Effects of dwelling buses on the traffic operations of non-motor vehicles at stops in China

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ABSTRACT:
This study proposed a quantitative approach to evaluate the effects of dwelling buses on the traffic operations of non-motor vehicles at stops in China. The primary objectives of this study were to compare the changes in non-motor vehicle speeds with/without dwelling buses by applying statistical methods; and to develop a generalized event count (GEC) model for traffic conflict prediction and analysis. Data were collected by a UAV with a visual range of 60 meters at near side, far side, and mid-block stops in China. In order to better understand the changes in speeds of non-motor vehicles at different sections of the bus stop, the area was divided into three sections: upstream area, bus stop area, and downstream area. The results showed that the dwelling buses could reduce the speeds of non-motor vehicles at bus stops. Furthermore, to evaluate the performance of the proposed GEC model, another model based on queuing theory method was used for comparison. According to the results, the GEC model had more accurate and reliable fitted values (with 12.80% of MAPE and 0.8442 of R-square) than the compared method (with 18.55% of MAPE and 0.7397 of R-square). Consequently, with the proposed method, it was feasible to evaluate the effects of dwelling buses on the traffic operations of non-motor vehicles at bus stops. Finally, to improve the traffic operations at stops, transportation agencies could consider implementing countermeasures to control the conflicts between dwelling buses and non-motor vehicles, such as reducing bus delay time at stops.

Keywords: dwelling bus; non-motor vehicle; generalized event count; queuing theory; traffic operation
1. INTRODUCTION

With the advance of modern technologies and the requirements to improve Level-of-Service (LOS) for public transportation, there has been a transition from ‘vehicle-oriented’ (private transportation) to ‘people-oriented’ (public transportation) in the development of urban transportation systems (1-3). Public transportation and bicycling, as modes of transportation with low energy consumption, pollution, and road space occupancy, perform an essential function in the mobility of citizens in metropolitan areas around the world (4-6).

As mentioned in the work of Khan and Maini (7), traffic conditions in developing countries, e.g., in China and India, are different from those in developed countries. Non-motor vehicles (such as bicycles and electric bicycles) are still prevalent for most short-distance trips due to low-income levels and convenient parking (8). The distinct traffic features in these developing countries are mixtures of motor vehicles and non-motor vehicles on the road, especially in the vicinity of bus stops. For instance, in China, buses often share the same paths or lanes with non-motor vehicles at stops. Non-motor vehicle lanes are separated from motor vehicle lanes and bus stops are set on the sidewalk. Buses pull over to the curbside and occupy non-motor vehicle lanes to dwell. In this case, the mixed traffic flow leads to speed drop, traffic conflicts, and traffic congestion. Therefore, the effects of dwelling buses on non-motor vehicles is an important problem for bus-stop operation.

Because of the large flow of buses and non-motor vehicles on the road, when a bus arrives at the bus stop, non-motor vehicles often are blocked in China. Thus, a dwelling bus may become a bottleneck that constrains traffic flow near the stop, and may degrade the bus system’s overall service quality (9). As a result, traffic conflicts and lane-changing behaviors frequently occur in this mixed traffic, resulting in decreasing speeds of non-motor vehicles and increasing conflicts (even potential traffic crashes) between dwelling buses and non-motor vehicles. In general, traffic crash data analysis is a time consuming method that requires a long-term observation (data collection). In addition, the random characteristics of crashes may result in significant biases in evaluating traffic safety performance (10). Hence, the speeds of non-motor vehicles and traffic conflicts between dwelling buses and non-motor vehicles are two feasible and crucial characteristics to investigate the effects of dwelling buses on the traffic operations of non-motor vehicles at stops, which are the focus of this study. It should be noted that, in this study, the non-motor vehicles consist of bicycles and electric bicycles.

Some research studies have addressed conflicts between bicycles and other transportation modes, such as freight, passenger car, and cab (11-13). However, cycle tracks and buffered bicycle lanes occupy a great deal of roadway space, and don’t apply to most roads in the practical applications. Koshy and Arasan (14) used a validated simulation method to investigate the impacts of curbside stops and bus bays on motor vehicles. They found that average speeds of motor vehicles decreased rapidly at curbside stops. Zhao et al. (15) proposed a model combining average
service time of buses, arrival rate of buses, and arrival rate of bicycles to predict the number of conflicts between buses and bicycles at stops based on queuing theory. In addition, since conflict data were non-negative integers, the regression method provided another tool to better predict traffic conflicts, such as Negative Binomial (NB) and Poisson models (16,17). However, the main disadvantage of these methods was that the models usually could not be generalized to other data sets (18).

Even though previous studies have, to some extent, been conducted to explore the interactions between dwelling buses and non-motor vehicles, quantitative approaches for evaluating the effects of dwelling buses on the traffic operations of non-motor vehicles at stops have rarely been developed (15). In addition, traffic conflict data from different studies usually show different degrees of dispersion (19-21). Practitioners often need to master the skills of different statistical models to correctly analyze conflict data. A more generalized model without constraints on the degree of dispersion is required. Consequently, this study aims to achieve two primary objectives. The first objective is to compare the changes in non-motor vehicle speeds with/without dwelling buses by applying statistical methods. t-Tests are conducted to compare non-motor vehicle speed observations taken at the upstream area, bus stop area, and downstream area for near side, far side, and mid-block stops, respectively.

The second objective is to develop a generalized event count (GEC) model for traffic conflict prediction and analysis. This model enables researchers to analyze unknown dispersion data easily without any prejudgments, and it has exhibited good performance in many fields, such as the evaluation of congressional challenges to presidential votes and superpower conflicts (22).

The remaining sections of the paper are organized as follows. Section 2 describes the proposed methodologies to compare the changes in non-motor vehicle speeds and predict the number of conflicts between dwelling buses and non-motor vehicles. Section 3 introduces the data collection and descriptive analysis. Section 4 shows the results and evaluates the performance by comparison and analysis. The findings and conclusions are presented in the last section.

2. METHODOLOGIES

In order to compare the changes in speeds of non-motor vehicles and predict the number of conflicts between dwelling buses and non-motor vehicles, the research team utilized the following methods in this study: 1) testing speed differences: on the basis of the collected data, statistical analysis is conducted to test the speed differences of non-motor vehicles between locations with dwelling buses and without dwelling bus at stops; and 2) generalized event count (GEC) prediction model: in real world scenarios, according to the relevant references (19-21), conflict data usually display different degrees of dispersion. In light of these considerations, a GEC model previously proposed by another researcher in statistics (22) is applied in this study. This model can be generally used without considering the degrees of dispersion to simplify the process of conflict data forecasting and analysis.
2.1 Testing Speed Differences
A t-test is often used to test the significance of the differences between two means from two different samples. Let \( \mu_1 \) and \( \mu_2 \), and \( s_1 \) and \( s_2 \) be the mean non-motor vehicle speeds and variance of non-motor vehicle speeds at two different sites, respectively. The null hypothesis states that the two means are equal:

\[
H_0: \mu_1 = \mu_2
\]  

versus

\[
H_1: \mu_1 \neq \mu_2
\]  

\( H_0 \) can be rejected if

\[
Z^* = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \geq Z_{\alpha/2}
\]

where \( n_1 \) and \( n_2 \) are the sample sizes for two different sites; \( \alpha (\alpha = 0.05) \) is the level of significance and \( Z_{\alpha/2} \) is the 100(1 - \( \alpha / 2 \))% percentile of standard normal distribution.

2.2 GEC Prediction Model
Since traffic conflict data are non-negative integers, the Poisson regression model is a commonly used method for conflict prediction. In many cases, however, conflict data show different degrees of dispersion, and the Poisson regression model may not be a suitable method to analyze and forecast the number of conflicts. Therefore, a GEC model with parameters \( \lambda_i \) and \( \sigma^2 \) was developed, for \( \lambda_i > 0 \) and \( \sigma^2 > 0 \). In this model, \( \sigma^2 \) represents the dispersion parameter. With the introduction of the parameter \( \sigma^2 \), the GEC model is able to model event counts with unknown degrees of dispersion. When \( 0 < \sigma^2 < 1 \), the GEC distribution can deal with under-dispersed data; when \( \sigma^2 = 1 \), the model has the same probability function as the Poisson regression model; and when \( \sigma^2 > 1 \), the data are over-dispersed, and its probability function is similar to the NB regression model. The GEC’s probability distribution offers smooth transitions between these scenarios.

The Poisson regression aims at modeling a conflict variable \( Y_i \) which follows a Poisson distribution with a parameter \( \lambda \). The probability that the number of conflicts takes the value \( y_i \) on the \( i \)th entity can be expressed as:

\[
P(Y_i = y_i) = f(y_i | \lambda_i) = \frac{e^{-\lambda_i} \lambda_i^{y_i}}{y_i!}, \ i = 1, 2, \ldots, n
\]

In the Poisson regression model, the mean can be written as \( \lambda_i = \exp(\beta X_i) \), where \( X_i \) is a vector of \( k \) explanatory variables and \( \beta \) is a 1\( \times \)\( k \) parameter vector that indicates the effect of the explanatory variables on the dependent variable. To derive the GEC’s probability distribution, a theory from a bilinear recurrence relationship (24) was introduced as follows:

\[
\frac{f_k(y_i + 1 | \theta_i, y_i)}{f_k(y_i | \theta_i, y_i)} = \frac{\theta_i + y_i}{y_i + 1}, \ y_i = 0, 1, 2, \ldots
\]
where $\theta_i$ and $\gamma_i$ are ancillary parameters. In this case, Equation (5) should be re-parameterized in order to make the relationship suitable for previous definitions. Statistical analysis shows that the expected value $E(Y_i)$ and variance $D(Y_i)$ of a random variable $Y_i$ that adheres to the relationship in Equation (5) are as follows:

$$
E(Y_i) = \lambda_i = \frac{\theta_i}{1-\gamma_i}, \quad D(Y_i) = \lambda_i\sigma^2 = \frac{\theta_i}{(1-\gamma_i)^2}
$$

Substituting Equation (6) into Equation (5), the GEC probability function can be expressed as:

$$
f_{g_{ec}}(y_i|\lambda_i, \sigma^2) = \left(\frac{\lambda_i+(\sigma^2-1)(y_i-1)}{\sigma^2 y_i}\right) f_{g_{ec}}(y_i-1|\lambda_i, \sigma^2) $$

$$
= \left(\frac{\lambda_i+(\sigma^2-1)(y_i-1)}{\sigma^2 y_i}\right) \left(\frac{\lambda_i+1}{\sigma^2(y_i-1)}\right) f_{g_{ec}}(y_i-2|\lambda_i, \sigma^2) = \cdots
$$

$$
= f_{g_{ec}}(0|\lambda_i, \sigma^2) \prod_{j=1}^{y_i} \left(\frac{\lambda_i+(\sigma^2-1)(j-1)}{\sigma^2}ight)
$$

In theoretical statistics, $\sum_{n=0}^{\infty} f_{g_{ec}}(n|\lambda_i, \sigma^2) = 1$ is one of the given conditions of probability, which means that the probability of all situations is 1.

To obtain $f_{g_{ec}}(0|\lambda_i, \sigma^2)$, using standard results on the convergence of infinite series leads to the final expression for the probability function (22):

$$
f_{g_{ec}}(0|\lambda_i, \sigma^2) = \begin{cases} 
\frac{e^{-\lambda_i}}{(\sigma^2)^{-\lambda_i/(\sigma^2-1)}} & \sigma^2 = 1 \\
\left(\frac{\lambda_i}{\sigma^2-1}\right)^{\lambda_i/(\sigma^2-1)} \sum_{n=0}^{\lambda_i} \left(\frac{\lambda_i}{\sigma^2-1}\right)^{\lambda_i} \left(\frac{n!}{n!(\lambda_i+1)^{n+1}}\right) (1-\sigma^2)^{n} (\sigma^2)^{\lambda_i/(\sigma^2-1)} & \sigma^2 > 1
\end{cases}
$$

For the estimation of the GEC’s probability distribution, a maximum log-likelihood estimator is introduced as the following equation:

$$
\ln L(\beta, \sigma^2|y) = \sum_{i=1}^{n} \left(C_i - y_i \ln(\sigma^2) + \sum_{j=1}^{y_i} \ln(\exp(\beta x_i) + (\sigma^2 - 1)(j-1))\right)
$$

$$
C_i = \begin{cases} 
-\exp(\beta x_i) & \sigma^2 = 1 \\
-\exp(\beta x_i) \ln(\sigma^2)(\sigma^2 - 1)^{-1} & \sigma^2 > 1 \\
\ln \left(\sum_{n=0}^{\lambda_i/(\sigma^2-1)} \left(\frac{\lambda_i}{\sigma^2-1}\right)^{\lambda_i} \left(\frac{n!}{n!(\lambda_i+1)^{n+1}}\right) (1-\sigma^2)^{n} (\sigma^2)^{\lambda_i/(\sigma^2-1)}\right)^{-1} & \sigma^2 < 1
\end{cases}
$$

This model produces estimations of $\beta$ and $\sigma^2$ in a single step simultaneously without specifying if the crash data are over-dispersed, under-dispersed, or Poisson dispersed. Since no additional parameters are introduced in the GEC distribution, this model actually reduced the chance for inconsistency with no need for additional assumptions.
3. DATA COLLECTION AND DESCRIPTIVE ANALYSIS

Bus stop locations can significantly impact the interactions between dwelling buses and non-motor vehicles at stops (15). Depending on the location, bus stops have three types: near side, mid-block, and far side (25). In China, non-motor vehicle lanes are widely used, so most urban roads have a motor vehicle lane and a non-motor vehicle lane. Bus stops are often set near the non-motor vehicle lanes. In order to explore the effects of dwelling buses on the traffic operations of non-motor vehicles at stops, all selected bus stops have the following characteristics: 1) no exclusive bus lane; 2) bus stops are on-line and set on the curbside; and 3) buses pull over to the curbside and occupy non-motor vehicle lanes to dwell.

In this study, data were collected at three different types of bus stops (near side, far side, and mid-block stops) in the city of Nanjing, China. The data were collected under good weather conditions between June 19 and July 5, 2015, to exclude potential influence of adverse weather. In addition, there was no curb parking around the stops.

An unmanned aerial vehicle (UAV) was set up on a high location (about 40-60m) to record traffic data with the visual range of 60 meters. In order to better understand changes in speeds of non-motor vehicles at different sections of the bus stop, the area was divided into three sections: upstream area, bus stop area, and downstream area, and the length of each section was 20 meters. The duration of data collection for each site was about 3 hours. The UAV captured 10 segments of videotapes at different times for each bus stop and every segment was 15-20 minutes in duration. Several trained graduate students reviewed the recorded videos to obtain bus arrival rate, bus average service time, flow rate of non-motor vehicles, number of conflicts, and average speed of non-motor vehicles. Table 1 presents the site and traffic flow characteristics of the bus stops.

TABLE 1 Site and Traffic Flow Characteristics of Bus Stops

<table>
<thead>
<tr>
<th>Sites</th>
<th>Type</th>
<th>Variables</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hongwu Road Stop</td>
<td>Near side</td>
<td>BAR</td>
<td>72.0</td>
<td>56.0</td>
<td>63.0</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AST</td>
<td>24.0</td>
<td>13.7</td>
<td>17.7</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FRN</td>
<td>1334.0</td>
<td>728.0</td>
<td>1031.0</td>
<td>200.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NC</td>
<td>143.0</td>
<td>46.0</td>
<td>89.1</td>
<td>36.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASN</td>
<td>8.9</td>
<td>1.6</td>
<td>3.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Houibiaoying Road Stop</td>
<td>Far side</td>
<td>BAR</td>
<td>88.0</td>
<td>48.0</td>
<td>64.1</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AST</td>
<td>17.8</td>
<td>10.2</td>
<td>13.3</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FRN</td>
<td>874.0</td>
<td>440.0</td>
<td>667.0</td>
<td>124.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NC</td>
<td>59.0</td>
<td>13.0</td>
<td>40.1</td>
<td>15.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASN</td>
<td>9.8</td>
<td>2.2</td>
<td>5.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Hunan Road Stop</td>
<td>Mid-block</td>
<td>BAR</td>
<td>56.0</td>
<td>22.0</td>
<td>36.5</td>
<td>11.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AST</td>
<td>24.4</td>
<td>15.8</td>
<td>20.1</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FRN</td>
<td>1812.0</td>
<td>674.0</td>
<td>1212.5</td>
<td>444.6</td>
</tr>
</tbody>
</table>
Table 1 presents a summary of the analytical results of the non-motor vehicle speeds at different locations for different types of bus stops. More than 100 non-motor vehicle samples were selected randomly for each bus stop to analyze the speed characteristics, including maximum value, minimum value, mean value, median value, and standard variation. The arithmetic means of non-motor vehicle speeds for near side stops at upstream, bus stop, and downstream areas were 3.66±0.86, 3.77±1.03, and 3.69±0.74 m/s (with bus); and 3.84±0.91, 4.46±1.31, and 3.92±1.05 m/s (without bus), respectively. The arithmetic means of far side stops at these three areas were 4.88±1.01, 4.31±1.00, and 5.26±1.37 m/s (with bus); and 5.31±1.00, 4.80±1.16, and 5.46±1.30 m/s (without bus), respectively. The arithmetic means of mid-block stops at upstream, bus stop, and downstream areas were 4.57±1.65, 4.15±1.56, and 5.15±1.79 m/s (with bus); and 5.32±1.89, 5.28±1.68, and 5.23±1.81 m/s (without bus), respectively. The mean and median values at stops without a bus were clearly higher than the corresponding values at stops with a bus, indicating the dwelling buses had impacts on the speeds of non-motor vehicles at bus stops.

<table>
<thead>
<tr>
<th></th>
<th>NC&lt;sup&gt;d&lt;/sup&gt;</th>
<th>ASN&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>152.0</td>
<td>10.8</td>
</tr>
<tr>
<td></td>
<td>45.0</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>85.5</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>36.9</td>
<td>1.7</td>
</tr>
</tbody>
</table>

<sup>a</sup> Bus arrival rate (bus/h)  
<sup>b</sup> Bus average service time (s)  
<sup>c</sup> The flow rate of non-motor vehicles (bic/h)  
<sup>d</sup> Number of conflicts  
<sup>e</sup> The average speed of non-motor vehicles (m/s)

In Table 1, the average speed of non-motor vehicles was calculated by measuring the elapsed time to travel a specific distance (typically about 4.5m) in the video (26). The VideoStudio application was used to process the video files in a frame-by-frame way so the observer could view videos at 25 frames per second. Traffic conflicts, defined as an event involving two or more road users where one or both users took evasive maneuvers to avoid a collision, were usually collected in the field by trained observers (27). A trained graduate student reviewed all of the videos to ensure that consistent criteria were applied for identifying conflicts across different sites. The student extracted traffic conflicts by identifying road users’ evasive actions, such as braking, swerving and noticeable deceleration. Brake applications and noticeable deceleration were frequently used to identify conflicts. To identify a conflict, the observer took into account not only the vehicle’s brake lights but also the speed of the motor/non-motor vehicles. Swerving was another indicator of traffic conflicts. Road users sometimes changed direction of the motor/non-motor vehicles or switched lanes to avoid a collision instead of applying brakes (10).
TABLE 2 Non-motor Vehicle Speeds at Different Locations for Different Types of Bus Stops

<table>
<thead>
<tr>
<th>Type</th>
<th>At stop</th>
<th>Location</th>
<th>Sample size</th>
<th>Max (m/s)</th>
<th>Min (m/s)</th>
<th>Mean (m/s)</th>
<th>Median (m/s)</th>
<th>SD (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near side</td>
<td>With bus</td>
<td>Upstream area</td>
<td>102</td>
<td>6.02</td>
<td>1.65</td>
<td>3.66</td>
<td>3.50</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus stop area</td>
<td>102</td>
<td>7.19</td>
<td>1.56</td>
<td>3.77</td>
<td>3.59</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Downstream area</td>
<td>102</td>
<td>6.71</td>
<td>1.85</td>
<td>3.69</td>
<td>3.59</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Without bus</td>
<td>Upstream area</td>
<td>102</td>
<td>7.55</td>
<td>2.16</td>
<td>3.84</td>
<td>3.63</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus stop area</td>
<td>102</td>
<td>8.93</td>
<td>1.96</td>
<td>4.46</td>
<td>4.27</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>With bus</td>
<td>Downstream area</td>
<td>102</td>
<td>8.14</td>
<td>2.26</td>
<td>3.92</td>
<td>3.73</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upstream area</td>
<td>105</td>
<td>8.34</td>
<td>2.55</td>
<td>4.88</td>
<td>4.71</td>
<td>1.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus stop area</td>
<td>105</td>
<td>7.65</td>
<td>2.26</td>
<td>4.31</td>
<td>4.22</td>
<td>1.00</td>
</tr>
<tr>
<td>Far side</td>
<td>Without bus</td>
<td>Downstream area</td>
<td>105</td>
<td>8.43</td>
<td>2.16</td>
<td>5.26</td>
<td>5.10</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upstream area</td>
<td>105</td>
<td>8.24</td>
<td>3.43</td>
<td>5.31</td>
<td>5.20</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus stop area</td>
<td>105</td>
<td>7.26</td>
<td>2.25</td>
<td>4.80</td>
<td>4.90</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>With bus</td>
<td>Downstream area</td>
<td>105</td>
<td>9.80</td>
<td>2.35</td>
<td>5.46</td>
<td>5.49</td>
<td>1.30</td>
</tr>
<tr>
<td>Mid-block</td>
<td></td>
<td>Upstream area</td>
<td>104</td>
<td>9.81</td>
<td>1.60</td>
<td>4.57</td>
<td>4.36</td>
<td>1.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus stop area</td>
<td>104</td>
<td>8.93</td>
<td>1.30</td>
<td>4.15</td>
<td>3.97</td>
<td>1.56</td>
</tr>
<tr>
<td></td>
<td>Without bus</td>
<td>Downstream area</td>
<td>104</td>
<td>10.30</td>
<td>1.50</td>
<td>5.15</td>
<td>4.81</td>
<td>1.79</td>
</tr>
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<td></td>
<td></td>
<td>Upstream area</td>
<td>104</td>
<td>10.40</td>
<td>2.26</td>
<td>5.32</td>
<td>5.00</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus stop area</td>
<td>104</td>
<td>9.81</td>
<td>2.26</td>
<td>5.28</td>
<td>5.00</td>
<td>1.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Downstream area</td>
<td>104</td>
<td>10.79</td>
<td>2.45</td>
<td>5.23</td>
<td>4.90</td>
<td>1.81</td>
</tr>
</tbody>
</table>

4. RESULTS AND ANALYSIS

4.1 Differences in Speeds of Non-motor Vehicles

t-Tests are conducted to compare the differences in non-motor vehicle speed observations taken at the upstream area, bus stop area, and downstream area for near side, far side, and mid-block bus stops. As shown in Table 3, results of t-tests revealed that the differences in speeds between locations with a dwelling bus and without a dwelling bus at stops for near side, far side, and mid-block stops were all statistically significant. However, the performance of different locations varied. As for the upstream area, there was no significant difference between the results at near side stops with a dwelling bus and without a dwelling bus, which was in contrast to the results from far side and mid-block stops. Within the bus stop area, there were obvious differences among the results for all types of bus stops (i.e., near side, far side, and mid-block), which were similar to the overall results. By contrast, none of the differences in speeds were statistically significant for the downstream area. The findings further indicated that dwelling buses could result in decreasing speeds of non-motor vehicles at the bus stop and in the vicinity of it. In addition, different
sections (i.e., upstream, bus stop, and downstream areas) had different performances, indicating it was necessary and feasible to explore the effects of dwelling buses on the traffic operations of non-motor vehicles by dividing the bus stop into three sections.

### TABLE 3 t-Tests Results of the Differences in Speeds at Different Locations

<table>
<thead>
<tr>
<th>t-Test results</th>
<th>With bus at stop vs. Without bus at stop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Near side</td>
</tr>
<tr>
<td>Upstream area</td>
<td>0.256 (No)</td>
</tr>
<tr>
<td>Bus stop area</td>
<td>0.000 (Yes)</td>
</tr>
<tr>
<td>Downstream area</td>
<td>0.133 (No)</td>
</tr>
<tr>
<td>Total</td>
<td>0.000 (Yes)</td>
</tr>
</tbody>
</table>

Note: Yes/No indicates whether the test result value is statistically significant.

### 4.2 Conflicts Prediction and Analysis

Based on the data collected for bus arrival rate, bus average service time, flow rate of non-motor vehicles, and number of conflicts, as summarized in Table 1, the GEC model was applied to the data set from bus stops in China. From Table 4, the modeling results showed that $\sigma^2$ was equal to 1.161, which indicated that this data set was over-dispersed. In the table, $\beta_0$ was a constant term, $\beta_1$ represented bus average service time, $\beta_2$ denoted flow rate of non-motor vehicles, and $\beta_3$ was bus arrival rate. The coefficients of these variables were -7.941, 1.415, 0.795, and 0.682, respectively. The P-values from the model showed that all factors including bus average service time, flow rate of non-motor vehicles, and bus arrival rate were significant variables affecting the number of conflicts between dwelling buses and non-motor vehicles.

### TABLE 4 Modeling Results for GEC

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>Std. Error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant ($\beta_0$)</td>
<td>-7.941</td>
<td>0.761</td>
<td>&lt;2E-16</td>
</tr>
<tr>
<td>AST ($\beta_1$)</td>
<td>1.415</td>
<td>0.149</td>
<td>&lt;2E-16</td>
</tr>
<tr>
<td>FRN ($\beta_2$)</td>
<td>0.795</td>
<td>0.086</td>
<td>&lt;2E-16</td>
</tr>
<tr>
<td>BAR ($\beta_3$)</td>
<td>0.682</td>
<td>0.108</td>
<td>1.63E-10</td>
</tr>
</tbody>
</table>

In addition to the proposed method, a model combining average service time of buses, arrival rate of buses, arrival rate of bicycles, and queuing theory (15) was selected to compare and forecast number of conflicts. The following description presents a brief summary of this modeling method.

Let $\lambda_{bus}$ be the arrival rate of buses ($bus/h$), $\lambda_{bic}$ be the arrival rate of
bicycles \((bic/h)\), and \(\mu\) be the service rate of buses \((bus/h)\). \(\lambda_{bus}\) and \(\lambda_{bic}\) are equal to the flow rate of buses and bicycles, respectively. \(\mu\) can be calculated as follows:

\[
\mu = 1/ST
\]  

(11)

where \(ST\) is the average service time of buses \((s)\).

Then, according to the queuing theory, the probability that there is at least one bus at the stop is given by:

\[
\rho = \frac{\lambda_{bus}}{\mu}
\]  

(12)

Because the flow rates of buses and bicycles are independent of each other, the number of conflicts between buses and bicycles \((NC)\) can be estimated by:

\[
NC = \rho \lambda_{bic}
\]  

(13)

The Mean Absolute Percentage Error (MAPE) was chosen to evaluate the performances of the proposed and compared methods. MAPE had no requirement for sample size and showed an obvious advantage in evaluating discrete data (26). The value of MAPE in this study was calculated using the following equation:

\[
MAPE = \frac{\text{Predicted number of conflicts} - \text{Observed number of conflicts}}{\text{Observed number of conflicts}}
\]

To fully evaluate the performances of the proposed and compared methods, the values of MAPE and linear regression analysis between predicted and observed number of conflicts were graphed, as shown in Figures 1 and 2. In Figure 1, the slope of the regression line was 0.9552, and was close to 1. Scattered data points were balanced on both sides of the lines of identity, which indicated that the proposed model was not overvalued or undervalued. R-square and MAPE for the proposed method were calculated to be 0.8442 and 12.80%, which was better than the compared method (R-square value of 0.7397 and MAPE value of 18.55%) as shown in Figure 2, indicating the proposed method could estimate the number of conflicts between dwelling buses and non-motor vehicles at stops relatively accurately.

Figure 1. Fitted relationships of number of conflicts between predicted and observed data using the proposed method
Figure 2. Fitted relationships of number of conflicts between predicted and observed data using the compared method.

Figure 3 presents the observed number of conflicts and forecasting results from the GEC and compared methods. The figure used 30 samples (i.e., 30 segments of videotapes, each 15-20 minutes in duration) for illustration purposes. Overall, the GEC model’s curve followed the observed curve more closely throughout all samples. The compared method, however, had obvious underpredictions and overpredictions, as shown in Figure 3. It should be noted that both the proposed and compared methods had poor prediction performance at segment No. 26, with MAPE values of 37.76% and 51.05%, respectively. From the recorded videos, a traffic crash occurred in that period. This finding indicated that traffic crashes and crash duration might have impacts on the number of conflicts. Therefore, further research is recommended to investigate their impacts in the future.
of conflicts between dwelling buses and non-motor vehicles at stops. There was a positive correlation between number of conflicts and these influencing factors. Therefore, transportation agencies could consider the implementation of countermeasures to control the conflicts between dwelling buses and non-motor vehicles to improve the traffic operations at bus stops, such as reducing bus delay time at stops.

5. CONCLUSIONS
This study proposed a quantitative approach to evaluate the effects of dwelling buses on the traffic operations of non-motor vehicles at stops in China. A dwelling bus may become a bottleneck that constrains traffic flow near the stop. As a result, traffic conflicts and lane-changing behaviors frequently occur in this mixed traffic, resulting in decreasing speeds of non-motor vehicles and increasing conflicts between dwelling buses and non-motor vehicles. Consequently, this study aimed to achieve two primary objectives. The first objective was to compare the changes in non-motor vehicle speeds with/without dwelling buses by applying statistical methods. The second objective was to develop a GEC model for traffic conflict prediction and analysis.

In this study, data were collected with a UAV with a visual range of 60 meters at three different types of bus stops (near side, far side, and mid-block stops) in China. In order to better understand the changes in speeds of non-motor vehicles at different sections of the bus stop, the area was divided into three sections: upstream area, bus stop area, and downstream area, and the length of each section was 20 meters. The results showed that the dwelling buses could reduce the speeds of non-motor vehicles at the bus stop and in the vicinity of it. Furthermore, to evaluate the proposed GEC model’s performance, another model based on queuing theory method was used for comparison. According to the results, the GEC model produced more accurate and reliable fitted values (with 12.80% of MAPE and 0.8442 of R-square) than the compared method (with 18.55% of MAPE and 0.7397 of R-square). The results of conflict analysis showed that bus average service time, flow rate of non-motor vehicles, and bus arrival rate were critical factors that affect the number of conflicts between dwelling buses and non-motor vehicles at stops. To improve the traffic operations at bus stops, transportation agencies could implement countermeasures, such as reducing bus delay time at stops.

With the proposed method, it is feasible to evaluate the effects of dwelling buses on the traffic operations of non-motor vehicles at bus stops. In addition, traffic crashes and crash duration might have impacts on the number of conflicts. Further research is recommended to investigate the associated impacts.

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