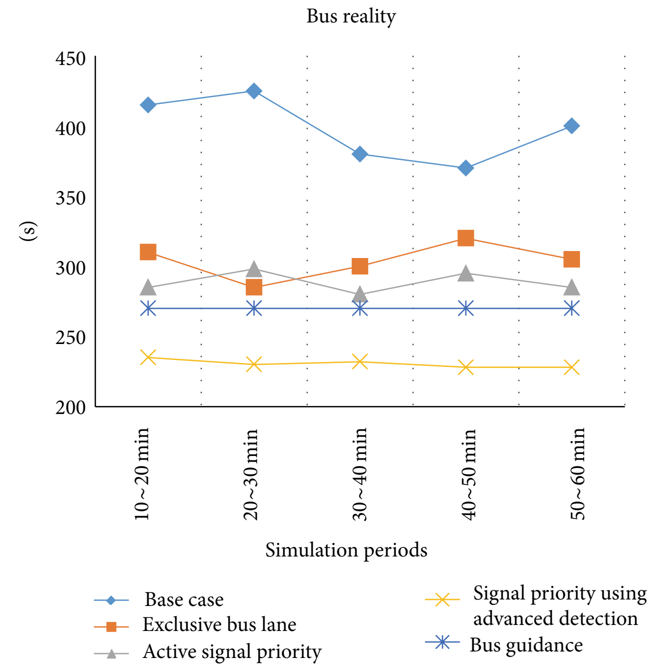


Figure 5: Reliability of bus travel time in five scenarios along Eastbound Shengli road.

Table 4: Average and standard deviation of bus travel time.

Scenario	1	2	3	4	5
Average (s)	399.5	304.3	290.0	233.8	264.8
Stdev (s)	19.7	11.4	5.9	2.6	1.9

Table 5: Car delays (s) in five scenarios along Eastbound Shengli road.

Scenario Section	1	2	3	4	5
Zhanjiang road to Shengli road	15.1	12.5	13.3	13.4	19.2
Jiaotong road to Shengli road	18.2	13.3	15.5	14.2	25.0
Zhengda road to Shengli road	17.4	12.6	16.1	15.1	18.9
Average value	16.9	12.8	15.0	14.2	21.0

Table 6: Average car travel speeds (km/h) in five scenarios along Eastbound Shengli road.

Scenario	1	2	3	4	5
Average speed	28.7	33.6	32.2	32.9	26.2

travel speeds of automobiles in five scenarios are shown in Tables 5 and 6.

We can see that adding an exclusive bus lane (scenario (2)) leads to the least delay (averagely 12.8 s) and the fastest travel speed (33.6 km/h), which means this strategy improves private traffic operation conditions at the highest level. On the basis of scenario (2), adding any priority strategies for buses will more or less impact the operation of private traffic in a bad way. What we need to know is which priority strategy will cast the least impacts on private traffic on earth. As we can see in the figures above, private traffic is influenced mostly

Table 7: Average person delay.

Scenario	1	2	3	4	5
Person delay (s)	26.7	20.6	16.8	13.3	17.2

in scenario (5) (transit speed control) in which automobile delays have increased averagely from 16.9 s to 21.0 s and travel speed has decreased from 28.7 km/h to 26.2 km/h compared to scenario (1). This is because when implementing nonreal-time speed control strategy in this study (because of the limitation of simulation software) we have to equalize signal cycle time of each intersection which certainly will have major impacts on private traffic. In scenario (4), private traffic operates most fluently (automobile delays have decreased averagely from 16.9 s to 14.2 s and travel speed has increased from 28.7 km/h to 32.9 km/h) because of the advanced detection strategy. As we have discussed before, advanced detection will provide more room for signal timing adjusting which leads to slight adjustment of each phase and impact least on private traffic.

4.4. Average Person Delay. In order to evaluate these strategies' impacts, both on public transit and on private traffic, we employ the indicator of average person delay. Average person delay is an indicator that is measured by person instead of vehicle, and it embodies that the priority for buses is actually the priority for persons. Therefore average person delay is an indicator often used in person-oriented projects. Average person delays of these scenarios are shown in Table 7, and we can find that scenarios (4) and (5) improve the system's efficiency mostly.

5. Conclusion and Future Directions

In order to seek new ways to improve BRT efficiency, we propose two priority strategies and integrate them with exclusive bus lane to see how they would impact public transport efficiency. These two proposed control strategies are implemented on the basis of BRT features including exclusive bus lanes, bus stops installed in front of stop lines, and bus upload and download passengers during red signal period at intersections. The method we used in this study is microscopic simulation. We modeled these two priority strategies (signal priority using advanced detection and transit speed control) and other three scenarios (base case, exclusive bus lane, and active signal priority) in VISSIM and compared them to analyze how these two priority strategies will impact public transit and private traffic.

Evaluation results show that, in the view of improving bus efficiency, four priority strategies (scenarios (2), (3), (4), and (5)) all have a positive influence on buses, and among those strategies, signal priority using advanced detection and transit speed control have the most positive impacts. Taking the improvement of bus reliability into account, we find that influences of exclusive bus lane and active signal priority are slight, while strategies like priority using advanced detection and speed control remarkably improve the reliability of buses. Considering the impacts on private traffic, we can see that adding an exclusive bus lane has a positive impact on private traffic; on the other hand, the other three strategies (scenarios (3), (4), and (5)) have negative impacts. However, among those three scenarios, private traffic in scenario (4) bears the least impact, which means that signal priority using advanced detection strategy causes negligible impact on automobiles. From the aspect of average person delay, signal priority using advanced detection improves the system's efficiency mostly, and speed control takes the second place.

When applying the proposed strategies in real world, more complex details should be taken into account, such as the size of intersections, the equipment used to collect data, and how to give the guidance information back to the bus drivers. If the intersection is too big, the time that a bus needs to travel across it and the possible disturbing factors a bus may face will all be worthy of more attention.

This study recommended two priority strategies that can improve BRT efficiency but still ameliorations can be made. In the future, this research can be carried on mainly from these three aspects. First, not only considering traffic flow and bus volume from both the major direction and minor direction in signal priority using advanced detection, but also making out the conflict between prior requests from different directions. Second, developing simulation method that can simulate real-time speed control strategy to test the true potential of this strategy on improving bus efficiency. Third, comparing the conditions where different distances are set for the bus stops from the sections with priority.

In the end, we hope this study will help to push research on public efficiency forward. This work provides a case study for simulation of BRT system in China and probes the ways of improving bus efficiency from the aspect of advanced traffic control strategy.

Conflict of Interests

The authors declare that they have no conflict of interests to this work. The authors declare that they do not have any commercial or associative interest that represents a conflict of interests in connection with the work submitted.

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