MTCS: A Method of Analyzing the Traffic Capacity of Urban Bus Lane Based on Vissim Simulation

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Abstract

As an effective method of improving the attractiveness of urban public transport and alleviating urban traffic congestion, bus lanes play an important role in the urban public transport system. The research on the capacity of bus lanes is conducive to improve the operation efficiency of urban bus roads and improve the service level of urban public transport. To obtain the maximum capacity of the bus lane, on one hand, the empirical formula can be used for theoretical calculation, and on the other hand, the simulation model can be established for analysis and verification. Based on the idea of simulation, a method using Vissim is proposed, called MTCS (Minimum Traffic Capacity Substitution Method). The method divides the bus lane into different sections by intersections and stops, establishes simulation model of the bus lane to calculate the traffic capacity of each section such as vehicle speed and flow and select the minimum traffic capacity of the sections as the traffic capacity of the bus lane, which is verified by using the road saturation. The simulation process uses the actual travel speed and traffic flow of the bus lane as evaluation indicators, with the aim of maximizing the road traffic flow while the actual speed of vehicles on the road is close to the desired speed, thus achieving the desired road traffic state. To verify and improve the effectiveness of the method, its analysis results are compared with the empirical formula, and various methods of enhancing traffic capacity are quantitatively simulated. The parameters of the simulation model are set by the actual bus lane example, and the experimental results show that by the methods of modifying the stop-station mode and the signal-lamp cycle, 10% and 14% improvements can be achieved, respectively. This has a good reference value for the construction of bus lanes and the adjustment of road facilities.

Introduction

With the rapid development of China's economy, the size of the city is expanding and the traffic demand is developing. With all kinds of motor vehicles, non-motor vehicles and buses competing for right of road use, bus delays and traffic jams are very common, and these phenomena are restricted by various factors, such as setting of road grade, expected road speed and composition of vehicle road etc. In order to alleviate urban traffic congestion, the construction of dedicated urban bus lanes has become one of the common solutions. In the study of bus lanes, the capacity of bus lanes is the starting point. According to which various measures and methods to optimize the current traffic situation are proposed to improve the efficiency of urban bus road operations and enhance the level of urban public services.

Domestic and foreign work on the calculation and simulation of bus lane capacity is more, and its capacity refers to the maximum number of bus vehicles carrying a certain number of passengers that can pass in one direction in a certain section over a period of time. In terms of capacity formula calculation: mainly based on the U.S. Highway Capacity Manual and Transit Capacity and Quality of Service Manual 2nd Edition, the existing methods are basically inherited from these two basic methods. Thus, Hua and Guangning Liu [1–2] calculated according to the influencing factors of each type of capacity, and the statistical order of each type of influencing factors was ranked. Ling Ding [3] studied dedicated bus lanes (DBL), intermittent bus lanes (IBL) and commonly used bus lane strategies to determine the best managed bus lanes (MBL) for different traffic conditions, using delay and time occupancy being as evaluation metrics. The results showed that traffic conditions have a significant impact on traffic performance, and volume having a higher impact on bus lane performance. Yongju Hu [4] et al. calculated the intersection capacity using the parking line method and following the Urban Road Design Code, and pointed out that the planar intersection is the key to influence the traffic capacity. Dingxin Wu [5] studied the operational characteristics of urban road traffic and traffic flow, and obtained the lane distribution and speed distribution of different vehicle types; based on the survey data, he studied the bus entry and exit times and stopping times, and fitted the relationship between the number of passengers getting on and off and the time of getting on and off; he also studied the interaction mechanism between urban bus and road traffic flow, including the relationship between bus flow and road capacity, and the impact of bus stopping on traffic flow; and he studied the setting conditions and impact of bus lanes. In terms of traffic simulation, traffic simulation can be divided into macro-simulation, meso-simulation and micro-simulation according to the different levels of detail of the traffic system described by the traffic simulation model, of which Vissim traffic simulation software is the main representative of micro-simulation. Yueying Huo and Wenquan Li [6] introduced the concept of unit bus lane delay, i.e., the sum of bus delays per unit length (100 m) section, single stop and single intersection, by modeling the relationship between bus lane delay and bus traffic, and used the data output from VISSIM simulation to establish a linear model of unit bus lane delay versus traffic for predicting bus delays in lanes. Yanyan Chen [7] established a simulation model using the third ring highway in southwest Beijing as an example, and conducted a pre-evaluation of the model before and after the setting of the bus lane, and conducted a post-evaluation of the model to verify the validity of the model. Song Xianmin and Ma Lin et al [8] proposed a mixed lane for bus vehicles and right-turn vehicles. They firstly proposed a lane group simulation process based on flow generation model and timing optimization model for the road environment, and then established a dual index evaluation matrix model of per capita delay and vehicle average delay considering the right-turn characteristics of red light, and finally evaluated the respective benefits of conventional lane group, hybrid bus-right-turn dedicated lane group and bus-only lane group in MATLAB and VISSIM simulation platform, and analyzed the key influencing factors. Guangyun Tian and Luo [9] took the bus lane on Jiuzhou Avenue in Zhuhai City as an example, and used the construction form of left-turn-right placement of the bus-only import lane, and used TransCAD and VISSIM to compare and analyze the operation results for the special lane usage object, activation time, signage system, and monitoring scheme, etc., to derive the relationship between the bus-only lane setting and road saturation, which provided research support for the bus-only lane concept. Xianmin Song and Minye Zhang et al [10] analyzed the variability of bus arrival moments based on the dissipation process of vehicle queues at intersections, and combined the HCM2010 vehicle delay formula and road resistance function to model the average vehicle and per capita travel time for unset, conventional and dynamic bus lanes to compare and analyze their operational benefits. Yajie Yang [11] calculated the road capacity by lane on the basis of HCM2010 and studied the impact of linear bus stops on road capacity in detail, and finally used Vissim to simulate and analyze the road capacity under the influence of different stopping times and different bus arrival rates. Changxi Ma [12] proposed a control strategy for bus rapid transit (BRT) lanes in terms of time and space. In space, by using corresponding sensing methods and operation rules, BRT lanes are divided into a certain number of fixed areas, to allow other vehicles to intermittently enter the bus lanes; in terms of time, a single-intersection bus priority strategy with intermittent bus lanes was proposed, and the results of simulation analysis showed that the intermittent BRT lane control scheme combining spatial and temporal optimized green wave coordination control outperformed other control schemes, using the BRT in Lanzhou, China, as an example.

In many studies on bus lane capacity, the changes in traffic flow and average vehicle speed of bus lanes are usually the main focus of consideration. Therefore, in this study, the traffic flow and travel speed are used as evaluation indicators for the bus lane capacity, and the road intersections and bus stops are used to divide the whole road into different sections, and the minimum value of the capacity of each section is taken as the upper limit of the capacity of the whole road; at the same time, the parameters affecting the bus lane capacity, such as the departure interval, traffic flow and travel speed, are studied quantitatively, and a variety of methods to improve the capacity of bus lane are verified by simulation.

1. Bus Lane Capacity Model

1.1 Empirical formula for public transport lane capacity

The section composition of the bus lane can be divided into road intersections, bus stops and basic travel surfaces, and the capacity of each part can be calculated separately based on the following empirical formula [13-15].

$$C_x = \frac{3600}{t_c} \times \frac{t' - t_w}{t_s} \tag{1}$$

$$C_s = \begin{cases} \dfrac{3600}{\sqrt{2l/b} + (\Omega k t_0)/n_d + t_{oc} + \sqrt{2l/a}} & \text{for single stop} \\ \dfrac{3600}{\sqrt{2l/b} + (\Omega k t_0)/n_d + t_{oc} + \sqrt{2l/a}} \times \mathrm{N}_{eb} & \text{for multiple stops} \end{cases} \tag{2}$$

$$C_{L_n} = \begin{cases} \dfrac{1000v}{l_s + l + v \times t_r + I \times v^2} \ , & n = 0 \\ C_{L_0} \times \beta \times \alpha \times \left(1 - \dfrac{\lambda_n t_d}{3600 \times N_{eb}}\right) + \lambda_n \ , & n = 1 \\ C_{L_{n-1}} \times \left(1 - \dfrac{\lambda_n t_d}{3600 \times N_{eb}}\right) + \lambda_n \ , & n \in N_+, n \geq 2 \end{cases} \tag{3}$$

Where: C_x indicates the road intersection capacity (number of vehicles/hour), C_s indicates the bus stop capacity (number of vehicles/hour), C_{Ln} indicates the basic travel road capacity after n stops (number of vehicles/hour), and the meanings of other related parameters are shown in Table 1.

Table 1

Parameter declaration of empirical formulas

Name	Meaning	Name	Meaning	Name	Meaning
t_c	Signal cycle	Ω	passenger capacity	α	Road classification factor
t_w	Green light loss time in one signal cycle	k	Ratio of boarding and alighting passengers to vehicle capacity	β	Intersection impact correction factor
t'	Phase green time	t_0	Passenger boarding and alighting time	t_d	Interaction time between vehicles
t_s	The average interval between two cars passing the stop line one after the other	N_{eb}	Effective stopping efficiency at bus stops	λ_n	Arrival rate of vehicles at the nth stop
l	Vehicle length	n_d	Number of doors for passenger boarding and alighting	l_s	Parking safety spacing
a	Vehicle departure acceleration	t_{oc}	Vehicle door opening and closing time	t_r	Driver response time
b	Vehicle entry acceleration	I	Road impact correction factor	v	Vehicle travel speed

As shown in Equation (4), the bus lane full road capacity C is generated from the Equation (1) – (3), which is the minimum value of capacity in the road intersections, bus stops and basic travel surface. The parameter γ indicates the road saturation, which is one of the important indicators reflecting the level of road service, calculated by the ratio of the current traffic volume and the maximum capacity of the road section, the larger the value represents the lower the level of road service.

$$C = \gamma \times \min(C_x, C_s, C_{Ln}) \tag{4}$$

1.2 Bus lane capacity simulation model

The simulation model is constructed based on Vissim simulation software, using actual Google Maps data to set the base map, and the parameters needed are the same as those used in the empirical formula. Some of the parameters use default values based on experience, while others need to be set according to actual conditions, mainly including bus routes, stop distribution and stopping methods, driving behaviour, etc. The driving behaviour parameters include the desired speed of the vehicle, the safety distance between the front and rear of the vehicle, the number of vehicles visible within the sight distance of the rear driver, and the distribution of bus stopping times.

As shown in Figure 1, the simulation process starts with the construction of the road network model, which requires the use of actual bus route data, stopping station data, and driving behaviour parameters like expected vehicle speed, safety distance, acceleration, deceleration reaction time, stopping time as inputs, and is completed by setting different road conditions on the actual traffic base map. The simulation process uses the actual travel speed and traffic flow of the bus lane as evaluation indicators, with the aim of maximizing the road traffic flow while the actual speed of vehicles on the road is close to the desired speed, thus achieving the desired road traffic state. Similar to the empirical formula calculation, the simulation model also divides the road into intersections, stops and the basic travel surface and other parts, taking the minimum value of the capacity of which as the capacity value of the whole road, and then finally using the road saturation for verification.

2. Algorithm Verification

2.1. Simulation model setting

Take the bus lane (from west to east) of Hubin East Road-Lotus Intersection in Siming District, Xiamen City, Fujian Province, for example, the road has two bus stops starting from the intersection at the west end, dividing the road into three basic travel sections, as shown in Figure 2.

For this road, the values of the relevant parameters in Table1 were obtained through the actual survey, as shown in Table2.

Table 2

Parameter declaration of empirical formulas

Name	Value	Name	Value	Name	Value	Name	Value
t_c	170s	a	10m/s^2	t_{oc}	3.500s	t_d	27.370s
t'	53s	b	1.500m/s^2	N_{eb}	1.750	l_s	2m
t_w	7.700s	Ω	70	λ_1	73pcu/h	t_r	1.500s
t_s	3.500s	k	0.300	λ_2	108pcu/h	v	25m
l	10m	t_0	2s	α	0.600	I	0.054
		n_d	2	β	0.800		

Substituting the parameter values into equations (1), (2) and (3), we can calculate the capacity values at road intersections, bus stops and the three basic traffic sections as follows: C_x=293*pcu/h*, C_s=262*pcu/h*, C_{L0}=1075*pcu/h*, C_{L1}=445*pcu/h*, C_{L2}=368*pcu/h*. Referring to the experience of other cities, we take the road saturation degree γ=0.4, and substitute it into equation (4) to obtain: $C=0.4\times262 pcu/h=104 pcu/h$.

Using Figure 2 as the traffic base map of the simulation model, the relevant roadway information to be set is mainly as follows.

- Intersection signal ratios;

East Hubin Road - Lotus intersection is a cross-shaped intersection, southeast and northwest four lanes are equipped with a signal, and traffic capacity is limited by the intersection signal green signal ratio. Green letter ratio refers to the proportion of time available for vehicle traffic in a signal cycle. Here, the signal proportioning using two-phase setting method, green letter ratio of 53/170.

- Bus routes;

For a total of 25 bus lines in three directions, the line trajectory and the corresponding stopping method are set according to the actual situation. The desired speed of each route is set to 25km/h, and the traffic flow of the road section is changed by adjusting the departure interval. The stopping methods all adopt the linear station stopping.

- Vehicle stopping time;

Since the study is concerned with the traffic flow rather than the number of passengers, the vehicle stopping time is set using a uniform method for the whole road. The vehicle stopping time is also used in the subsequent quantitative simulation of the method to enhance the capacity of the bus lane.

2.2. Analysis of simulation results

1) Average travel speed;

The running speed of the vehicle is affected by the road traffic flow, and the traffic flow is related to the departure interval, therefore, different departure intervals are selected in the simulation experiment to measure the corresponding average travel speed, and the results are shown in Figure 3.

From the speed curve in the figure, it can be found that the average speed of the vehicle has a large increase, higher than 15km/h, starting from the departure interval of 240s; after the departure interval of 600s, the average speed increase trend becomes slower. This indicates that, with the increase of the departure interval, the influence of the reduced traffic flow on the vehicle speed improvement becomes smaller and smaller. Therefore, the departure interval should not be set too large from the perspective of roadway use efficiency.

2) Traffic flow;

Traffic flow is the most intuitive measure of road capacity, which is directly affected by the departure interval. Theoretically, the smaller the departure interval, the larger the traffic flow should be. Figure 4 gives the simulation results of the traffic flow on the road section 0 after the road intersection, the road section 1 after the first stop and the road section 2 after the second stop at different departure intervals.

From the curve of Fig. 4, it is found that with the increase of the departure interval, the traffic flow presents a situation that rises first and then decreases, and achieves the maximum value at the departure interval of about 310s, and the three cases are 276 pcu/h, 268 pcu/h and 258 pcu/h. The analysis of the reason why the traffic flow is not decreasing in the interval of 30-310s is mainly due to the stopping station setting on the road. The stopping station setting makes vehicles need to slow down and stop, thus causing congestion on the road section. The smaller the departure interval, the more serious the congestion is, which is also illustrated by the rising curve of the average travel speed in this interval in Figure 3.

Since the origin of the road in the example is the road intersection at the west end, the above traffic flow simulation results are actually limited by the traffic flow at the road intersection, which is different from the basic traffic road capacity calculation model of empirical equation (3). In order to better compare the simulation results of the basic road section with the results of the empirical formula, the design capacity of the road section set in Equation (3-2) is used as the origin traffic flow instead of the intersection traffic flow in the simulation model to calculate the capacity-related indexes after passing the first stop; and then as the traffic flow after passing the first stop, used in the simulation model to calculate the capacity-related indexes after passing the second stop The results are shown in Table 3.

Table 3

Comparison of traffic ability between simulation model and empirical formula

Passing stops	Inflow traffic (pcu/h)	Outflow traffic 1 (Empirical formula，pcu/h)	Outflow traffic 2 (Simulation Model，pcu/h)	Simulated travel speed (km/s)	Corresponding departure interval (s)
stop 1	519	445	445	22.9	174
stop 2	445	368	342	20.1	202

2.3. Empirical indicators and method validation

1) Road saturation validation;

In the calculation of the empirical formula, the road saturation γ is taken as 0.4, which is an empirical value in traffic science, indicating that the road traffic flow is 40% of the maximum traffic flow when the actual travel speed on the road is close to the desired speed. Using the designed simulation model, the different values of road saturation are verified and the results obtained are shown in Figure 5.

From Figure 5 can be seen, the saturation in 0.1 to 0.4 change, the average speed of the road basically unchanged, in a state of gentle change, at this time to increase the saturation to increase traffic flow, there is no impact on the speed of traffic; and when the saturation is greater than 0.4, the average speed of traffic began to decline significantly, and the downward trend as the saturation increases and accelerates, indicating that the road traffic flow is too large at this time, which significantly affects the road service level. Therefore, the road saturation set to 0.4 is feasible and reasonable.

2) Traffic capacity improvement method verification

Simulations were conducted to validate three methods of improving roadway capacity, including: (a) modifying the intersection signal cycle; (b) reducing the vehicle waiting time; and (c) adjusting the stopping station pattern. The obtained results are shown in Figure 6.

If the signal cycle is shortened when the road intersection green time remains unchanged, the intersection green signal ratio will be increased, which will be beneficial to improve the road traffic capacity. From Figure 6(a), it can be found that every 10s shortening of the signal cycle will increase the road communication capacity by nearly 10%. The reduction in vehicle stopping time will inevitably bring about an increase in roadway throughput, especially for the single-lane case. As can be seen in Figure 6(b), for every 1 second reduction in stopping time, the traffic flow will gain 1.2% improvement. Changing the stopping pattern of stops can improve roadway capacity to a greater extent, and the results in Figure 6(c) show that the use of harbor stops can bring about a 14% increase in capacity compared to straight-line stops.

Conclusions

For urban bus lane capacity, a method combining empirical equations and simulation models for comparative calculations was proposed. The target road is divided into several sections by road intersections and bus stops, and the minimum capacity value is used as the upper limit of the capacity of the whole road. At the same time, a variety of methods to improve the capacity of bus lanes are verified and analysed using simulation, which is a good reference for the construction of urban bus lanes and the adjustment and improvement of road facilities.

For the calculation of the actual bus lane capacity, the road intersection and bus stop tandem constraint method can also be used, using the last section of the vehicle direction of travel capacity as the full road capacity index. In this case, the vehicle loss function needs to be added to the travelled road surface after the intersection or stop, and the vehicle delay time can be added as the evaluation index of the capacity. These issues are analysed in depth in the next research work, so as to improve the simulation model involved.

Declarations

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Declarations of conflict of interest

Authors declare that they do not have any competing financial, professional, or personal interests from other parties.

Author contributions

HTY and HZZ conceived the study and were responsible for the design and development of the data analysis.

HTY and CW collected the data.

HTY, HZZ, and MLL analyzed the data.

HTY, HZZ, MLL and YBP wrote the first draft of the paper; JW reviewed the paper for the first time and all authors participate in the follow-up review of the paper.

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Figures

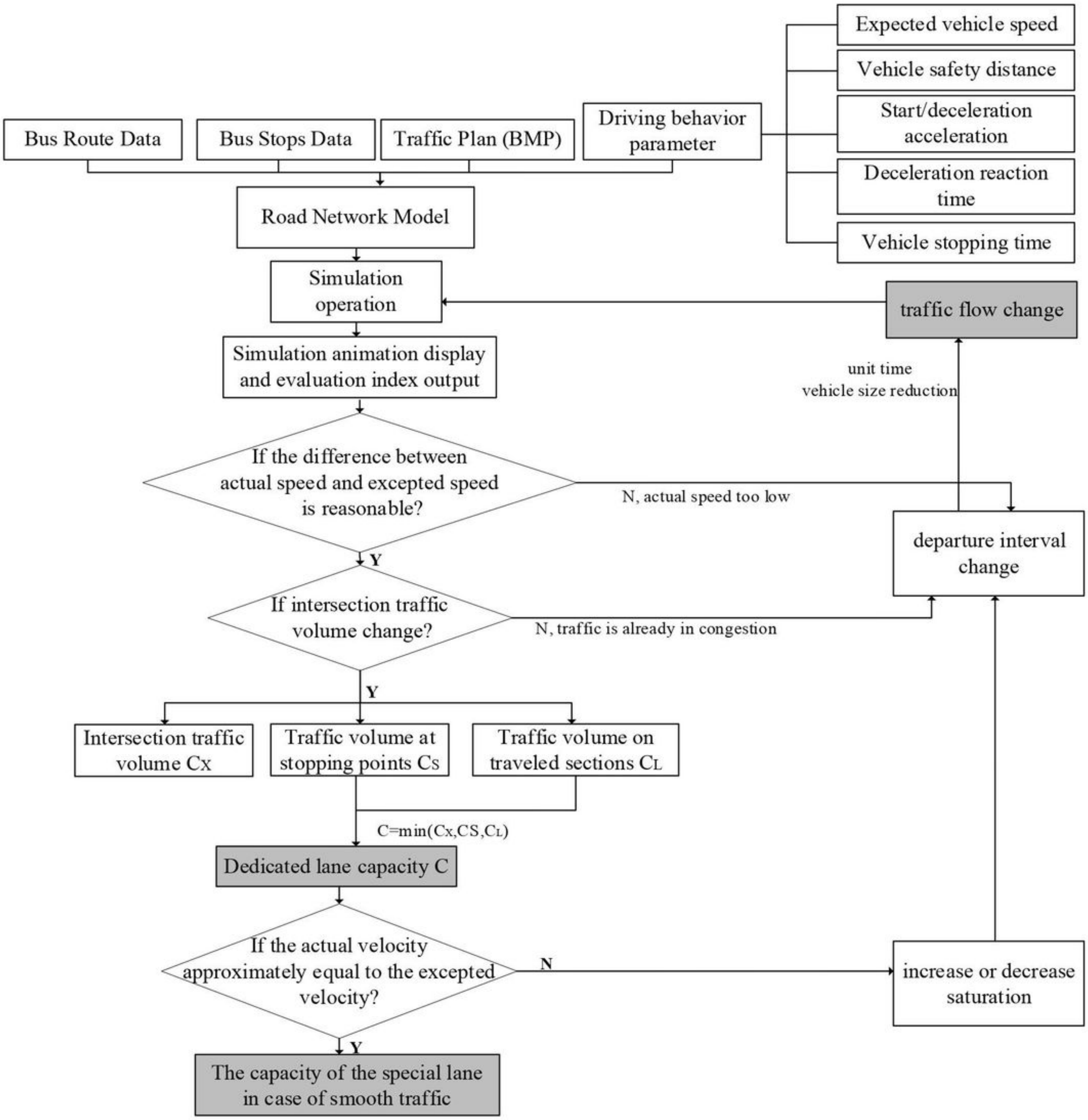


Figure 1

Flow of simulation

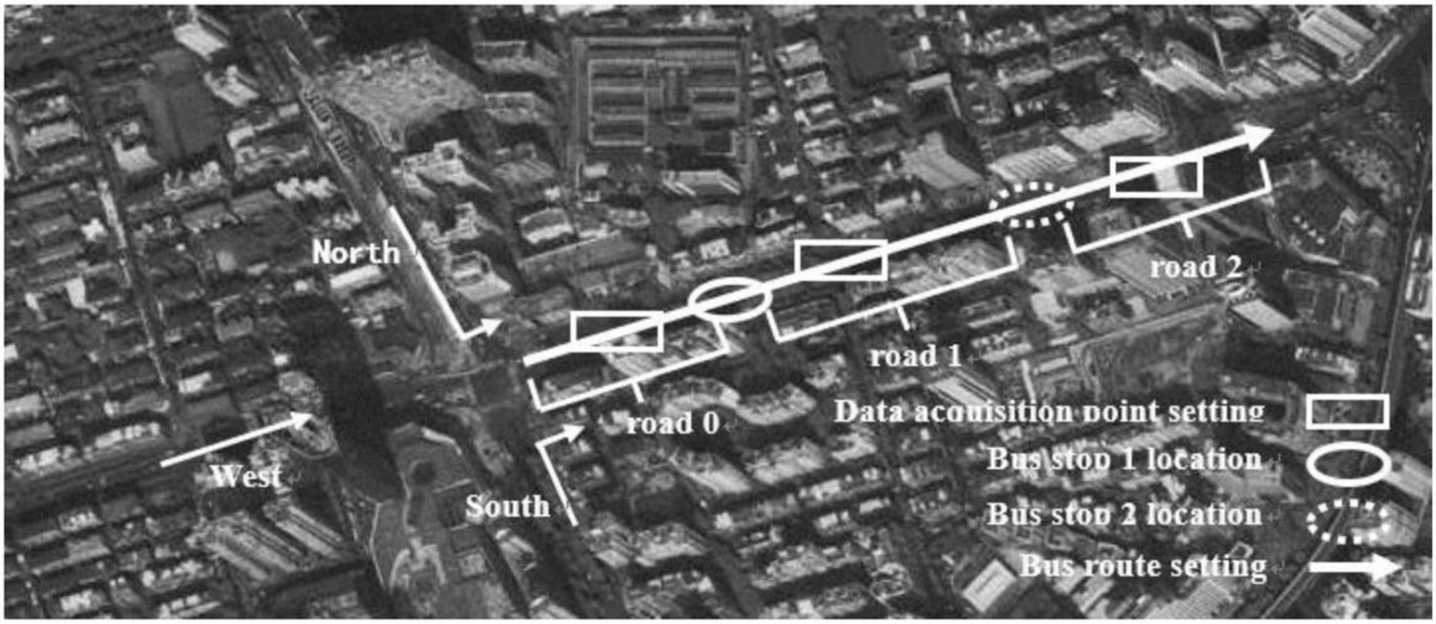


Figure 2

Base map of simulation

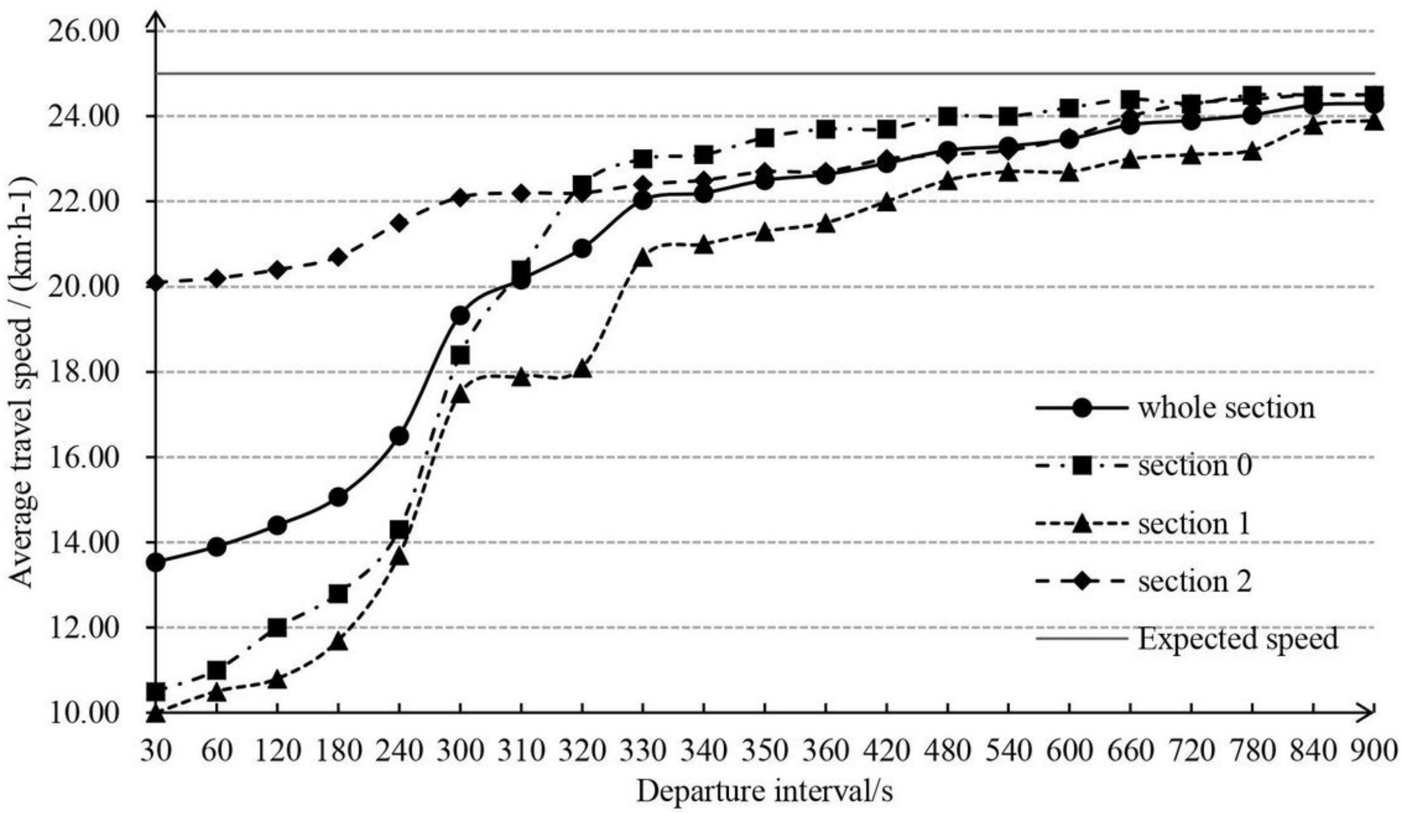


Figure 3

Simulation results of vehicle speed

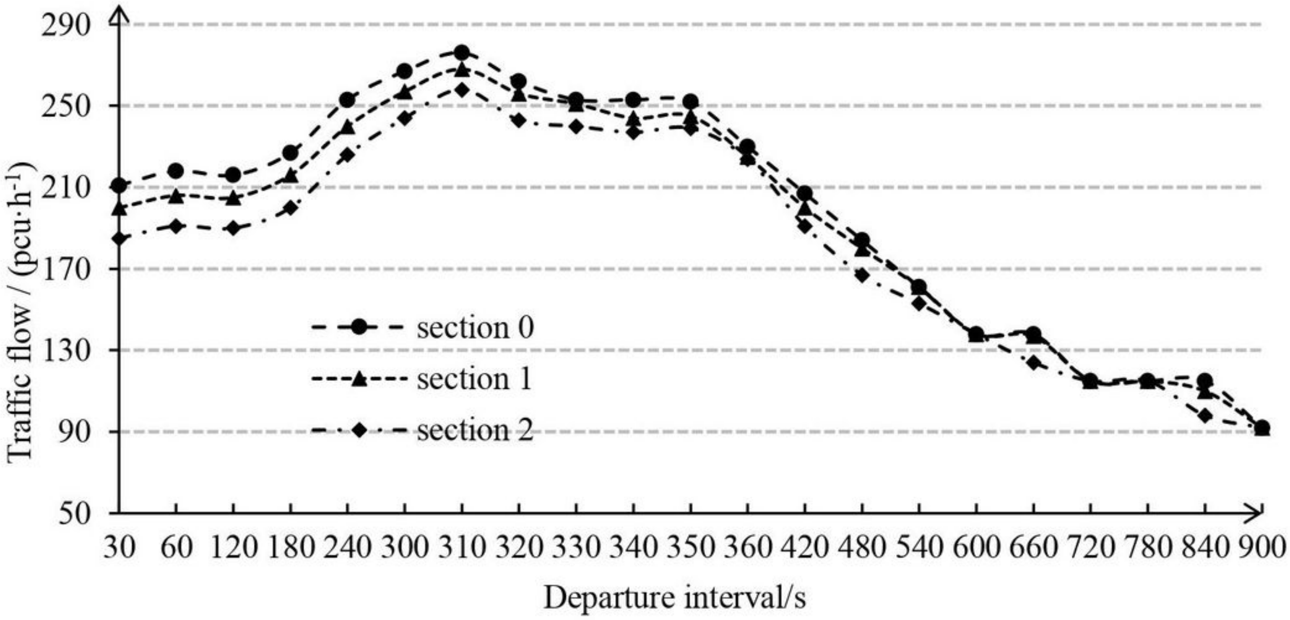


Figure 4

Simulation results of vehicle flow

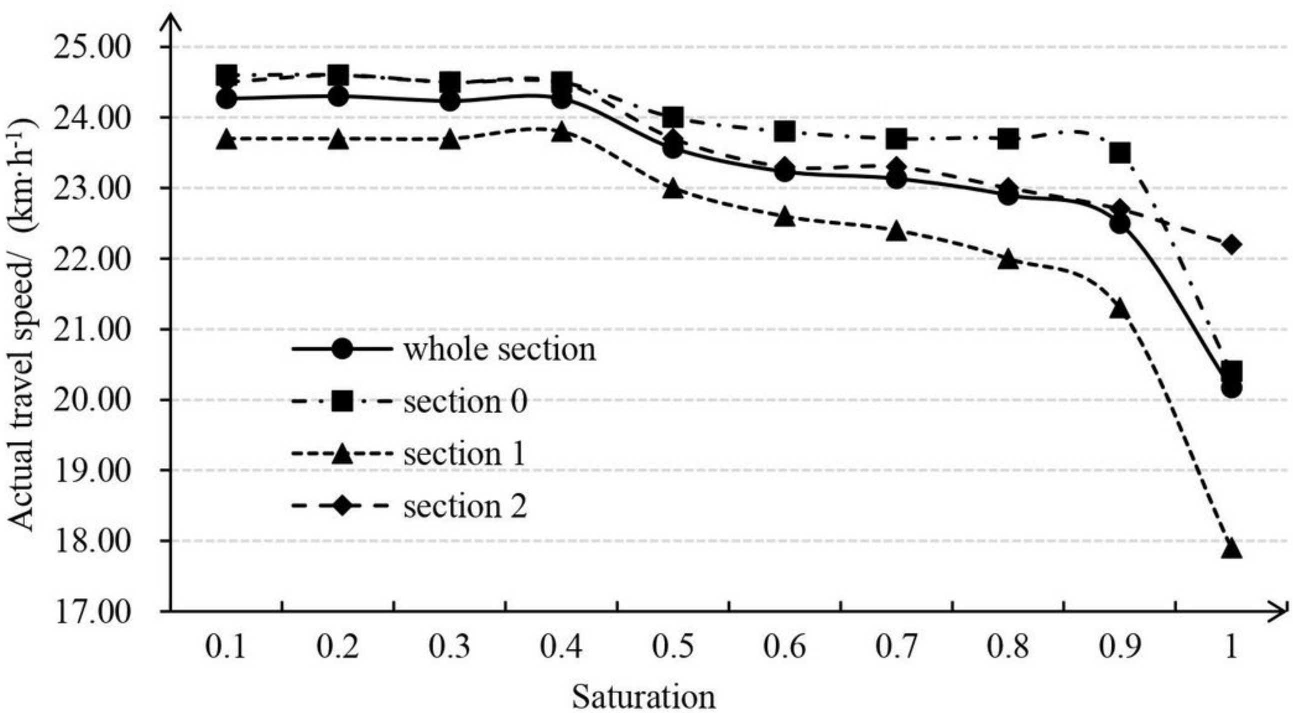
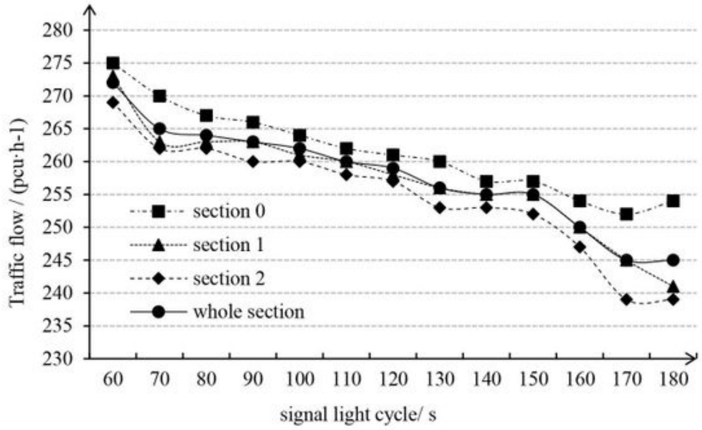
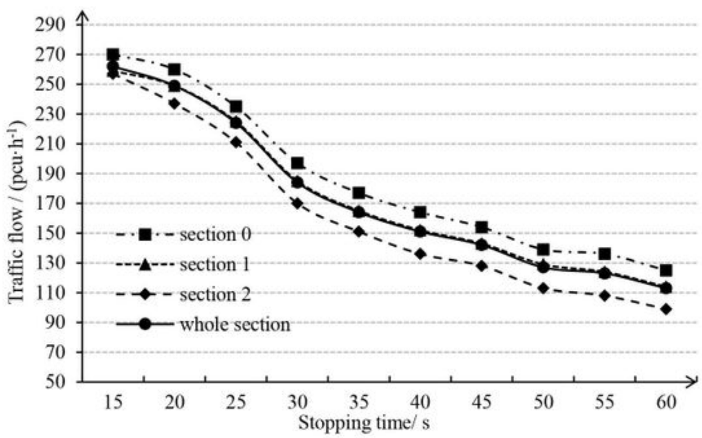


Figure 5

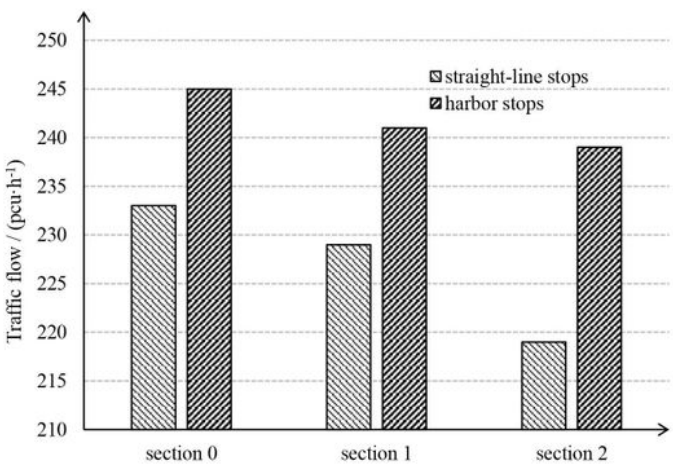
Simulation results of saturation



(a) modifying the intersection signal cycle



(b) reducing the vehicle waiting time



(c) adjusting the stopping station pattern

Figure 6

Simulation results of three methods to improve traffic capacity