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 pedestrian was 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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*Fund project: National Natural Science Foundation of China (51078168)
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, Lp, v and Δt, respectively. Then the number of row of pedestrians crossing the pedestrian crosswalk can be defined as:

  \[ n = \left\lfloor \frac{L_p}{L_{np}} \right\rfloor \]  

  where, \( n \) is the number of row of pedestrians can crossing the pedestrian crosswalk; \( \lfloor \ldots \rfloor \) is the operative symbol represents round down.

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

  \[ n = \frac{N_p}{n_p} = \frac{N_p}{L_p/L_{np}} \]  

  The passing time for the first row of pedestrians is:

  \[ t_1 = \frac{L_p}{v} \]  

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

  \[ t - t_1 + (n - 1)\Delta t = \frac{L_p}{v} + \left( \frac{N_p}{L_p/L_{np}} - 1 \right) \Delta t \]  

  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:

  \[ T = q_b t = q_b \left( \frac{L_p}{v} + \left( \frac{N_p}{L_p/L_{np}} - 1 \right) \Delta t \right) \]  

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

  \[ Q_i = S \cdot \max \{0,1 - T/3600\} \]

  where, \( Q_i \) 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 \( q_r \), the service level of each bus at the bus stop is \( s \), then the time buses occupied the bus stop during the time period \( t \) is \( q_r \cdot s \cdot t \). Thus, capacity of lane 4 under the influence of regular transit is:

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\[ Q_{t,t} = S \cdot \max \{0.1 - q_b, t_u / t_1\} = S \cdot \max \{0.1 - q_b, t_u\} \quad (7) \]

- **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 fit the distribution of pedestrians' arrival rate, depending on earlier surveys. Based on regression analysis, when flow of pedestrian is \( q_b \), the average number of pedestrian in each cluster is:

\[ n_p = n_0 + \alpha_n q_b \quad (8) \]

The average gap between two arrival clusters is:

\[ H_p = \frac{3600}{q_b / n_p} = \frac{3600(\alpha_n + \alpha_q q_b)}{q_b} \quad (9) \]

where, \( \alpha_n \) and \( \alpha_q \) are the regression parameters.

Use \( N \) represents the number of cluster passing pedestrian crosswalk during a unit time, then \( N = q_b / n_p \). 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:

\[ \frac{N}{[N/(Q - N \cdot t_u)]^{1/2}} e^{[(Q - N \cdot t_u)/t_u]} \quad (10) \]

where, \( t_u \) represents the following time between two vehicles; \( t_u \) represents the gap between two pedestrians' clusters which usually considered to be 1s; \( t_u = t_{r2} / 2 \); \( t_{r2} \) 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:

\[ t_l = \frac{q_b}{N_b} \left( \frac{t_v}{V} + \left( \frac{N_b}{L_v / L_p} - 1 \right) \Delta t \right) \quad (11) \]

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

\[ Q_p = S \cdot \max \{0.1 - (3600 - t_l) / t_l\} \quad (12) \]

**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...

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### Table 1: Current data of sensitive point of roads

<table>
<thead>
<tr>
<th>Road name</th>
<th>Traffic flow (veh h(^{-1}))</th>
<th>Road width (m)</th>
<th>Service time of regular buses (min)</th>
<th>Passengers getting off/BRT/vehicle (p/veh)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baziqiao</td>
<td>2020</td>
<td>120, 50</td>
<td>6.5, 9.1</td>
<td>22, 1100</td>
<td>BRT not stop</td>
</tr>
<tr>
<td>Huanglong centre</td>
<td>2549</td>
<td>160, 48</td>
<td>6.5, 8.5</td>
<td>30, 35</td>
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</tbody>
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### Table 2: Loss time caused by bus stop of BRT

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<th>BRT influencing analysis</th>
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<td>Road name</td>
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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 Qingsfcngun 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.

REFERENCES


