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Optimization for Bus Stop Design Based on Cellular Automaton Traffic Model*

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Abstract

Bus is a main component of public transportation, and then the design of bus stop position, size and form should improve efficiency of public transportation. The optimization of bus stop is studied in this paper. According to the observation and analysis of realistic traffic, a micro-cellular automaton mixed traffic flow model with bus stop is established. And then a new evaluation index for the bus stop design is introduced. Finally, an optimized bus stop scheme is obtained by simulation. This research is studied for providing a theoretical basis for the construction of bus stop.

Keywords: Urban Traffic; Evaluation Index; Cellular Automata; Bus Stop; Mixed Traffic Flow

1 INTRODUCTION

With the continuous development of China, the problem of urban traffic has become more and more serious, and the traffic jam has become one of the most annoyed problems to urban residents. Public transport is a reasonable and economical solution to this problem. As a key node in public transportation, bus stop is the main factor affecting public travel, service level and operational efficiency of the traffic system. However, many small and medium cities' bus stops' designs are not reasonable. These heavily affect efficiency and the level of service of transportation.

The effect of bus stop setting on traffic flow has been studied by scholars. X.-m. Zhao et al. [1] researched on the effect of the bus stop between two neighboring signal-controlled intersections and pointed out the bus stop near an intersection served as a bottleneck. Bin Jia et al. [2] compared, analyzed non-harbor shaped, and harbor-shaped bus stops under different traffic mix proportion. Song Yu-Kun et al. [3] studied the traffic characteristics of a combined bottleneck with an on-ramp and its nearby bus stop and came to the conclusion that bus stop in the upstream section of the on-ramp would enhance road capacity. X-j Zhang et al. W. Gu et al. [4] developed formulas using Markov chain to predict the maximum bus flows that could be served by a select class of bus stops. Nevertheless, there was no specified research concerning optimization of bus stop position, form and size.

In this paper, a setting method for bus stop is proposed at the micro-level. First, a new urban traffic flow model is established based on cellular automaton. The model includes cars, trucks, buses and takes different road conditions into account, such as intersection, bus stops. Second, a new evaluation index for different bus stop setting scheme is set up, and the index value of different bus stops are calculated according to the simulation result of traffic flow model. Finally, the most reasonable setting scheme can be selected by comparing the evaluation index value.

2 CELLULAR AUTOMATON URBAN AFFIC MODEL

Cellular Automaton (CA) is a powerful tool for establishing models to study complicated systems. It is also widely applied to traffic flow models. By simple rule definition, many behaviors of real traffic can be reproduced. In addition, Cellular Automaton is easy for computer operation. Therefore, CA model has been widely studied and

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applied in the research of traffic flow. The most typical CA traffic flow models are Nasch model [5]and BML model [6]. These models are established for the highway traffic flow and are not suitable for urban road traffic flow. According to the urban road traffic characteristics, this paper establishes a CA urban traffic flow model.

2.1 Model Setting

The research object is a two-lane road between two intersections. Vehicles enter this section from right hand side and leave at right hand side. At the leaving side, there is a traffic signal. In this model, the default size of one cell is 7.5 meters. Cellular status is empty or occupied by a vehicle. The model has 3 kinds of vehicle, cars, trucks, buses. Their length is 1cell, 2cells, 2 cells respectively.

The new inflow vehicle comes from the right intersection. Vehicles are randomly generated, and each vehicle has its own flow direction. The inflow vehicle data can be adjusted by the generation probability according to the actual needs or import the fixed vehicle data. The model setting can be shown in Fig. 1

FIG. 1. ROAD MODEL

2.2 Moving Rule

The moving rule consists of forwarding rule, overtaking rule and special moving rule for bus.

1) Forwarding Rule

In urban area, the average speed of vehicle is 30~40 km/h. Therefore, the maximum speed is set as two cells/s, that is, 54 km/h. Forwarding rule defines the common way of driving on the road without changing lanes. Assume that the vehicle n is being concerned. The rules are as follows:

$$if\,(d_n = 0,1),\ v_n = d_n \tag{1}$$

$$if\,(d_n = 2), v_n = \begin{cases} 1,\ p_{acc} < rand() \\ 2,\ p_{acc} \geq rand() \end{cases} \tag{2}$$

$$x_n = x_n + v_n \tag{3}$$

d_n ---the distance between vehicle n and the vehicle in front

v_n --- the speed of vehicle n

p_{acc} --- given acceleration probability

x_n --- the position of vehicle n

2) Lane-changing Rule.

Lane-changing happens when the road is blocked by another vehicle and the adjacent lane driving condition is better than the current lane. For vehicle n, when the followed equation is met, lane-changing happens.

$$d_n = 0, d_{n,other} = 2, d_{n,back} = 2, rand() < p_t \tag{4}$$

$d_{n,other}$ ---the distance between vehicle n and the vehicle in front at adjacent lane

$d_{n,back}$ --- the distance between vehicle n and the vehicle behind it at adjacent lane

p_t ---lane change probability, on behalf of the driver's willingness to change lanes

3) Special Lane-changing Rule.

In this model, the vehicle has three kinds of flow direction, which will enter the corresponding road at the intersection. However, taking into account multi lane, there will be left, straight or right lane lanes, so the vehicles need to change based on with their own flow direction in advance. There is a special lane changing area in the model, and the vehicle needs to complete the lane change before it. Special lane-changing rule is shown as follow:

$$d_{n,back} = 2, d_{n,other} \neq 0 \tag{5}$$

2.3 Special Moving Rule for Bus

In this model, taking into account the 2 forms of bus stop. Stops can be set up different sizes. Unit size is 2 cells. In bus stop area, moving rule is a little bit different. For vehicles like cars and trucks, they just treat bus stop area as normal area. However, for buses, they have to park at bus stop for some time to load and unload passengers. So, special rules need to be set.

Step 1

After the bus into the stop area, it would check the stop. If there is vacant, enter the stop nearest exit; If not, wait. If the form is harbor, the bus need to change lane into stop.

Step 2

Stop at bus stop for passengers to get on and off the bus. The stop time is T_s . It can be set as a random time that obeys a probability distribution according to the actual investigation or it can be set to a fixed time.

Step 1

After step 2 is completed, the bus moves forward according to the established rules. If the form is harbor, the bus need to change lane.

3 EVALUATION OF BUS STOP SETTING SCHEME

In traffic flow theory, several indicators are used to represent traffic condition such as throughput, velocity and traffic density. All these common indicators can be measured by monitors in road network. However, there is no unified performance index for the influence on road traffic caused by bus stop. It is important to introduce an evaluation index for road traffic with bus stop to determine the best bus stop design.

This paper puts forward an evaluation index based on bus’s service capacity and road traffic capacity. It can determine the optimal bus stop settings on a certain road, through the simulation of CA traffic flow model

3.1 Evaluation Index

When bus stop setting is reasonable, its service capability and road traffic should be well. For this reason, the paper takes the travel time of buses and cars, service ability and the road capacity into account, and put forward a new evaluation index---A. It is defined by Eq. (1).

$$A = \alpha s_1 r_1 T_1 + \beta s_2 r_2 T_2 \tag{7}$$

α and β are adjustment factors for buses and cars, which represent the importance of buses and cars. It can be determined according to the degree of emphasis on public transport and private transportation. s_1 is the service level of the bus stop. It can be determined according to the service radius of the stop, number of serviced people, service efficiency, service time and costs, etc. s_2 is the road service level, It can be determined according to the average speed, the accident rate, the inflow condition of vehicles etc. r_1 and r_2 are the pass ratio of buses and cars, which is through the road vehicles and the proportion of all vehicles. T_1 is bus travel time. T_2 is car travel time.

3.2. Scheme Selection Process

The modified cellular automaton traffic model and evaluation index are used to get the most optimal bus stop scheme. The procedure of the optimization for bus stop is in shown Fig.2.

Step1: set the parameters of the CA model

The initial macro parameters of the CA model should be set firstly, including the length of the road, the inflow rate of the vehicle, the composition of the vehicle, the proportion of different driving directions, the acceleration rate, the simulation time, the parameters of the traffic light, etc.

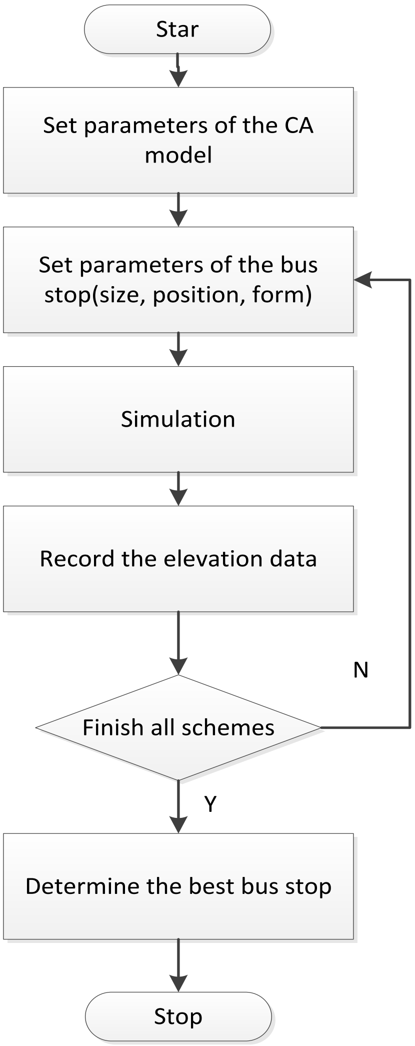

FIG. 2. PROCEDURE OF THE OPTIMIZATION

Step2: set bus stop schemes

According to the bus stop schemes, set the parameters of the bus stop, including size, position and form.

Step3: simulation

After the parameters are set, the program is started to run the simulation. And then the output data is recorded.

Step 4: record the evaluation data.

Step 5: if simulate all bus stops, then continue the next step, else go to step 2.

Step6: select the best scheme

According to the simulation output data, the evaluation index value is calculated, and then the best scheme can be selected.

4 SIMULATION EXERCISES AND ANALYSIS

In order to verify the proposed evaluation index to choose the bus stop scheme, a JAVA simulation interface is compiled, according to the cellular automaton traffic flow model. It is shown in Fig. 3.

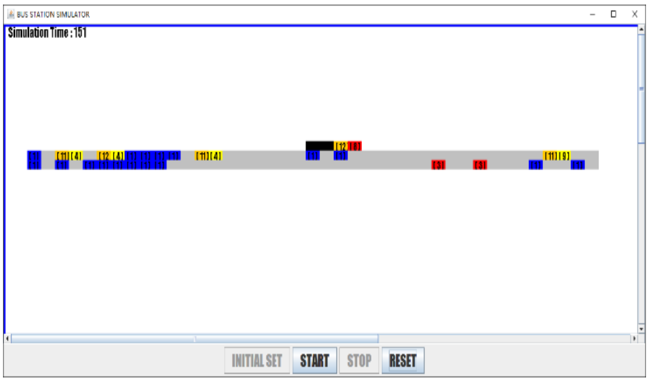

FIG. 3. SIMULATION INTERFACE

4.1 Simulation Condition

There are 10 different bus routes, bus interval of about 10 minutes. The simulation parameters of road are shown in Table 1.

In order to ensure consistency, each simulation uses the same traffic flow data, the specific traffic flow and composition as shown in table 2.

TAB.1 ROAD PARAMETERS

Road length	525m(70cells)
Signal light time (green light, red light)	45,30
Bus service time T_s	30
Acceleration probability P_t	0.85

TAB. 2 THE INFLOW DATA (VEHICLE/H)

Car		Bus	Truck
Turn left	Go straight and turn right		
85	1282.5	62	29.5

There are 36 bus stop schemes. Their parameters are shown in table 3.

TAB. 3 SCHEME PARAMETERS

Form	Linear type, Harbor type
Position	75m,150m,225m,300m,375m,450m
Size	1,2,3

4.2 Evaluation Index Description

In this paper, α is 0.8 and β is 0.2, which are obtained according to the number of passengers in one cell.

s_1 is the service level of the bus stop. It is determined based on service time in an hour. Specific classification is shown in Table 4

TAB. 4 SERVICE COEFFICIENT OF STOP

Service coefficient	**Service time （s）**
1	>1250
2	1100-1250
3	950-1100
4	800-9500
5	<800

s_2 is the road service level. Reference to the United States "Highway Capacity Manual", it is based on the average speed of the vehicle and is shown in Table 5

TAB. 5 SERVICE COEFFICIENT OF ROAD

Service coefficient	Average speed（km/h）
1	>20
2	18-20
3	14-18
4	10-14
5	<10

r_1 is calculated according to the ratio of the inflow and outflow of the bus. r_2 is calculated based on the ratio of the inflow and outflow of cars.

4.3 Results Analysis

According to the above settings, 36 different bus stop setting schemes are simulated, and the simulation results are shown in table 6.

TAB. 6 SIMULATION RESULT

form	position	size	evaluation index				
			s_1	r_1	s_2	r_2	A
linear	10	1	4	0.77	5	0.47	596.87
	10	2	4	0.77	5	0.41	509.55
	10	3	5	0.82	5	0.40	549.89
	20	1	1	0.39	3	0.37	128.09
	20	2	1	0.39	2	0.37	68.64
	20	3	1	0.39	2	0.37	69.12
	30	1	1	0.39	2	0.37	67.39
	30	2	1	0.39	2	0.37	68.03
	30	3	1	0.39	2	0.39	70.44
	40	1	1	0.39	2	0.37	65.67
	40	2	1	0.39	2	0.37	67.03
	40	3	1	0.39	2	0.37	67.87
	50	1	1	0.39	2	0.37	66.03
	50	2	1	0.39	2	0.37	66.53
	50	3	1	0.39	2	0.37	68.03
	60	1	4	0.61	1	0.35	78.05
	60	2	4	0.64	2	0.34	107.33
	60	3	4	0.65	1	0.34	80.10
harbor	10	1	2	0.49	4	0.46	309.19
	10	2	2	0.49	4	0.46	331.12
	10	3	1	0.47	3	0.40	131.31
	20	1	1	0.39	1	0.39	36.96
	20	2	1	0.39	1	0.37	34.47
	20	3	1	0.39	1	0.37	35.48
	30	1	1	0.39	1	0.39	35.09
	30	2	1	0.39	1	0.37	34.18
	30	3	1	0.39	1	0.37	34.01
	40	1	1	0.39	1	0.41	35.78
	40	2	1	0.39	1	0.37	32.96
	40	3	1	0.39	1	0.37	33.98
	50	1	1	0.39	1	0.41	36.20
	50	2	1	0.39	1	0.37	33.93
	50	3	1	0.39	1	0.37	33.70
	60	1	1	0.42	1	0.40	36.04
	60	2	1	0.45	1	0.36	34.33
	60	3	4	0.50	1	0.36	57.83

Table 6 shows the following conclusions:

(1) The average value of evaluation index of harbor bus stop is 73.14, the linear is 155.28. Harbor stop is better than linear stop. Because harbor stop does not occupy the driveway and the traffic flow is less affected. However, the harbor bus stop requirements more space and higher cost. If the actual conditions allow, the construction of the harbor bus stop is a better choice.

(2) No matter is the harbor or the linear, the average value of the site is small at the distance of 225m-375m (30-

50cell).That indicates that stop should be close to the central road. If built on both sides of the road, the stop will block the traffic. Because the stop will cause jam at the entrance and exit. That not only affects the road, will also affect the adjacent section.

According to the micro traffic flow simulation model, which is established in this paper, the best scheme can be obtained. The optimal design scheme of linear stop is that length is 2cells and position is at the exit of the road 300m (40cell) and the optimal design of the harbor stop is that that length is 4cells and position is at the exit of the road 300m (40cell).

5 CONCLUSION

This paper establishes a micro bus stop CA mixed traffic flow model, and puts forward a new evaluation index according to the road traffic and stop service and other factors. By the simulation, the general principles and the optimal bus stop setting scheme are get. However, the model still needs to be improved; the evaluation method is not perfect. Future work is to simulate based on the actual data and to study different road conditions.

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