Capacity Drop of Urban Arterial due to a Curbside Bus Stop

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ABSTRACT: Road transport infrastructure typically consists of road and highway networks, including structures, electrical systems, edge treatments and specialized facilities such as bus stops, pedestrian walkways, etc. Bus stops are the designated places where passengers alight and board a public transport bus. They are vital links in a city’s public transportation network. Three types of bus stops namely curbside bus stops, bus bays and segregated bus bays are generally present on Indian urban roads. However among these, curbside bus stops are predominant. They are generally provided on urban roads when sufficient land is not available to construct bus bays or segregated bus bays. These type of bus stops have adverse effect on various traffic characteristics such as speed and roadway capacity. The present study demonstrates the capacity drop of an urban arterial road due to a curbside bus stop. Data were collected on seven sections of 6-lane-divided urban arterial roads in New Delhi. Three sections were without any side friction and the remaining four sections were with curbside bus stop. Speed and volume data were collected in field and these data were used to estimate the capacity of a section. The average midblock capacity of a 6–lane divided urban road without side friction was found to be 6314 PCU/hr which was termed as base capacity. This base capacity was used to compare the capacity of a section with curbside bus stop. Mathematical relations between bus frequency and capacity drop; dwell time and capacity drop have been proposed. These relations would be very useful for practising engineers to estimate capacity loss due to bus stop.

INTRODUCTION

Highway Capacity Manual [8] defines the capacity as the maximum hourly rate at which persons or vehicles can be reasonably expected to traverse a point or a uniform segment of a lane or roadway during a given time period, under prevailing roadway, traffic and control conditions. The capacity of a road section can be influenced by various factors such as surface type, shoulder and roadway width, terrain, driver
skills, side friction or side activities, road maintenance etc. However among all the factors, side frictions i.e. bus stops, on-street parking, encroachments etc. significantly reduce the capacity of an urban arterial road. Extensive research has been done till date on the effect of these side friction factors on the capacity of urban roads. However the researchers have concentrated more on the homogeneous traffic conditions that prevail in developed countries. For mixed traffic situations as existing in India, much research has not been done relating capacity with side frictions.

Public transport system is the backbone of every country. People of urban areas in developing countries rely heavily on public transit buses for mobility. Most of the midblock bus stops in India are curbside bus stops, due to the lack of sufficient space for construction of segregated bus bays. Even if bus bays are provided at some locations, most of the time it is observed that these bays are occupied by the passengers waiting for the buses. This phenomenon is more prevalent during peak hours. Under moderate to high traffic conditions, curb side bus stops can cause more detrimental effect on traffic flow characteristics and substantial delay to vehicular traffic as compared to bus bays. This is because buses stop right on the carriageway in case of curbside bus stops. The type of bus stop, frequency of stopping buses, number of buses stopping simultaneously at bus stop, bus dwell time etc. are some of the important parameters that effect the capacity of the midblock sections near bus stops. The mixed traffic existing on urban roads of developing countries is characterized by the presence of vehicles of wide ranging static and dynamic characteristics and higher bus frequencies. Thus, bus stops are the most common features of the links of urban road networks in developing countries. Hence the present study is taken up with the objective of evaluating the influence of bus stops on 6-lane divided urban arterials in New Delhi. The outcome of this research paper can be helpful for traffic engineers to effectively plan for suitable location and type of bus stop in mixed traffic conditions.

**LITERATURE REVIEW**

Koshy and Arasan [4] studied influence of bus stops on flow characteristics of mixed traffic by using microscopic simulation model and stated that the presence of bus stops on urban roads often leads to congestion and deterioration in the quality of traffic flow. They studied the influence of curbside stops and bus bays on traffic flow with specific reference to a reduction in the speed of traffic for various dwell times of buses. They found that the quality of traffic stream, in terms of average speed, decreases rapidly beyond certain flow levels, in the case of curbside stops. However, they did not come up with a formula for calculating capacity of roads on which bus stops have influence on the traffic flow. Tang et al. [7], with the help of numerical results showed that bus stops have great effects on traffic flow and that the effects are related to the initial density and the number of bus stops. Kwami et al. [5] calibrated a model for bus parameters in case of bus bays and concluded that with the increase in bus arrival frequency, the actual curb lane traffic capacity decreases. Yang et al. [11] presented a road capacity model based on gap acceptance theory and queuing theory for mixed traffic flow at the curbside stop in China. Zhao et al. [12] analyzed traffic interactions between motorized vehicles and non-motorized vehicles near a bus stop and presented a simulation model for mixed traffic flow by using BCA model for
non-motorized vehicles. They found that flow rates of motorized and non-motorized flows exhibit phase transition from free flow to congested flow. Xia and Xue [10] used a modified 1-D pipe-flow model to stimulate the effect of bus bay stop on Beijing city traffic. Ben-Edigbe et al. [1], while determining impact of bus-stops on roadway capacity found significant differences in roadway capacities for the on and off street bus stops. They recorded a roadway capacity loss of 23.4 per cent for carriageway lane with bus stops. Xiao-Bao et al. [9] developed a new theoretical approach on the basis of additive-conflict-flows procedure to determine car capacity at bus stops with mixed traffic. Mushule [6], while analyzing bus bay performance and its influence on the capacity of road network in Dar-es-Salaam found that parameters such as dwell times and clearance times are major determinants of bus stop capacity.

**DATA ANALYSIS**

Figure 1 is a snapshot of section with bus stop whereas Figure 2 shows the base section without any side friction. Traffic studies were planned to determine the traffic flow, traffic composition and speeds of the different types of vehicles at selected road sections. Videography method was used to collect the data. A high resolution camera was fixed at an elevated position and recording was performed for 6 to 8 hours at each section.

**FIG. 1. Curbside bus stop on six-lane road in New Delhi**
A trap of about 60 m length was made on the section so as to obtain speeds of vehicles in the traffic stream. All the vehicles in traffic stream were categorized as shown in Table 1. Even in the same category of car, there are several models plying on Indian roads. Therefore cars were also divided into two categories as small car (standard car) and big car. Small car in Table 1 represents all cars having their engine power of around 1400 cc and average length and width of 3.72 m and 1.44 m respectively. This is also taken as the standard car in the present study and passenger car unit (PCU) factors were derived for all vehicles with respect to this car. The big car is the one having length of 4.58 m, width 1.77 m and engine power of around 2500 cc. The size of a vehicle was measured in field by taking its maximum length and maximum width. In case, where more than one type of vehicle is included in a category (for example motorized two wheeler) the average dimensions were considered. Table 1 shows the observed vehicle categories and their physical sizes.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Rectangular Plan Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Car</td>
<td>3.72</td>
<td>1.44</td>
<td>5.36</td>
</tr>
<tr>
<td>Big Car</td>
<td>4.58</td>
<td>1.77</td>
<td>8.11</td>
</tr>
<tr>
<td>Heavy Vehicle</td>
<td>10.10</td>
<td>2.43</td>
<td>24.54</td>
</tr>
<tr>
<td>3-wheeler</td>
<td>3.20</td>
<td>1.40</td>
<td>4.48</td>
</tr>
<tr>
<td>2-wheeler</td>
<td>1.87</td>
<td>0.64</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Recorded film was replayed on a large screen monitor and 5-minute classified traffic volume counts were made. To ensure accuracy in the count, vehicles of one particular category were counted in one round of play of the film and the film was rewound as many times as the number of vehicle categories in the count. For measurement of speed, time taken by a vehicle to cover the trap length of 60 m was noted with an accuracy of 0.01 s. The data were analyzed to obtain the composition of traffic stream, hourly traffic volume (vph) and speed (km/hr) of each type of vehicle.
on different sections. The average compositions of traffic stream at different sections are given in Table 2.

**Speed-Volume Relationships**

Three basic parameters of traffic flow: speed, volume and density were used for estimation of traffic carrying capacity of a road. For determination of speed-volume relationship in heterogeneous traffic condition, the volume calculated by total vehicles recorded for each counting period of 5-min was converted into equivalent number of passenger cars. Chandra and Kumar [2] proposed a formula to determine the PCU of a vehicle category as given in Equation 1 and the same is used in the present study also.

\[
P_{CU_i} = \frac{V_c}{V_i} \frac{A_c}{A_i}
\]

(1)

where \(V_c\) and \(V_i\) are speed of small car and vehicle type \(i\) respectively, and \(A_c\) and \(A_i\) are their projected rectangular area on the road as given in Table 1. In a mixed traffic situation, large variation exists in speeds of slow moving and fast moving vehicles. Therefore, spot speeds of cars cannot be considered for mixed traffic. It needs to be modified to suit the heterogeneous traffic conditions. For this purpose mean stream speed or weighted average space mean speed has been used as suggested by Chandra and Prasad [3] which is given by Equation 2. This equation is used in the present study.

\[
V_m = \frac{\sum_{i=1}^{N} n_i V_i}{\sum_{i=1}^{N} n_i}
\]

(2)

where,

- \(V_m\) = mean stream speed (km/hr),
- \(n_i\) = number of vehicles of category \(i\), in a count period
- \(V_i\) = Speed of vehicles of category \(i\) (km/hr), included in the count period
- \(N\) = Total number of categories of vehicles in the traffic stream.

**Capacity of Base Section**

As may be seen in Table 2, traffic flow data collected at first three sections are under no influence of side friction. Therefore capacity estimated at these sections is taken as the base capacity of a midblock section of 6-lane divided urban arterial road. The speed-volume data on a section were used to obtain the speed-density data using the fundamental relation between the flow, density and speed. The speed–density curve for section I is shown in Figure 3. Various forms of relations were tried, but the straight line relation as suggested by Greenshields was found to be the best based on \(R^2\) value of the model. This model was then used to plot the speed-flow curve over the entire range of traffic volume to determine the capacity as shown in Figure 4 where field data are also plotted on Greenshields speed-flow model. The capacity of this section was obtained as 6300 pcu/hr for one direction of traffic flow. Similarly the capacity for sections II and III was obtained. The average directional capacity was found to be 6314 pcu/hr.
Table 2. Observed Traffic Compositions at Different Sections

<table>
<thead>
<tr>
<th>Section</th>
<th>Road</th>
<th>Location</th>
<th>Site Condition</th>
<th>Average Composition (%)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Small Car (CS)</td>
<td>Big Car (CB)</td>
<td>Heavy Vehicle (HV)</td>
<td>3-wheeler (3W)</td>
<td>2-wheeler (2W)</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Outer Ring Road</td>
<td>Swami Nagar</td>
<td>No Side Friction</td>
<td>46.54</td>
<td>7.11</td>
<td>1.65</td>
<td>16.63</td>
<td>28.07</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Outer Ring Road</td>
<td>Hauz Khas</td>
<td>No Side Friction</td>
<td>40.22</td>
<td>5.27</td>
<td>3.10</td>
<td>17.46</td>
<td>33.95</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Lodhi Road</td>
<td>Dyal Singh College</td>
<td>No Side Friction</td>
<td>38.30</td>
<td>5.10</td>
<td>3.60</td>
<td>20.60</td>
<td>32.40</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Outer Ring Road</td>
<td>Pamposh Enclave</td>
<td>Bus Stop</td>
<td>48.42</td>
<td>5.46</td>
<td>3.98</td>
<td>11.72</td>
<td>30.42</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Outer Ring Road</td>
<td>Munirka</td>
<td>Bus Stop</td>
<td>41.82</td>
<td>8.42</td>
<td>4.11</td>
<td>12.43</td>
<td>33.22</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>Outer Ring Road</td>
<td>Nehru Place</td>
<td>Bus Stop</td>
<td>42.53</td>
<td>4.08</td>
<td>4.15</td>
<td>11.90</td>
<td>37.34</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>Mathura Road</td>
<td>ITPO</td>
<td>Bus Stop</td>
<td>48.16</td>
<td>6.26</td>
<td>3.54</td>
<td>14.54</td>
<td>27.50</td>
<td></td>
</tr>
</tbody>
</table>

FIG. 3. Speed-density relationship at section-I
Capacity under influence of bus stop

The speed–density curve for section IV is shown in Figure 5. The data points follow a straight line trend and it was used to develop theoretical speed–flow curve (Greenshields model) as shown in Figure 6. The capacity of this section was obtained as 5745 pcu/hr for one direction of traffic flow. Similar curves were drawn at other sections also and capacity values were estimated. The capacity values and bus frequency at each of the sections are given in Table 3.
FIG. 6. Speed-Flow Relationship at Section-IV.

<table>
<thead>
<tr>
<th>Section</th>
<th>Average bus frequency per hour</th>
<th>Average dwell time (min) in one hour</th>
<th>Average directional capacity (pcu/hr)</th>
<th>Capacity drop (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV</td>
<td>52</td>
<td>8.15</td>
<td>5745</td>
<td>9.01</td>
</tr>
<tr>
<td>V</td>
<td>65</td>
<td>11.4</td>
<td>5710</td>
<td>9.57</td>
</tr>
<tr>
<td>VI</td>
<td>75</td>
<td>15.1</td>
<td>5502</td>
<td>12.86</td>
</tr>
<tr>
<td>VII</td>
<td>39</td>
<td>7.7</td>
<td>5803</td>
<td>8.10</td>
</tr>
</tbody>
</table>

It can be understood from Table 3 that capacity of urban midblock section decreases due to the presence of a curbside bus stop. An effort has been made to relate bus arrivals i.e. bus frequency per hour at each section with the respective capacity reduction. Figure 7 shows the relation between bus arrivals i.e. bus frequency and capacity reduction at the observed sections. The curve follows a second degree polynomial equation with a high $R^2$ value of 0.94. The minimum and maximum bus frequencies observed were 39 and 75 respectively. Hence the developed relation is suitable for any other section that has bus frequency in the range of 39 to 75.

The relation between total time for which a bus stop was occupied by a stopping bus i.e. total dwell time in an hour and capacity reductions at the sections is shown in Figure 8. Dwell time in this graph indicates the total time for which a bus stop was occupied by a stopping bus. In this case also second degree polynomial was observed with $R^2$ value of 0.97.
CONCLUSIONS

Curbside bus stops are very common on urban roads in India and many other developing and developed nations. When a bus arrives and stops at these bus stops, it obstructs the flow of upstream vehicles and thus reduces capacity of midblock section. This reduction in capacity depends on the bus frequency and dwell time of buses. To analyze this effect, data were collected at six-lane urban roads in New Delhi. Three sections of six-lane were chosen where there is no bus stop or any other kind of side friction and these sections were termed as the base sections. The capacity of these sections was estimated by plotting the speed-flow curves and average of these capacity values was found to be 6314 PCU/hr which is termed as base capacity. The capacity values of other sections which are under the influence of bus stop were also determined from speed-flow plots and these capacities were compared with the
base capacity. The reduction in capacity due to a bus stop was found to be in the range of 8 to 13 percent. From the graph developed between bus frequency and capacity reduction, it was observed that the relation follows a second degree polynomial equation. Total dwell time in an hour was plotted against capacity reduction and in this case also the relation followed a second degree polynomial function with significantly high $R^2$ value. At the sections with high reduction in capacity, authorities might consider provision of bus bay. With construction of a segregated bus bay, capacity reduction will not be as significant as in the case of a curbside bus stop.

REFERENCES


