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Road Capacity under the Influence of Bus Stops*

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Abstract: To analyze the operation efficiency of a bus stop, the influencing factors of operation efficiency of Bus Rapid Transit and Regular Transit have been summarized. Then the loss of road capacity model and capacity model under the influence of BRT were proposed based on the pulse characteristics of passengers' on-off board. Later, the road capacity model under the influence of regular transit and pedestrianwas proposed and Tianmushan bus stop was chosen as an example to analyze the proposed model. The results showed that setting a bus lane can eliminate congested area caused by bus stop and pedestrians and then increase the operation efficiency of road traffic.

Key words: Delay, bus, capacity, pedestrian

INTRODUCTION

Urban traffic congestion has been a difficult issue for most cities in our country and the congested lasted time and area expanding continuously. The core reason for traffic congestion is the unbalance of traffic demand and supply, to be specific, traffic demand is more than traffic supply. This reason mainly reflects as the following two aspects: The first one is the rapidly increasing car ownership; the second one is the low service level of transit system. Both two aspects have mutual effects. On the one hand, travelers tend to drive their own cars rather than take public transit when they are going out because of the low service level of transit system; on the other hand, because of the limitation of road resource, the increasing car ownership can result in an decreasing operation efficiency of the network which will let transit system operated under a worse condition in turn. A effective method to solve the traffic congestion can be concluded from the mutual effects that is, level up the transit service to let more travelers willing to choose public transportation to go out (Mesbah *et al*., 2011; Arasan and Vedagiri, 2010).

There are complex interaction between transit and other traffic flow. Li *et al.* (2010) referred to function of road resistance and proposed a model considering the minimum trip time per person as the object. This model determined the optimal bus ratio for setting a bus lane on a road or intersection. Liu *et al*. (2005) analyzed the road condition which is suitable to set a bus lane, finally established a critical flow model for setting bus lane and discussed the influencing factors. Huang *et al.* (2003) proposed speed models of buses and regular transportations for roads with or without a bus lane.

A number of cities in our country have set BRT system. As a result, traffic flow on urban roads is influenced by buses of BRT or regular transit system and pedestrians. This mixture traffic flow is far more complex than those general roads without buses. This study established a capacity model considering several influencing factors based on the pulse passenger flow of BRT. Field investigations were made to compare the travelling benefit of roads with and without a bus lane. Results showed that setting a bus lane can eliminate congested area caused by bus stop and pedestrians and then increase the operation efficiency of road traffic.

ANALYZED METHOD

Influencing factors: Figure 1 displays a typical illustration of a road section with pedestrian crosswalk and bus stop. Pedestrians have the priori crossing right. Motor vehicles must wait until there is an enough gap for them to cross. This rule has two results: on one hand, pedestrians crossing behavior has a great effect on capacity of the section on pedestrian crosswalk; on the other hand, when there is a bus at the curbside bus stop, the following cars should make a lane change to continue their moving, thus, there will be a loss of capacity on the road section. What's more, when the curbside bus stop is close to the pedestrian crosswalk, capacity of road between pedestrian crosswalk and curbside bus stop will decrease

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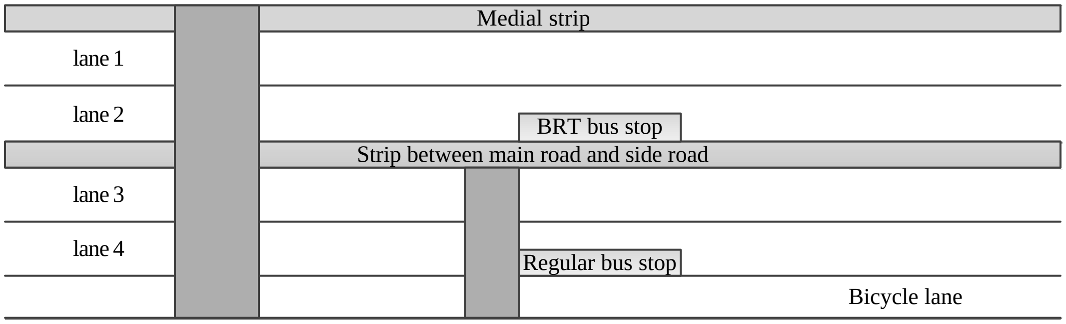

Fig. 1: Typical illustration of a road section with pedestrian crosswalk and bus stop

significantly. Taking Tianmushan Road as an example, there are plenty of pedestrian crosswalk and curbside bus stop along it. It is necessary to analysis of the influence of pedestrian crossing and curbside bus stop on the v/c ratio, since the results can provide a theoretical support to establish the improvement method.

As it is showed in Fig. 1, pedestrians' on and off board the BRT must cross the side road, so there will be an effect on lane 3 and 4; after the regular bus stopped, the following social vehicles on lane 4 must change their lanes which will have an influence on capacity of lane 4. Pedestrians get off the BRT or regular buses and residents nearby may cross the road because their trip destinations maybe at the north side of the road. This will also block the vehicle on lane 4.

Pedestrians getting of BRT display an obvious pulse arrival. Pedestrians crossing the pedestrian crosswalk display a random arrival. The arrival rule of pedestrians determines how the motor vehicles on the road can be influenced.

Calculating method of capacity:

- **Influence of passengers getting on or off BRT:** Pedestrians getting of BRT cross lane 3 and 4 as a "cluster". The number of pedestrians getting off each BRT, the width of side road, the minimum distance between two pedestrians, the average speed of pedestrians crossing the street and the distance between two "clusters" are defined as Np, Lp, lp, Lrp, v and Δt, respectively. Then the number of row of pedestrians crossing the pedestrian crosswalk can be defined as:

$$n_r = \left\lfloor \frac{L_p}{L_{rp}} \right\rfloor \quad (1)$$

where, n_r is the number of row of pedestrians can crossing the pedestrian crosswalk; $\lfloor\ \rfloor$ is the operative symbol represents round down.

Number of rows formed by the passengers getting of a BRT is:

$$n = \frac{N_p}{n_r} = \frac{N_p}{\lfloor L_p / L_{rp} \rfloor} \quad (2)$$

The passing time for the first row of pedestrians is:

$$t_1 = {l_p}/{v} \quad (3)$$

Distance between two adjacent "clusters" is Δt, so the passing time for the last row of pedestrians is:

$$t = t_1 + (n-1)\Delta t = {l_p}/{v} + \left(\frac{N_p}{\lfloor L_p / L_{rp} \rfloor} - 1 \right) \Delta t \quad (4)$$

Assume the number of BRT buses stopped at the bus stop is q_b, then the loss time of lane 3 and 4 caused by passengers in an hour is:

$$T = q_b t = q_b \left[{l_p}/{v} + \left(\frac{N_p}{\lfloor L_p / L_{rp} \rfloor} - 1 \right) \Delta t \right] \quad (5)$$

So, the capacity of lane 3 and 4 under the influence of BRT is:

$$Q_b = S \cdot \max\{0, 1 - T/3600\} \quad (6)$$

where, Q_b is the capacity under the influence of BRT (veh/h); S is the saturated flow of lane 1 and 2.

- **Road capacity under the influence of regular transit:** Denote the arrival rate of regular buses is q_p, the service level of each bus at the bus stop is t_w, then the time buses occupied the bus stop during the time period t is q_b*t*t_w. Thus, capacity of lane 4 under the influence of regular transit is:

$$Q_{p,4} = S \cdot \max\{0, 1 - q_b \cdot t_w \cdot t / t\} = S \cdot \max\{0, 1 - q_b \cdot t_w\} \quad (7)$$

- **Road capacity under the influence of pedestrians:** When the number of pedestrians is more than 4000 person h^{-1}, displaced negative exponential distribution can be used to fitting the distribution of pedestrians' arrival rate, depending on earlier surveys. Based on regression analysis, when flow of pedestrian is q_r, the average number of pedestrian in each cluster is:

$$n_p = \alpha_0 + \alpha_1 q_r \quad (8)$$

The average gap between two arrival clusters is:

$$H_p = \frac{3600}{q_r / n_p} = \frac{3600(\alpha_0 + \alpha_1 q_r)}{q_r} \quad (9)$$

where, α_0 and α_1 are the regression parameters.

Use N represents the number of cluster passing pedestrian crosswalk during a unit time, then N = qr/np. Considering there is a median strip between main road and side road of Tianmushan road. Motor vehicles on the road usually apply the side road to avoid pedestrians. Based on the gap theory, road capacity under the influence of pedestrians can be obtained:

$$\frac{N}{[N/(1 - N \cdot t_m)] t_f} e^{-[N/(1-N \cdot t_m)](t_0 - t_m)} \quad (10)$$

where, t_f represents the following time between two vehicles; t_m represents the gap between two pedestrians' clusters which usually considered to be 1s; $t_0 = t_c - t_f/2$; t_c represents the critical gap between two pedestrians' clusters that vehicles can get across.

What's more, if most of the pedestrians are passengers getting off the bus, arrival rule will display an apparently pulse phenomena. At this time, the loss time of motor vehicles caused by passengers on each bus is:

$$t_r = \frac{q_r}{N_b} \left\{ l_p / v + \left(\frac{N_p}{\lfloor L_p / L_{rp} \rfloor} - 1 \right) \Delta t \right\} \quad (11)$$

Road capacity influenced by pedestrians crossing the street can be obtained:

$$Q_r = S \cdot \max\{0, 1 - (3600 - t_r) / t_r\} \quad (12)$$

FIELD SURVEY

Current traffic operation condition: To verify the validity of models proposed in this study, take Tianmushan road in Hangzhou as a study object. Among the transit lines on the road, Baziqiao and Huanglong center are two typical road which are affected by pedestrian crosswalk and bus stop significantly. The lane width, number of passengers getting on and off, vehicle flow and average bus service time are showed in Table 1.

Pedestrians on Baziqiao and Huanglong center are mainly passengers getting off buses. The arrival mode of pedestrians displayed a pulse phenomenon. How the passengers getting on and off buses and pedestrians crossing the street can affect motor traffic flow was investigated. Take 180s as the data collected interval. Analyzed results are showed in Table 2-3.

Four lanes on the road were influenced by the three factors mentioned before. Table 4 displays the capacity and v/c ratio of the selected roads.

Traffic operation analysis after implemented the improved project: If set a bus lane, bus flow will separated

Table 1: Current data of sensitive point of roads

	Traffic flow (veh h^{-1})			Road width (m)					
Road name	Social cars	Regular buses	BRT	Main road	Side road	Pedestrian flow	Service time of regular buses	Passengers getting off BRT/vehicle (p/veh)	Remarks
Baziqiao	2020	120	50	6.5	9.1	900	22	20	
Huanglong centre	2549	160	48	6.5	8.5	1100	30	35	BRT not stopp

Table 2: Loss time caused by bus stop of BRT

		BRT influencing analysis			
Road name	Lane No.	Passengers getting off	Arrival rate of BRT (cycle)	Loss time caused by passengers getting off	Total loss time
Baziqiao	1	20	2	0.0	0
	2	20	2	5.3	12
	3	20	2	14.3	31
	4	20	2	17.0	34
Huanglong centre	1	35	2	0.0	0
	2	35	2	0.0	0
	3	35	2	0.0	0
	4	35	2	0.0	0

Table 3: Loss time caused by bus stop of regular transit and pedestrians

Road name	Lane No.	Influence of pedestrian: Pedestrian flow	Loss time (sec)	Influence of regular transit: Bus arrival rate (veh/c)	Average service time	Loss time (sec)
Baziqiao	1	900	21	0	0	0
	2	900	21	0	0	0
	3	900	13	0	0	0
	4	900	13	5	22	110
Huanglong center	1	1100	16	0	0	0
	2	1100	16	0	0	0
	3	1100	23	0	0	0
	4	1100	23	6	21	126

Table 4: Loss time and road capacity under the influence of BRT, regular transit and pedestrians

Road name	Lane No.	Loss time caused by BRT	Loss time caused by regular transit	Loss time caused by pedestrian	Ratio of remaining capacity	Saturated flow	Actual capacity	Capacity of common lanes	v/c ratio of common lanes
Baziqiao	1	0	0	21	0.87	1440	1251	2322	0.86
	2	12	0	21	0.79		-		
	3	31	0	13	0.73		1044		
	4	34	110	13	0.02		27		
Huanglong center	1	0	0	16	0.90		1296	2628	0.97
	2	0	0	16	0.90		-		
	3	0	0	23	0.86		1233		
	4	0	126	23	0.07		99		

Table 5: Pedestrian flow for current road condition and new road condition

Road name	Current pedestrian flow: Main road	Side road	New pedestrian flow: Main road	Side road
Baziqiao	900	900	850	1480
Huanglong center	1100	1100	960	1400

Table 6: Loss time caused by pedestrians

Road name	Lane No.	Pedestrian flow	Loss time caused by pedestrian	Ratio of remaining capacity	Designed capacity	Actual capacity	Flow of lane group	v/c ratio of road
Baziqiao	1	1480	26	0.84	577	485	170	0.35
	2	1480	26	0.84				
	3	850	13	0.92	1800	3308	2020	0.61
	4	850	13	0.92				
Huanglong center	1	1100	24	0.85	577	490	208	0.43
	2	1100	24	0.85				
	3	900	13	0.92	1800	3308	2049	0.62
	4	900	13	0.92				

from others traffic flow. This method can reduce the mutual interference between buses and other vehicles then make transit system operate more efficiently. However, most of the bus stop set on the main roads which will result in an increase of the frequency of passengers passing through the street. This will make negative influence on society cars. Thus, it is necessary to analyze the traffic operated condition after implementing the new project.

After implementing the new project, bus flow on main road and other traffic flow on side road are only influenced by pedestrians. At the same time, flow of pedestrians is more than the current condition. Table 5 lists the pedestrians' flow crossing the street on the road section between Baziqiao-Tianmushan road and Tianmushan-Huanglong road, after implementing the new project.

Assume the average time headway between two buses is 6 sec and the average time headway between two cars is 2 sec. Then the ratio of the remaining capacity, actual capacity and v/c ratio of the road section are showed in Table 6.

As it is showed in Table 4 and 6, after implementing the new project, v/c ratio of Baziqiao bus stop and Qingfengcun bus stop are declined from 0.86 and 0.97 to 0.61 and 0.62, respectively. It is obvious that under the new traffic condition, traffic operated on a more stable condition and there is less obstacles which would interrupt the running of vehicles. The results show that the new project can eliminate the congested area caused by bus stops and pedestrians and improve the traffic operation efficiency.

CONCLUSION

Setting a bus lane is one of the public transport priority methods. This method can improve the operation efficiency and service level of buses. This method also can make transit system more attractive to travelers. As a result, more travelers would like to choose public transportation rather than private cars when they go out which can reduce the resident riding trip. It is obvious an effective method to remission traffic congestion and a correct way for the future urban transportation system should follow. This study analyzed the road capacity under the influence of BRT, regular buses and pedestrians, respectively. Then compared the traffic operation efficiency before and after a bus lane was set. Results showed that setting a bus lane can eliminate the congested area caused by bus stops and pedestrians and improve the traffic operation efficiency.

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