**Simulation Study of Dedicated Bus Lanes on Jingtong Expressway in Beijing**

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ABSTRACT
Traffic congestion on urban roads is forcing city authorities to look at innovative transportation solutions. Bus Rapid Transit (BRT) systems are internationally recognized as an effective means to deal with the urban traffic congestion problems. The authors have undertaken a simulation study to pre-evaluate the effectiveness of a BRT plan on the Jingtong Expressway to ensure the effectiveness of traffic organization scheme. The simulation results showed that the dedicated bus lanes can greatly improve the carrying capacity and buses’ operating speed though there may have some negative impact on the private vehicles. The comparison of the implementation effect was carried out between the pre-evaluated data (simulated data) and the field data after the implementation of dedicated bus lanes on Jingtong Expressway at May 24th, 2011. There is a good agreement between the pre-evaluated data and the field data. The results should encourage cities to consider dedicated bus lanes as one of the strategies to implement BRT service.
I. INTRODUCTION

With the development of car manufacturing, almost all the big cities in the world have encountered transportation problems, such as traffic congestion, accidents and environmental pollution. Transportation has become one of the biggest concerns of local authorities in China. Traffic congestion on urban roads is forcing many city authorities to look at innovative transportation solutions. Bus Rapid Transit (BRT) system is internationally recognized as an effective means to deal with the above-mentioned urban transport problems. BRT has been widely implemented in both developed and developing countries with problem of urban traffic congestion.

BRT is “A flexible, high performance rapid transit mode that combines a variety of physical, operating and system elements into a permanently integrated system with a quality image and unique identity. [1]”

Many of the concepts at the heart of BRT have been in use for decades. Dedicated bus lanes/transitways, limited-stop and express services and exclusive bus lanes have become part of the transit planning vocabulary because they have enhanced speed and reliability and thus encouraged transit usage [2]. Dedicated Bus lanes are bus only, grade-separated right-of-way. A dedicated bus lane allows the bus to operate separately, without interference from other modes of traffic. If BRT buses are operated in dedicated lanes, where the buses are separated from other traffic, they can achieve rail-like performance [3]. With dedicated lanes, buses generally can avoid congestion in the normal traffic lanes, thereby reducing their nominal travel time and its variability significantly. Buses’ operating speed, punctuality and safety can also be improved by using dedicated bus lanes.

It has taken local authorities’ consideration to figure out how to deploy dedicated bus lanes on the expressway to reduce traffic jams. Dedicated bus lanes were suggested to be deployed on the Jingtong Expressway that connects the downtown area and Tongzhou District in Beijing, China to reduce traffic jams during rush hours and induce office workers to choose public transportation over private cars.

The microscopic simulation model is now widely accepted as the most appropriate analytical tool for understanding traffic capacity problems and for assessing the effectiveness of ameliorative measures. Therefore, the microscopic simulation model was employed to pre-evaluate the effectiveness of a BRT plan on Jingtong Expressway to ensure the scientific and effectiveness of traffic organization scheme. The pre-evaluation function of traffic simulation would be fully put into effect and the interference to traffic would be minimized. The implementation effect confirms the results of the pre-evaluation and there is a good agreement between the simulated data and the field data.

II. CHARACTERISTICS OF JINTONG EXPRESSWAY

Jingtong Expressway is a highway, which connects the downtown area and Tongzhou District in Beijing urban area. The Location of Jingtong Expressway is shown in Figure 1. The total length of Jingtong Expressway is about 14 kilometers, and the speed limit is 80-100 kilometers per hour (km/h). Ten interchanges are included on Jingtong Expressway. The locations of these interchanges on the Jingtong Expressway are illustrated in Figure 2.
The Jingtong Expressway has long been known for traffic congestion, and the situation is very severe at certain points on the roadway.

A. The tide traffic situation is serious:
Jingtong Expressway passes through the CBD (Central Business District) and the International Trade Business Center. Because of the rapid development of real estate in Tongzhou District, most of the traffic is residential communities. The majority of the residents travel into downtown Beijing for work in the morning and travel back to home in Tongzhou District in the afternoon. Therefore, the main trip purpose on Jingtong Expressway is commute-based and the peak period is 7:00-9:00 in the morning and 17:00-19:00 in the afternoon.

The equilibrium degree of traffic was used to measure the balance of traffic flow.
in both directions. The larger of the value is, the more uneven the two directions of traffic are.

Equilibrium Degree of Traffic = \[
\frac{\text{the difference of the two directions of traffic flow}}{\text{the sum of the two directions of traffic flow}}
\] (1)

The equilibrium degree of traffic on Jingtong Expressway is illustrated in Table 1.

Table 1: Equilibrium degree of Traffic on Jingtong Expressway

<table>
<thead>
<tr>
<th></th>
<th>From East to West (From Tongzhou District to Downtown)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morning Peak Period</td>
</tr>
<tr>
<td>Equilibrium degree of traffic</td>
<td>68%</td>
</tr>
</tbody>
</table>

It can be seen from table 1 that the tide traffic situation is serious especially during morning peak period.

B. Traffic is very high especially during morning peak hours

The traffic flows are very high on the Jingtong Expressway especially during the morning peak hours (From 7:00 am to 9:00 am). According to the data collected on March 22th, 2011, the morning peak hour traffic flow was 4089 pcu/h, and the queue length of the main road was approximately 6.2 kilometers. The 24 hours traffic flows at Yuantong Bridge are showed in Figure 3 and 4. It can be seen that the in-town light and heavy vehicle flow are high during morning peak period at Yuantong Bridge.

Figure 3: In-town Light Vehicle Flow of Yuantong Bridge
Figure 4: In-town Heavy Vehicle Flow of Yuantong Bridge

C. Buses and private vehicles always cut in

Because of the imperfect of public transport system and the lack of dedicated bus lanes, buses and private vehicles always cut in, resulting in a loss of road capacity.

III. PROPOSALS

The key point to solve the problem of congestion on the Jingtong Expressway is to maximize the existing road conditions and increasing the transport capacity. Rearranging the road resources to induce commuters to choose public transportation more often would be a good option. It has taken local authorities’ consideration to figure out how to deploy specialized bus lanes on the Jingtong Expressway. Dedicated bus lanes were suggested to be put into use on the Jingtong Expressway that connects the downtown area and Tongzhou District.

The microscopic simulation model was employed to assess the effectiveness of BRT plan on the Jingtong Expressway to ensure the scientific and effectiveness of traffic organization scheme before the implementation. VISSIM was selected as the simulation toll for the pre-evaluation. VISSIM is a general-purpose computer-based stochastic traffic simulation system, which models links, roundabouts, priority junctions, signal-controlled intersections, and road networks in great detail [4].

IV. SIMULATION PRE-EVALUATION BEFORE IMPLEMENTATION

A. Data collection

Data collection was required to provide simulation program input parameters and output measures of performance for the microscopic simulation model. Uncontrollable input parameters and measures of performance should be collected from the field. Uncontrollable input parameters include existing geometry, traffic counts, current signal timing plans, and so on [5].

Morning and evening peak hour traffic flows were collected at 18 locations covering all the entrances and exits of the Jingtong Expressway. The traffic flow at each location is shown in Table 2.
Table 2: Traffic flow at each location

<table>
<thead>
<tr>
<th>NO</th>
<th>Location</th>
<th>Traffic Flow (vehicle per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Morning Peak 2011.3.22 (7:45 am~8:45 am)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light Vehicle</td>
</tr>
<tr>
<td>1</td>
<td>Huamao Bridge West Exit 1</td>
<td>880</td>
</tr>
<tr>
<td>2</td>
<td>Huamao Bridge West Exit 2</td>
<td>1498</td>
</tr>
<tr>
<td>3</td>
<td>Sihui Bridge Entrance</td>
<td>1528</td>
</tr>
<tr>
<td>4</td>
<td>Sihui Bridge Exit</td>
<td>2756</td>
</tr>
<tr>
<td>5</td>
<td>Sihui Station Entrance</td>
<td>1166</td>
</tr>
<tr>
<td>6</td>
<td>Sihui East Entrance</td>
<td>414</td>
</tr>
<tr>
<td>7</td>
<td>Gaobeidian Entrance</td>
<td>2012</td>
</tr>
<tr>
<td>8</td>
<td>Gaobeidian Exit</td>
<td>542</td>
</tr>
<tr>
<td>9</td>
<td>Yuanlong Bridge Entrance</td>
<td>1474</td>
</tr>
<tr>
<td>10</td>
<td>Yuanlong Bridge Exit</td>
<td>1172</td>
</tr>
<tr>
<td>11</td>
<td>Shuang Bridge Entrance</td>
<td>538</td>
</tr>
<tr>
<td>12</td>
<td>Shuang Bridge Exit</td>
<td>36</td>
</tr>
<tr>
<td>13</td>
<td>Guanzhuang Toll Gate 1 Entrance</td>
<td>220</td>
</tr>
<tr>
<td>14</td>
<td>Guanzhuang Toll Gate 2 Entrance</td>
<td>782</td>
</tr>
<tr>
<td>15</td>
<td>Beijing-Herbin Highway Entrance</td>
<td>480</td>
</tr>
<tr>
<td>16</td>
<td>Xinhuaxi Street Entrance</td>
<td>1984</td>
</tr>
<tr>
<td>17</td>
<td>Huamao Bridge Section</td>
<td>3899</td>
</tr>
<tr>
<td>18</td>
<td>Yuanlong Bridge Section</td>
<td>3782</td>
</tr>
</tbody>
</table>

B. Calibration and Validation

The validity of the models is a topic of increasing concern, as the quality of the presentation often exceeds the models ability to predict what is likely to happen [6]. A simulation model should be reliable, error-free and credible. To be credible, a model has to be carefully calibrated and validated before application. Cohen [7] defined validation as a comparison of measures of effectiveness as computed by a model and as observed in field data under the same traffic conditions. Extensive model calibration and validation...
has been carried out. Model calibration and validation procedures were conducted based on data collected in field. Multiple runs are conducted to verify whether the parameter sets identified generate statistically significant results. The simulation results show that the data observed and simulated are very close after validation with the parameter settings as shown in Table 3.

Table 3: Best parameter set

<table>
<thead>
<tr>
<th>Motor Vehicle free-flow speed (km/h)</th>
<th>Average stop space (m)</th>
<th>Minimum space headway (m)</th>
<th>waiting time for diffusion (s)</th>
</tr>
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<tr>
<td>Light Vehicle</td>
<td>80-100</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Heavy Vehicle</td>
<td>60-80</td>
<td></td>
<td>45</td>
</tr>
</tbody>
</table>

C. Evaluation of Simulation Results

Typical measures of effectiveness such as traffic flow, travel time, delay, and average queue length were selected as the measurable index. The main simulation results are given in Table 4 and Figure 5, 6 and 7.

Figure 5: Comparison of Private Traffic Flow Before and After Dedicated Busways Implementation

![Comparison of Private Traffic Flow Before and After Dedicated Busways Implementation](image-url)
The carrying capacity was calculated to compare the difference before and after the dedicated bus lanes implementation. The official seating capacity of bus in China is around 60 passengers per bus plus 10 standing passengers [8]. It was assumed that the buses were full of passengers during the morning peak hours. According to the record [9], the average occupancies of private cars are 1.68 persons per car in Beijing. Considering the morning peak hour situation, 2 persons per vehicle was adopted as the average occupancy of private cars in this research. The real carrying capacity was calculated based on the surveyed data at Huamao Bridge Section and Yuantong Bridge Section. The expected private and public flow after implementation of dedicated bus lanes was evaluated via simulation. The simulation results and the growth rate of carrying capacity were calculated and illustrated in Table 4.
Table 4: Growth rate of Carrying Capacity

<table>
<thead>
<tr>
<th>Section</th>
<th>Before Implementation (Field Data)</th>
<th>After Implementation (Simulated)</th>
<th>Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Public Vehicle</td>
<td>Private Vehicle</td>
<td>Total (person/h)</td>
</tr>
<tr>
<td>Huamao Bridge</td>
<td>95*70 =6650</td>
<td>3899*2 =7798</td>
<td>14448</td>
</tr>
<tr>
<td>Section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yuantong Bridge</td>
<td>271*70 =18970</td>
<td>3782*2 =7564</td>
<td>26534</td>
</tr>
</tbody>
</table>

It can be seen that the bus flow increased from 95 to 259 vehicles per hour after dedicated bus lanes implementation at Huamao Bridge Section. Though the private vehicle flow reduced from 3899 to 3353 vehicle per hour, the total carrying capacity increased around 71.9% due to the greater carrying capacity of buses. The carrying capacity at Yuantong Bridge increased about 5.2%.

Person delay was also calculated. Average person delay increased from 8.2 minutes per person to 9.9 minutes per person.

The simulation results showed that the dedicated bus lanes can greatly improve the carrying capacity though there may have some negative impact on the private vehicles and a slight increase in person delay. At this stage, in order to attract commuters from private vehicles to public transport, dedicated bus lanes would still be a good option even at the cost of minor disadvantages to private vehicles.

V. EVALUATION AFTER IMPLEMENTATION

Due to the good results of pre-evaluation of the dedicated bus lanes plan, specialized bus lanes were put into use at May 24th 2011 on the Jingtong Expressway that connects the downtown area and Tongzhou District. Field data were collected and analyzed after the implementation to verify the accuracy of pre-evaluation results.

A. Traffic Flow

It can be seen that the private traffic flow experienced a significant drop from 3899 vehicles per hour to 3152 vehicles per hour at Huamao Bridge and from 3782 vehicles per hour to 1634 vehicles per hour at Yuantong Bridge after the implementation of dedicated bus lanes, which is due to the decrease of lanes by deploying the dedicated bus lanes. However, the public traffic flow increased from 95 vehicles per hour to 272 vehicles per hour at Huamao Bridge and from 271 vehicles per hour to 360 vehicles per hour at Yuantong Bridge, which is consistent with the previous simulation forecast.
Figure 8: Comparison of Private Traffic Flow Before and After Dedicated Bus lanes Implementation between Simulated and Field Data

Figure 9: Comparison of Public Traffic Flow Before and After Dedicated Bus lanes Implementation between Simulated and Field Data

B. Travel Time

A comparison for average travel time from Shuanghui Bridge to Sihui Bridge between simulated and field data after implementation of dedicated bus lanes was conducted below. From the result shown in Figure 10, there is a sharp increase for private vehicle travel time from 18.2 minutes to 45 minutes, while average travel time decrease for public vehicle from 19 minutes to 15 minutes.
C. Queue length

The comparison for queue length of eastbound traffic at Huamao Bridge was conducted between simulated and field data after the implementation of dedicated bus lanes. The results are shown in Figure 11. It can be found that the queue length of private vehicles increased from 6.2 kilometers to 10.8 kilometers, while the queue length of public vehicles decreased from 6.2 kilometers to 0. The reductions of queue length for public vehicles mean the improvement of the efficiency of public transportation, which will encourage more commuters to choose public transport over private cars.

Figure 11: Comparison of Queue Length Before and After Dedicated Bus lanes Implementation between Simulated and Field Data
D. Analysis

Table 5, shows that, the relative error, designed as:

\[
\text{Relative Error} = \frac{\text{Field Data} - \text{Simulated Data}}{\text{Field Data}} \times 100
\]  

(2)

between the field and simulated data, is in the range of 0-6%. It can be seen from the table 5 that there is no significant difference between the pre-evaluated data (simulated data) and the field data. There is a good agreement between the pre-evaluated data and the field data.

Table 5: The difference between the pre-evaluated data (simulated data) and the field data

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Carrying Capacity at Huamao Bridge (person/h)</th>
<th>Carrying Capacity at Yuantong Bridge (person/h)</th>
<th>Average Travel Time for Private Vehicle (minutes)</th>
<th>Average Travel Time for Public Vehicle (minutes)</th>
<th>Queue Length for Private Vehicle (Kilometers)</th>
<th>Queue Length for Public Vehicle (Kilometers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before (Field Data)</td>
<td>95<em>70+3899</em>2=14448</td>
<td>271<em>70+3782</em>2=26534</td>
<td>16.2</td>
<td>19</td>
<td>6.2</td>
<td>6.2</td>
</tr>
<tr>
<td>After (Simulated Data)</td>
<td>259<em>70+3352</em>2=24686</td>
<td>351<em>70+1669</em>2=27908</td>
<td>42.3</td>
<td>15.3</td>
<td>11.3</td>
<td>0</td>
</tr>
<tr>
<td>After (Field Data)</td>
<td>372<em>70+3152</em>2=25344</td>
<td>360<em>70+1634</em>2=28468</td>
<td>45</td>
<td>15</td>
<td>10.6</td>
<td>0</td>
</tr>
<tr>
<td>Relative Error</td>
<td>2%</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

VI. CONCLUSIONS

The work presented in this paper has shown that the pre-evaluated data (simulated data) and the field data matches very well, which indicates that microscope simulation models can be effective tools to pre-evaluate urban traffic management. The key to obtain reliable simulation results is model calibration and validation. The simulation model was fully calibrated and validated with data collected in Beijing.

Dedicated bus lanes can greatly improve the carrying capacity though there may have some negative impact on the private vehicle traffics. It would be helpful to reduce the traffic jams during rush hours and induce office workers to choose public transportation over private cars.

VII. ACKNOWLEDGEMENT

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