Influences of Various Types of Bus Stops on Traffic Operations of Bicycles, Vehicles, and Buses

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Abstract:
On urban streets the arrival of buses could disturb the traffic flow in the vicinity of bus stop stations. Different types of bus stops could have distinct impact on the operation of different road users. The primary objective of this study is to evaluate how different types of bus stops influence the operation of bicycles, vehicles, and buses. Four types of stops were considered according to the geometric feature and lane arrangement. Field data collection was conducted on 8 typical roads in Nanjing and Shanghai, China. The results of this study showed that different bus stop designs had quite different impacts on the operations of traffic flow. More specifically, Type 3 stop had the least impact on bicycle speed, but had the largest impact on vehicle speed. Type 4 stop had the least impact on bicycle and vehicle traffic operation, but occupied the most road resource. Type 1 stop had better operational feature of traffic flow as compared to that near the Type 2 stop. Suggestions regarding the design of bus stops were discussed according to the delay of bicycles, vehicles, and buses produced at each stop type.
INTRODUCTION

In recent years, as the urban streets becoming more congested, many cities and countries in the world have considered developing public transit systems within urban areas (1-5). On urban streets with bus lines, bus stop stations are usually designed on the roadside to allow travelers to get on and off the buses. The arrival of buses at stops could disturb the continuing traffic flow in the nearby areas and result in impacts on the delay of road users. An evaluation on the impact of different bus stops on the operations of traffic flow can provide useful information to the city planners for the design of bus stops under different traffic and environmental conditions.

Previously, numerous studies regarding the traffic operations near bus stops have been conducted. Several studies have evaluated the traffic flow characteristics in the vicinity of bus stops (6-10). For example, Sun and Elefteriadou analyzed the characteristics of vehicle lane-changing behaviors near the bus stops (9). Tirachini et al. evaluated the impact of the passenger crowding at the bus stops on the operations and travel time of buses (10). Some other studies focused on evaluating the conflicts between different road users at the bus stop areas (11-15). For example, Zhao et al. evaluated the traffic interactions between the motorized and nonmotorized vehicles near a bus stop station (15). However, the above studies did not distinguish the different types of bus stop during the analyses.

Until recently, only a few studies have compared the operational features among different types of bus stops. Koshy et al. compared the influence of the curbside stops and bus bays on the operations of motorized vehicles (16). It was found that the average speed of motorized vehicles decreased rapidly at the curbside stops. However, the study was conducted in the simulation environment without validating their findings with actual data. In our previous study, the interactions between the buses and the bicycles at different types of bus stops were evaluated (17). However, only the impacts of bus stops on bicycle speeds were analyzed. We did not evaluate how different bus stops impact the operations of vehicles as well as buses. As a result, it is still not clear to policy makers that how various types of bus stops should be selected under different traffic flow situations.

The primary objective of this study is to evaluate the influences of different types of bus stops on the operation of traffic flow near the bus stop stations. Four types of stops were considered according to the geometric feature and lane arrangement. The impacts of bus stops on the operating speed of bicycles, vehicles, and buses were analyzed with the filed data collected on urban streets. In the following section, the data collection is presented. In section 3, the methodologies used in the study are introduced. The results of data analysis are shown in section 4. The policy suggestions regarding the design of bus stops are given in section 5. The paper ends with brief concluding remarks in section 6.

DATA COLLECTION

Our research team carefully examined the design of bus stops on the streets within the urban areas in several cities of China. The bus stops are usually implemented near the bike lanes or bike paths on the right side of urban streets. After a careful examination, four most common types of bus stops are identified as illustrated in Figure 1. The description of each bus stop is given as follows.

Type 1: Near the Type 1 bus stop, the urban street is designed with the bike lane on the right side of the vehicle lanes (see Figure 1 (a)). When a bus arrives, it occupies the space of the bike lane. Bicyclists would go through from either the right or left side of the bus.
Type 2: Near the Type 2 bus stop, the bike lane is physically separated from the vehicle lanes (see Figure 1 (b)). But at the bus stop stations, the physical separation is removed such that the bus could occupy the space of bike lane to stop. Bicyclists would go through from either the right or left side of the bus.

Type 3: The bicycle lane is totally physically separated from the vehicle lanes and the bus stop is a curbside design (see Figure 1 (c)). When a bus arrives it occupies the space of the outer vehicle lane to drop off and pick up passengers. Vehicles would change lanes to the left to pass the bus or wait after the bus.

Type 4: The bicycle lane is totally physically separated from the vehicle lanes and the bus stop is designed with a bus bay (see Figure 1 (d)). When a bus arrives it goes into the bay area to drop off and pick up passengers. It doesn’t occupy the spaces of the vehicle lane or the bike lane.

**FIGURE 1 Illustration of four types of bus stops.**

Field investigations were conducted to obtain the traffic flow data near different bus stops. The urban streets selected for data collection should satisfy the following requirements: (1) the streets should contain typical bus stops considered in the study; (2) there should be no pedestrians in the bus lane and bike lane; (3) the bus stop station should be far away from the upstream and downstream intersections; and (4) the traffic in the street section should be free flowing such that the speeds are affected only by the bus stop.

Finally, eight typical urban streets in Nanjing and Shanghai, China were selected for the data collection. The information of study sites are shown in Table 1. The selected streets include two samples for each type of bus stop. Field data were collected on weekdays under fine weather conditions in May and June, 2014. Video cameras were placed on tall buildings near the investigated street sites to capture the overall traffic operations, as shown in Figure 2. Each site contained 3 hour video data covering both peak and non-peak period. The investigated segment includes three sections which are the upstream section, the bus stop section, and the downstream section. The total length of the investigated segment is 50 m.
### TABLE 1 Information of Study Sites

<table>
<thead>
<tr>
<th>Number</th>
<th>Street name</th>
<th>Stop type</th>
<th>Bus arrival frequency</th>
<th>Vehicle flow (veh/h)</th>
<th>Bicycle flow (bike/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>Hunan Rd, Nanjing</td>
<td>Type 1</td>
<td>1.9 min</td>
<td>653</td>
<td>1023</td>
</tr>
<tr>
<td>Site 2</td>
<td>Shanxi Rd, Nanjing</td>
<td>Type 2</td>
<td>1.1 min</td>
<td>726</td>
<td>1333</td>
</tr>
<tr>
<td>Site 3</td>
<td>Hongwu Rd, Nanjing</td>
<td>Type 3</td>
<td>1.42 min</td>
<td>707</td>
<td>874</td>
</tr>
<tr>
<td>Site 4</td>
<td>Houbiaoing Rd, Nanjing</td>
<td>Type 4</td>
<td>0.8 min</td>
<td>984</td>
<td>612</td>
</tr>
<tr>
<td>Site 5</td>
<td>Longsheng Rd, Shanghai</td>
<td>Type 1</td>
<td>1.7 min</td>
<td>1084</td>
<td>1179</td>
</tr>
<tr>
<td>Site 6</td>
<td>Renmin Rd, Shanghai</td>
<td>Type 2</td>
<td>1.5 min</td>
<td>953</td>
<td>980</td>
</tr>
<tr>
<td>Site 7</td>
<td>Wenchang Rd, Shanghai</td>
<td>Type 3</td>
<td>1.1 min</td>
<td>902</td>
<td>1209</td>
</tr>
<tr>
<td>Site 8</td>
<td>Wenhui Rd, Shanghai</td>
<td>Type 4</td>
<td>1.2 min</td>
<td>828</td>
<td>787</td>
</tr>
</tbody>
</table>

**FIGURE 2 Data collection with video camera.**

**METHOD**

Two methods were considered in this study. The first method was to extract the traffic information from the video camera data. The student’s t-test was then used to examine if the difference of speed groups was statistically significant. The methods are briefly introduced in this section.

**Extraction of Traffic Flow Information**

Traffic flow information for bicycles, vehicles, and buses were extracted from the video camera data. As shown in Figure 3, the arriving location A and leaving location B are marked in the investigated street section. The distance between the two locations is $L$. During the data processing procedure, the time that each bicycle passed the location A and B was recorded as $t_A$.
and \( t_B \). Then the speed of the bicycle can be calculated as \( v = \frac{L}{(t_A - t_B)} \). The type of bike (i.e., electric bike or conventional bike) as well as the position of bike (i.e., passing from the left or the right) were also recorded. The same procedure was followed for each vehicle. The position of vehicles (i.e., inner lane or outer lane) was recorded.

For each bus, four types of time information were recorded including the time that the bus passed location A \( (t_A) \), the time that the bus completed the full stop \( (t_{\text{STOP}}) \), the time that the bus started leaving \( (t_{\text{START}}) \), and the time that the bus passed location B \( (t_B) \). With the time information on location A and B, the status of bus stop station, i.e., with bus or without bus, was obtained for each time slice. Then the average speed and the standard deviation of speed for bicycles and vehicles at each type of bus stop can be calculated for comparison purposes. With the bus stopping and leaving time information, the operation of buses at different stops can be evaluated as discussed in the later section.

**Student’s \( t \)-Test**

Student’s \( t \)-test has been extensively used to identify if the difference between two population means is statistically significant \((18)\). In this study, the \( t \)-test was conducted to identify if the difference between the speeds with and without buses at the stop station was statistically significant. Let \( \mu_1 \) be the mean of average bicycle/vehicle speed during the period that no bus was at the stop station, and \( \mu_2 \) be the mean of average bicycle/vehicle speed during the period that at least one bus was at the stop station. The sample standard deviation \( s_1 \) and \( s_2 \) were obtained for the two groups with the sample size \( n_1 \) and \( n_2 \), respectively.

The hypothesis states that

\[
H_0: \mu_1 = \mu_2
\] (1)

can be rejected if

\[
t = \frac{\mu_1 - \mu_2}{\sqrt{s_1^2 + s_2^2}} \geq t_{\alpha/2}
\] (2)

where \( \alpha \) is the level of significance and \( t_{\alpha/2} \) is the 100\((1-\alpha/2)\) % percentile of \( t \) distribution. The corresponding \( p \)-value of the test is given by

\[
p = \Pr(|t| \geq \frac{\mu_1 - \mu_2}{\sqrt{s_1^2 + s_2^2}})
\] (3)
RESULTS OF DATA ANALYSIS

The operational features of traffic flow at various types of bus stops were analyzed in this study. The impact of bus stop on bicycle traffic was first evaluated. Then the impact of bus stop on vehicle traffic was analyzed. We also evaluated the bus operations at different bus stops.

Impact of Bus Stop on Bicycle Traffic

The bicycle speed in the situation with and without the bus at the stop were calculated from the data. For comparison, the electric bicycles and conventional bicycles were analyzed separately. The average bicycle speeds at the four types of bus stops are shown in Figure 4. It is identified that at the Type 1 and Type 2 bus stops, the bicycle speeds with bus at stop (i.e., within the measurement area) are obviously lower than the situation without bus at stop. The reductions of speeds of electric bicycles are larger than those of conventional bicycles. At the Type 3 and Type 4 bus stops, the arrival of bus does not have large impact on the speeds of conventional bicycles. The speeds of electric bicycles are reduced a little bit.

The t-test was conducted to identify if the differences in the bicycle speeds were statistically significant. The results are shown in Table 2. It is found that all the t-tests are significant at a 95% significance level. It indicates that the bus stops have significant impact on
the average speed of bicycles. Type 1 and Type 2 bus stop reduce the average bicycle speed by 2.76 km/h to 2.79 km/h. This is because that the bus occupies the space of bike lanes which blocks the maneuvers of bicyclists. Type 3 and Type 4 bus stop reduce the average speed by 1.06 km/h to 1.29 km/h. It suggests that because of the physical separation between buses and bicycles, the interactions between them are reduced. But the existence of bus at stop still has some impacts on the bicycle speed, probably due to the getting off passengers.

### TABLE 2 Statistical Tests for Speed Differences of All Bicycles

<table>
<thead>
<tr>
<th>Speed</th>
<th>With bus at stop</th>
<th>Without bus at stop</th>
<th>ΔV Mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample size</td>
<td>V Mean</td>
<td>V Std</td>
<td>Sample size</td>
</tr>
<tr>
<td>Type 1</td>
<td>38</td>
<td>13.12</td>
<td>2.21</td>
<td>82</td>
</tr>
<tr>
<td>Type 2</td>
<td>114</td>
<td>14.61</td>
<td>4.48</td>
<td>160</td>
</tr>
<tr>
<td>Type 3</td>
<td>176</td>
<td>14.56</td>
<td>3.33</td>
<td>158</td>
</tr>
<tr>
<td>Type 4</td>
<td>28</td>
<td>14.07</td>
<td>1.74</td>
<td>72</td>
</tr>
</tbody>
</table>

*a* Mean bicycle speed including electric bicycles and conventional bicycles

*b* Standard deviation of bicycle speed including electric bicycles and conventional bicycles

*c* Difference between mean speed with bus at stop and without bus at stop

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### Impact of Bus Stop on Vehicle Traffic

The vehicle speed in the situation with and without the bus at the stop were calculated. The inner and outer vehicle lanes (see Figure 1) were distinguished during the analysis. The average vehicle speeds at different types of bus stops are shown in Figure 5. It is quite obvious that the existence of bus at stop has great impact on the vehicle speed on the outer lane. The bus has minor impacts on the vehicle speed on the inner lane. Type 4 bus stop has the least impact on the vehicle speed as compared to the other three stops. It suggests that the bus bay can remarkably reduce the conflicts between the buses and the vehicle traffic. Type 3 bus stop has the largest impact on the vehicle speed, because the arrival of bus occupies the vehicle travel lane and blocks the continuing vehicle traffic.

The quantitative impacts of bus stops were calculated. The vehicle speed information is summarized in Table 3. The results of t-test show that the difference in vehicle speeds at different stops with and without buses are all statistically significant at a 95% significance level. Type 3 bus stop has the largest impact on the vehicle speed, followed by the Type 2 bus stop. The average vehicle speed is reduced by 6.82 km/h and 6.06 km/h respectively at the two stops. Type 4 bus stop only decreases the vehicle speed by 2.19 km/h which is much smaller as compared to those at other stops. Type 1 bus stop has slightly smaller impact on vehicle speed as compared to that at Type 2 stop. This would because that near the Type 1 stop vehicle drivers would observe the overall traffic situations better than near the Type 2 stop and take proactive actions to avoid travel delay.
FIGURE 5 Vehicle speeds at different types of bus stop areas.

TABLE 3 Statistical Tests for Speed Differences of All Vehicles

<table>
<thead>
<tr>
<th>Type</th>
<th>Sample size</th>
<th>With bus at stop</th>
<th>Without bus at stop</th>
<th>ΔV&lt;sub&gt;Mean&lt;/sub&gt;&lt;sup&gt;c&lt;/sup&gt;</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample size</td>
<td>V&lt;sub&gt;Mean&lt;/sub&gt;&lt;sup&gt;a&lt;/sup&gt;</td>
<td>V&lt;sub&gt;Std&lt;/sub&gt;&lt;sup&gt;b&lt;/sup&gt;</td>
<td>V&lt;sub&gt;Mean&lt;/sub&gt;</td>
<td>V&lt;sub&gt;Std&lt;/sub&gt;</td>
</tr>
<tr>
<td>Type 1</td>
<td>26</td>
<td>18.22</td>
<td>3.82</td>
<td>156</td>
<td>22.32</td>
</tr>
<tr>
<td>Type 2</td>
<td>76</td>
<td>18.87</td>
<td>4.66</td>
<td>170</td>
<td>24.93</td>
</tr>
<tr>
<td>Type 3</td>
<td>144</td>
<td>21.43</td>
<td>6.32</td>
<td>178</td>
<td>28.24</td>
</tr>
<tr>
<td>Type 4</td>
<td>102</td>
<td>24.10</td>
<td>7.24</td>
<td>156</td>
<td>26.29</td>
</tr>
</tbody>
</table>

<sup>a</sup> Mean vehicle speed on the two travel lanes
<sup>b</sup> Standard deviation of vehicle speed on the two travel lanes
<sup>c</sup> Difference between mean speed with bus at stop and without bus at stop

Impact of Bus Stop on Bus Operation

Different types of bus stops could have different impacts on the operation of buses. In this study, two measures were calculated to present the operational features of buses. The bus stopping time was calculated as the difference between the \( t_A \) and \( t_{STOP} \). This measure indicates that if a bus can complete the stopping action easily. The bus leaving time was calculated as the difference between the \( t_{START} \) and \( t_B \). It indicates the easiness of merging into the street mainline. The bus
stopping time and the bus leaving time at each type of bus stop were calculated, as shown in Figure 6.

The results show that Type 3 bus stop has the smallest bus stopping and leaving time than the other stops. It suggests that buses could complete the stopping and merging actions quickly, and the bus operation is not impacted by other road users. Buses can complete the stopping actions easily at Type 4 stops, but could have some difficulties in merging into the street mainline due to the bus bay design. Type 1 and Type 2 bus stop have relatively longer time in the stopping and leaving processes. The possible reason would be that there could be bicyclists around the bus such that the bus driver should drive cautiously to avoid the potential conflicts with bicycles. Type 2 stop has longer bus leaving time than Type 1 stops, probably because that the bus driver needs to avoid the physical separation barrier in the ahead street section.

![Figure 6 Bus operations at different types of bus stop areas.](image)

**POLICY SUGGESTIONS**

The above analyses suggest that the traffic flow features at different types of bus stops are quite different, resulting in different impacts on the operation of bicycles, vehicles, and buses. This section summarized the impacts of the four types of bus stops, as shown in Figure 7. It is quite clear that Type 1 and Type 2 bus stop have large impact on the bicycle speed, and moderate impact on the vehicle speed. They have large impact on the bus operation, and require moderate road space measured by the number of occupied lanes. Type 3 bus stop has the least impact on the bicycle traffic but has the largest impact on the vehicle traffic. Type 4 bus stop has the smallest impact on both the bicycle traffic and the vehicle traffic. However, it requires more travel lanes and occupies large road resource.

The policies regarding the selection of bus stop type should be determined according to the practical road and traffic situations. If the urban street has enough road spaces and the city planners cares greatly about the delay in both bicycle and vehicle traffic caused by buses, Type 4 bus stop is recommended for practical application. If the urban street has limited road resource and the city planners pay more attentions on the vehicle delay on the urban streets, then Type 1 bus stop is recommended. Type 3 bus stop can be considered an appropriate option if the bus operations are the primary consideration by city planners.
To help determine how to select the appropriate bus stop, a procedure was proposed in this study as shown in the following equation:

$$Fitness(i) = -\left( \alpha \cdot F_{\text{Bicycle}}(i) \cdot D_{\text{Bicycle}}(i) + \beta \cdot F_{\text{Vehicle}}(i) \cdot D_{\text{Vehicle}}(i) + \gamma \cdot (T_{\text{Stop}}(i) + T_{\text{Leave}}(i)) + \kappa \cdot R_{\text{Space}}(i) \right)$$  (4)

where $Fitness(i)$ is the fitness value for stop type $i$, $\alpha$, $\beta$, $\gamma$, $\kappa$ are weight coefficients for different aspects, $F(i)$ is the flow rate for stop type $i$, $D(i)$ is the average delay for stop type $i$, $T_{\text{Stop}}(i)$ and $T_{\text{Leave}}(i)$ are the bus stopping and leaving time for stop type $i$, and $R_{\text{Space}}(i)$ is the requirement of lanes for stop type $i$.

The fitness value of different bus stops can be calculated using actual traffic flow information on the streets and the weight coefficients can be determined by city planners according to their preferences. The bus stop with the largest fitness value is considered the most appropriate type for the practical application. The procedure can also be used to direct the policy decisions on how existing bus stops should be re-designed to improve the overall traffic operations on urban streets.
CONCLUSIONS
This study evaluated the impact of different types of bus stops on the operational features of bicycle traffic, vehicle traffic, as well as buses. Based on the traffic flow data collected from four types of bus stops, the bicycle speeds and vehicles speeds in the situations with buses at the stop and without any buses were evaluated and compared. The average bicycle speed was reduced by 1.06 km/h to 2.79 km/h near the bus stops. The average vehicle speed was reduced by 2.19 km/h to 6.82 km/h. The bus stopping time and leaving time were also evaluated for different bus stops.

The results showed that different bus stop designs had quite different impacts on the operations of traffic flow. It was found that Type 3 bus stop had the least impact on bicycle speeds, but had the largest impact on vehicle speeds. Type 4 bus stop did not disturb the bicycle and vehicle traffic flow greatly, but it occupied the most road resources. According to the impacts of different bus stops, a procedure was proposed to help determine which bus stop should be considered for practical application under actual traffic and environmental situations.

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