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IMPACTS OF SUPPRESSING BICYCLES ON MOBILITY AND TRANSPORTATION EFFICIENCY

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1. Introduction

Stimulated by the economic boom since 1980s, Chinese cities began to experience serious urban transportation problems such as congestion and environmental deterioration. Affordability of households and government promotion of automobile stimulated automobile ownership and usage.

Figure 1 shows the rapid growth of private car ownership as well as the passenger car productions in China during the period 1990-2003\(^1\). To meet the increasing travel volume and higher mobility, road networks have been expanded and streets have been widened. However, the infrastructure construction has never caught up with the vehicular travel volume. Transition from the flow of mainly buses and bicycles to highly mixed flow of automobiles, bicycles and buses has created severe road congestion. It is predictable that if the trend of increasing share of automobiles in the traffic flow continues, the conflict between the demand and supply of road space will become much more severe in the foreseeable future.

In July 2005 a law banning electric bicycles on public streets was adopted in the city of Zhuhai. That event deepened further the concern about the move toward a car culture in China. Before it, the transportation policy applied by Guangzhou government since 1993 discouraged any other private transportation mode than private automobile, by prohibiting bicycle access to main roads at some segments and at peak hours, opening some cycling roads to automobiles, and other measures discouraging bicycle use. This policy affected strongly the mode choice of travelers. Till 1998, the mode share of cycling dropped over 20\%\(^2\). Furthermore, more bicycle parking spaces give way to auto parking, and new parking places for bicycles are no longer planned or provided, which makes cycling less convenient. In consideration of unsafe riding environment, cycling becomes much less attractive. Travel surveys in several large cities (Table 1) reflect the trend of losing modal share of cycling (not including walking)\(^3\). Improper transportation management and policies lead to deterioration of the transportation condition in large urban areas. An undesirable cycle has been formed. The deterioration of cycling environment discourages cycling, inadequate public transit service drives people away, and improving environment for auto attracts more driving. As space occupied per person by auto user is much larger than bicycle and public transit for both driving and parking, more auto use makes road more crowded and increases congestion, which results in worse public transit performance, stimulating more driving. It is a “vicious circle” which will continue, as shown in Figure 2, unless present policies and practices change.

![Figure 1: Private Car Ownership and Passenger Car Production](image)

### Table 1: Bicycle modal share in several large cities, %

<table>
<thead>
<tr>
<th>City</th>
<th>Shanghai</th>
<th>Nanjing</th>
<th>Guangzhou</th>
<th>Shijiazhuang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit</td>
<td>24.9</td>
<td>17.9</td>
<td>28.7</td>
<td>27.5</td>
</tr>
<tr>
<td>Bicycle</td>
<td>58.9</td>
<td>45.9</td>
<td>65.9</td>
<td>53.5</td>
</tr>
<tr>
<td>Others</td>
<td>16.2</td>
<td>36.2</td>
<td>5.4</td>
<td>19.0</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Figure 2  A conceptual diagram of the “vicious circle” in urban transportation.
2.  Importance of bicycle as an independent transportation mode

The experience of the developed world in the past several decades has proved that a city’s policy of “building itself out of congestion,” aiming at accommodation of continuously increasing car travel demand, fails in the main goal: elimination of highway congestion. Scholars in Western countries began to realize that the true problem lies in the inherent bias favoring automobile transportation, which has been summed up by Johnson in one phrase, “collision of cities and cars”. This bias is reflected in the public and transportation policies that have promoted auto usage while simultaneously discouraging other modes. To apply the lessons, maintaining bicycles as an independent transportation mode is more meaningful.

First, the extremely high density of urban development and residence does not allow private automobile as a leading transportation mode choice. Compared to public transit and non-motorized modes, a traveler by automobile needs more space both for parking and on the way, as depicted in Figure 3. This high land demand of automobiles hence consumes more high-value urban land to accommodate the same travel volume.

Second, bicycle is required for increased mobility and accessibility demands. Table 2 shows the private mode vehicle ownership and public transit availability. Even in Beijing, the city with the highest automobile ownership, if assume 3.4 people (average size of a household) are accessible to an automobile, at most less than 25% people have access to automobile and more than 75% people are left to other transportation modes than automobile. On the other hand, shrank transit network relative to expanded urban territory (Figure 4), reflects lower accessibility by public transit service. The less wealthy households outside transit service coverage who cannot afford automobiles are left behind and their mobility is impaired by discouraging bicycle. Obviously providing cycling facility and encouraging modest cycling is necessary and a must to improve the mobility for all.

Furthermore, bicycle is the most efficient mode in short-haul traveling, besides walking. Higher density of urban development and residence generally results in relatively short trip length compared to developed countries. Though not enough information is available in China, a survey conducted in Beijing showed that over 60% trips were less than 5 km long, a feasible and comfortable travel by bicycle in less than 20 minutes.

In addition, non-motorized modes started to attract global attention and the benefits of non-motorized modes, walking and bicycling, were highly valued in terms of social impacts such as tail emissions, noise, energy consumption, and safety. It is believed that about 21% greenhouse gas emissions are from ground transportation worldwide, and exhaust gas pollution accounts largest part of air pollution in urban areas. Moreover, transportation sector accounts for about 25% global energy consumption.
Without direct gas emissions and fuel consumption, obviously bicycle is a clean and efficient mode with respect to both air pollution and energy consumption. In addition to the social impacts such as land use, environmental and energy aspects, moderately encouraging travel by bicycle has positive impacts on traffic calming and congestion reduction. Next section gives a quantitative impact analysis of current bicycle policies on traffic congestion and transportation capacity.

3. Quantitative analysis of current bicycle transportation policies

To analyze the impacts of bicycle transportation policies on transportation system performance, transportation efficiency, defined as users’ travel time, and system capacity which is the maximum passenger volume transported are analyzed. Among all factors in evaluating transportation system efficiency, travel time is one of the most critical.

3.1 Assumptions and approaches

A “model corridor” of two-way 21-m wide and 6-km long urban corridor is assumed. A travel volume, Q, is flowing from one end of the corridor to the other. It is assumed that three transportation modes, bike, automobile and bus, are available in mode choice. Figure 5 depicts two types of cross sections. Motor vehicle lane is 3.5 m wide while bicycle lane is 2.5 m (the most common bicycle lane width in China). In type a, no bicycle lane is provided along the corridor, and motor vehicles including automobiles and buses run on two-directional 6-lane roadway. In type b cross section, a 2.5-m bicycle lane is set along with 2 motor vehicle lanes in each direction.

User travel time and total travel time are used to compare the transportation system efficiency. User travel time is the travel time by any individual traveler, while total travel time refers to the total travel time for all users. User travel time consists of in-vehicle and out-of-vehicle time. For private modes such as automobile and bike, in-vehicle time includes time spent in traveling the path as well as delays experienced at intersections, while out-of-vehicle time is the time in accessing vehicle from the trip origin and leaving from the vehicle to the trip destination. For bus riders, besides the time spent similar to private modes, in-vehicle time includes additional delays at bus stops along the trip and out-of-vehicle time also

Table 2: Bicycle and automobile ownership and transit availability

<table>
<thead>
<tr>
<th>City</th>
<th>Bikes per 10^3 households, 2002</th>
<th>Autos per 103 capita, 2002</th>
<th>Transit vehicles* per 103 capita, 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>1982</td>
<td>71.4</td>
<td>2.64</td>
</tr>
<tr>
<td>Tianjin</td>
<td>2181</td>
<td>31.6</td>
<td>0.94</td>
</tr>
<tr>
<td>Shanghai</td>
<td>1240</td>
<td>39.6</td>
<td>1.68</td>
</tr>
<tr>
<td>National</td>
<td>N/A</td>
<td>N/A</td>
<td>0.77</td>
</tr>
</tbody>
</table>

* Transit vehicle no. is in equivalent passenger car unit.
includes the waiting time at the boarding bus stop.

To compute the running time of motor vehicle traffic flow speed, a Chinese research based empirical traffic volume-delay function\(^{14}\) is used. The average traffic flow speed, \(V\), is

\[
V = V_f / [1 + \alpha \cdot (v / c)\beta],
\]

in which \(V_f\) is the free-flow-speed and \(v/c\) is the ratio of vehicular traffic volume to capacity, and coefficients are \(\alpha = 1.4\) and \(\beta = 3.4\).

Due to less clear relationship between bicycle volume and travel speed, a rough model developed by Botma\(^{15}\) is used to compute the average bicycle flow speed, \(V^b\), as

\[
V^b = 20.8 - 0.00068 \cdot \text{vol}^b,
\]

where \(\text{vol}^b\) is the bicycle traffic flow rate.

For bus riding, transit operating theory is used to compute the bus travel time\(^{16}\). When there is a ROW B type facility, protected bus lane, buses run at a constant design speed. When ROW C facility is provided and buses operate in mixed traffic with automobiles, buses run at the same speed as that of automobile in traffic. In addition, with two service patterns of regular service and skip-stop service, the delay at bus stops varies.

In multi-mode systems, the total travel time of all users, \(TT\), is computed as a function of respective travel times and modal split among bike, automobile and bus, written as

\[
TT = Q (\rho^a \cdot T^a + \rho^b \cdot T^b + \rho^k \cdot T^k),
\]

in which \(Q\) is the total travel volume, superscripts of a, b, and k representing auto, bus and bike, and \(\rho\) are modal share, and \(T\) are user travel time for the modes, respectively.

### 3.2 Comparison of transportation efficiency

Bicycle suppressing policies include many measures that result in a less attractive bicycling environment and discourages bicyclists, so that they tend to shift from bicycle to other modes. Restriction of bicycle parking and reduction of the capacity of bicycle parking lots in city center and in other high density work/commerce places make some bicycle trips infeasible and force bicyclists to turn to other modes, like auto driving or bus riding. In an extreme, bicycle lanes are turned to other use and bicycling is prohibited. Possible measures include converting the existing bicycle lanes to dedicated motor vehicle lanes for automobile use, for bus use, or for use of both these two modes. Whatever bicycle suppressing measures are applied, bicycle travel is discouraged, even banned, and modal shift from bicycle to other modes occurs.

To give a brief bus systematic overview of intermodal transportation policies, three different policies toward bicycles are applied to two different analyzed cases, T1 and T2. Table 3 presents a review of such policies and measures and their likely impacts on intermodal distribution among bicycle, automobile and bus.

<table>
<thead>
<tr>
<th>Initial conditions</th>
<th>Suppressing bicycle policies</th>
<th>Impacts on facilities and operations</th>
<th>Impacts on likely modal shifts</th>
</tr>
</thead>
</table>

Table 3 Bicycle suppressing policies and their likely impacts on intermodal distribution
<table>
<thead>
<tr>
<th>Case T1</th>
<th>Reduced bicycle parking or other disincentive measures</th>
<th>Reduced bicycle modal share. Shifted bicyclists possibly turn to auto.</th>
</tr>
</thead>
<tbody>
<tr>
<td>One 2.5-m wide bicycle lane and 2 motor vehicle lanes for automobile and bus per direction; Buses operate in mixed traffic with regular service pattern.</td>
<td>Prohibiting bicycle travel and turning bicycle lanes to automobile use only</td>
<td>All bicyclists turn to either auto driving or bus riding. Increased auto and bus modal shares.</td>
</tr>
<tr>
<td>Case T10: Same as in Case T1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case B1: No bicycle lanes; 2-way 6-lane for automobile and bus; Buses operate in mixed traffic at regular service.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case B3: No bicycle lanes; 2-way 4-lane for automobile; Buses operate at skip-stop service pattern in mixed traffic with automobiles.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case T2</th>
<th>Reduce bicycle parking or other disincentive measures</th>
<th>Reduced bicycle modal share. Shifted bicyclists turning to auto or bus.</th>
</tr>
</thead>
<tbody>
<tr>
<td>One 2.5-m wide bicycle lane 1 motor vehicle lanes for automobile per direction; Buses operate in separated lanes from automobile with regular service pattern.</td>
<td>Prohibiting bicycle travel and turning bicycle lanes to automobile use only</td>
<td>No bicycle modal share. More bicyclists shifting to auto than bus.</td>
</tr>
<tr>
<td>Case T20: Same as in Case T2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case B2: No bicycle lanes; 2-way 4-lane for automobile; Buses operate at regular service pattern on protected bus lanes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case B4: No bicycle lanes; 2-way 2-lane for automobile; Buses operate at skip-stop service pattern on protected dual bus lanes.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To compute the travel times by these modes in different scenarios, a travel volume of 8000 prs/h is observed and various intermodal distributions with decreasing bicycle modal share and likely modal shifts under various bicycle depressing policies are analyzed and shown in Figure 6. Shaded areas show the
total users’ travel time in original situation (T1 and T2), while heavily framed areas depict the total users’ travel time under the applied bicycle policies. The difference in travel times, between shaded and framed area, shown as white area, reflects the impacts of depressing bicycle policies on the transportation system efficiency. Obviously, the larger the white area, the longer are travel times and the lower is the system efficiency.

![Diagram showing modal splits and impacts of policies on intermodal distribution and efficiencies of three basic modes](image)

**Figure 6**  Impacts of policies on intermodal distribution and efficiencies of three basic modes

It is observed that with a given travel volume suppressing bicycle policies result in a deterioration of the transportation system. In the first case, the first alternative T10 with reduced bicycle modal share leads to a little shorter bicycle travel time, but meanwhile both auto and bus travel time increase very significantly. For the other two alternatives, B1 and B3, no bicycling is available and both auto and bus travel times soar. It is worth noting that the increases in travel times of both individual user and the system total in B3 by alternating bicycle lanes to bus use are not so significant as those in B1 in which bicycle lanes are shifted to auto use only. However, all alternatives in the first situation, in which
bicycles are discouraged or even prohibited, result in the longer travel time for all users except bicyclists. In the other case, the diagram shows that average travel times on each mode increase as does the total travel time on the whole system. Though alternatives in the second case show some advantage over alternatives in the previous case, that is, the total travel time increase of at most 23% in the second compared to at least 40% in the first, the comparison results clearly show the impacts of reduced or null bicycle modal share are negative to transportation efficiency and deliver a strong argument that existence and encouragement of bicycle use improves the transportation system performance.

3.3 Comparison of passenger transporting capacity

In addition to efficiency, transportation capacity is very important in evaluating transportation system performance. It is very crucial in Chinese cities because of tremendous population densities and travel intensity. Street provision sets the limit on the maximum travel volume, either in vehicles or persons, for both motorized and non-motorized transportation modes. For motor vehicle traffic, the maximum traffic vehicular capacity is set at LOS E\textsuperscript{17}. The bicycle saturation flow rate is set as 8000 bike per hour in terms of observations in literature\textsuperscript{18},\textsuperscript{19}. For bus operations, maximum capacity is a function of the average load of each bus and the maximum frequency at the critical bus stop, which depends on many factors, including service pattern and bus stop layout. Restricted by various generic capacity factors of each mode, it is obvious that the maximum passenger volume transported at different combinations as modal shares vary. Considering the capacity constraints of facilities, and the complementary constraint that the sum of all modal shares is 1, the system maximum total transportation capacity, $Q$, for case B and case T are

$$\max Q \quad \text{s.t.} \quad Q \cdot \frac{\rho^a}{\alpha^a} \leq C_{\text{max}}^a; \quad Q \cdot \frac{\rho^b}{\alpha^b} \leq C_{\text{max}}^b; \quad Q \cdot \frac{\rho^k}{\alpha^k} \leq C_{\text{max}}^k; \quad \rho^a + \rho^b + \rho^k = 1;$$

in which superscripts $a$, $b$ and $k$ represent, respectively, auto, bus and bike, $\rho$ is the modal share as defined before, $C_{\text{max}}$ is the maximum capacity of any mode, $\alpha$ is the average vehicle occupancy, and $pce$ reflects the passenger car equivalent of a bus.

Figure 7 shows the maximum passenger volumes transported by the corridor in Case T1, B1 and B3. Case T1 is plotted with bicycle modal share of 35%, while B1 and B3 are with 0% bike modal shares. It is seen that with the same bus modal share, the transportation capacity in the tri-mode system is higher than those in both bi-mode systems of B1 and B3. The figure also shows that with very high bus modal share, the bi-mode system with accelerated bus

![Figure 7 Transportation capacity in Case T1, B1 and B3](image-url)
service (Case B3) shows an advantage over Case T1 in transporting passengers. Comparison of transportation capacities between T-cases to B-cases are listed in Table 4. When bicycle lanes are changed to automobile use only, the maximum transportation capacity decreases over 20%, as shown in the scenarios of T1/B1 and T2/B2. However, shifting bicycle lanes to exclusive bus use increases the maximum transportation capacity by more than 10%, and even high as 23% in the scenario T2/B4 in which protected and accelerated high performance bus service is provided. Obviously, prohibiting bicycle from the transportation system and shifting bicycle lane for automobile use decreases the transportation capacity dramatically, while turning bike lanes to bus use, the system capacity is improved. Their efficiency falls in Case B3, while it rises a little in Case B4.

However, even though the overall transportation capacity and system efficiency in Case B4 is better than those in tri-mode systems, the cost of higher performance bus system is much higher than that of bicycle system. For street facility only, it is estimated that the construction and maintenance of bicycle lane is only about 1/5 of motor vehicle lane costs. This difference increases dramatically when bus vehicle, stops and employment, and environmental costs are included.

### 4. Conclusion

Higher automobile ownership, together with the encouraged use of cars by the current urban transportation policies has, brought serious transportation problems, such as congestions and other environmental impacts. To reduce or stop this deterioration, the role of bicycle in a transportation system and the impacts of bicycle as a mainstream mode choice on transportation performance have been explored in this research.

Comparison of transportation by different urban transportation modes shows that from decreased bicycle modal share to prohibiting bicycle on the way the total travel time of the whole system increases dramatically. Meanwhile travel times of both automobile and transit users climb up significantly due to fewer bicyclists. Obviously that existence of bicycling improves the system efficiency. Also among bicycle discouraging measures, turning bicycle lanes to automobile use only results in the lowest capacity and make the system least efficient.

In capacity analysis, impacts of prohibiting bicycles vary depending on bicycle lane usage. When it turns to automobile use only, the passenger transportation capacity falls dramatically. Shifting bicycle lanes to bus transit provides a higher performance bus service and increases the whole system transportation capacity considerably. However, this is in fact the least likely measure to be applied in China of all bicycle disincentives, because bicycles are deterred for the sake of more automobile driving. This quantitative analysis demonstrates that with moderate level of bicycle modal share, total system travel time stays short so transportation efficiency maintains high. Also, multi-mode systems with bicycle as an independent and feasible mode choice serves medium to high travel volume. In spite of its inferiority to high-performance bus operation in capacity competition, when mobility and accessibility of

<table>
<thead>
<tr>
<th>Case</th>
<th>T1</th>
<th>B1</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum capacity, prs/h</td>
<td>12550</td>
<td>9680</td>
<td>15060</td>
</tr>
<tr>
<td>Average travel time, h/prs</td>
<td>0.65</td>
<td>0.76</td>
<td>0.73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case</th>
<th>T2</th>
<th>B2</th>
<th>B4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum capacity, prs/h</td>
<td>12220</td>
<td>9390</td>
<td>14290</td>
</tr>
<tr>
<td>Average travel time, h/prs</td>
<td>0.44</td>
<td>0.54</td>
<td>0.43</td>
</tr>
</tbody>
</table>
the whole urban area, environmental impacts and investments and operation cost of bus service improvements are put into consideration, multi-mode systems with bicycling show their big advantage. In Chinese cities, where very large travel volume generated with extremely compact lane-use development pattern and high population density, impact of eliminating bicycling from transportation mode choice is even more severe. Traffic condition will deteriorate even more due to the impact of “vicious circle”, which consequently worsens the urban living environment and lowers livability in cities. To prevent this downgrading trend, putting bicycling mode into the transportation planning process and providing safe and convenient bicycle facilities hence maintaining or encouraging bicycle use would be constructive transportation policies.

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