Incorporating Cycling in Ottawa-Gatineau Travel Forecasting Model [ITM # 26]

Abstract

The paper presents an approach that goes beyond the traditional travel modeling paradigm by incorporating cycling as an explicitly defined mode alternative in the recently developed model for the Ottawa-Gatineau region. Current models mostly operate with a simplified cycling Level-of-Service (LOS) measures (most often an arbitrary specified average speed across the entire network) and do not model details associated with actual cycling routes and facilities, as well as cross-modal impacts. As a result, policies that affect cycling conditions, for example cycling lanes and/or related traffic regulations cannot be evaluated with the current models. The presented cycling simulation model for Ottawa-Gatineau is based on a cycling route choice model that is designed to be sensitive to a wide range of LOS measures including time, speed, level-of-stress, pavement conditions, vehicular traffic, area type effects etc. The interaction between bicycle and autos in mixed traffic is also modeled at the regional assignment level. This regional assignment model is integrated into the overall regional travel model that predicts the share of cycling trips versus auto, transit, and other non-motorized modes for different types of trips and population segments.

Statement of Financial Interest

The authors do not have any direct financial interest with regard to this research. The described methods are used in the Ottawa TRANS travel demand model which is owned by the public agency (TRANS). The only indirect interest of the PB as a consultant is to portray the methodology developed as state-of-the-practice. However, this is based on the objective discussion of the technical merits and is free of any advertisement.

Statement of Innovation

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Surabhi Gupta,
Parsons Brinckerhoff, New York, NY

Peter Vovsha,
Parsons Brinckerhoff, New York, NY

Roshan Kumar,
McKinsey & Company, Boston, MA

Ahmad Subhani,
City of Ottawa, Ottawa, ON

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Introduction

Bicycling is on the rise in bike friendly communities (BFCs) like Ottawa-Gatineau. For example, according to the 2011 TRANS\(^1\) Origin-Destination (O-D) Survey, compared to 2005, bicycling has grown by 40% in the Ottawa-Gatineau region. Given the steady increase of bicycling, especially in BFCs, it is essential to study and model the impacts of bicycling on the region’s traffic congestion and travelers’ mode choice. The recent advances in transportation planning with respect to bicycle environment and ever-increasing computational resources have made it possible to incorporate bicycling into the travel demand modeling paradigm. This paper describes the approach to incorporate bicycling as an explicitly defined mode alternative in the recently updated regional model for Ottawa-Gatineau.

While there exist mode choice models that include bicycling as a mode (for example, San Francisco and Portland regional models developed by the local planning organizations), these models still treat bicycles in the network assignment in a simplified fashion. Many of current models tend to operate with greatly simplified bicycling LOS measures (most often an arbitrary specified average speed across entire network) and do not model details associated with actual bicycling routes and facilities. Also, current models largely ignore the cross-modal impacts which bicyclists and motorised traffic place upon each other. The main objective of the current research is to incorporate bicycling in both mode choice and network assignment in a consistent way.

Literature Review

While there were many publications that dealt with quantifying LOS variables for bicyclists and bicycle facilities, the authors found practically no literature on applied models for bicycle routing and assignment. Contributions of a few relevant papers are discussed below.

Landis et al. (1) developed a statistically calibrated Bicycle Level-of-Service (BLOS) model. This model was based on real-time perceptions from bicyclists traveling in actual urban traffic and subject to roadway conditions. The study included a regression analysis of BLOS measures as a function of roadway and traffic characteristics. The FHWA developed a Bicycle Compatibility Index (BCI) to evaluate the capability of urban and suburban roadway sections to accommodate both motorists and bicyclists (2).

The National Cooperative Highway Research Program published a report that developed a methodology to calculate LOS for various modes on urban streets. The recommended Bicycle LOS model is a weighted combination of the bicyclists’ experiences at intersections and on street segments in between the intersections (3). The Mineta Transportation Institute (4) developed a BLOS model based on people’s

\(^1\) TRANS is a joint technical committee established in 1979 to co-ordinate efforts between the major transportation planning agencies of Ottawa’s National Capital Region.
tolerance for traffic stress and classified bicyclists into three classes by level of experienced traffic stress. In addition to this study, Dill et al. (5) and Stimson and Bhat (6) also classified bicycle users.

The proposed model considered similar classifications to develop BLOS segmented by cyclist type. However, there was no data available to segment the bicycle trip tables by different cyclist types. For the current model, only one cyclist type is considered and placeholders have been created for other cyclist types for future improvements. TRANS plans to conduct a bicyclist survey which would provide the appropriate data which could be used for introducing multiple cyclist types in the model system. The BLOS is then used in the route choice model that is used in the bicycle assignment and generates route level skims that affect mode choice. The route level skims are similar to the ones studied by Hood et al. (7).

Bicycle OD Data Analysis

TRANS conducted a Travel Origin-Destination Survey in 2011 which included 25,374 households and 62,897 people. Close to 2% of the trips were made by bicycle. Among all bicyclists, 67% are male and only 32% are female. The trip characteristics of bicyclists also differ by age categories. As expected, children under 15 years of age make the shortest trips and ride the least amount of time per trip. Adults between 35 and 65 years of age make the most of and the longest bicycle trips.

The proportion of bikes used during each of the time-of-day periods is somewhat similar. However, there is a slight spike in the AM peak period between 8:30 AM and 9:30 AM. Similarly, during the PM period between 4:30 PM and 6:30 PM there is a slight spike in bike usage. Bike usage seems to be higher during the tapering shoulder of the peak period than during the peak hour itself.

Auto – Bicycle Assignment Model

As stated previously, while a large number of qualitative studies and initial modeling efforts for bicycle assignment exist, no study to date has attempted to develop LOS measures that can be used in a bike assignment model; further, no study has examined the cross modal impacts of vehicular and bike movements in the equilibrium network assignment framework. The auto-bike assignment model developed in this section represents an attempt to fill this gap.

The methodology presented here first describes a framework for calculating the generalized cost and volume delay functions for bicycles and then, outlines the auto-bicycle assignment equilibrium framework used in the Ottawa TRANS model.

Bike Facility Type

The bike facility type affects the bicyclist’s travel time as well as travel times of motorized vehicles in mixed traffic. For example, a bicyclist using a bike separated facility will not impact motorized vehicles and get impacted by motorized vehicle as much as a bicyclist using a mixed-traffic lane. There are 6 bike facility types specified in the Ottawa network:
1) Multi-use Stone pathway
2) Multi-use Asphalt pathway
3) Separated Bike Lanes
4) Sharrow Lanes (curb lane is marked for used by bikes but not exclusively)
5) Bikes allowed in mixed traffic
6) Paved Shoulders

Impact on Travel Time (Bicycles)

Different variables affect the bicycle level of service. This BLOS can be interpreted as the additional time required for traversing a link compared to free flow conditions. For example, if it takes 6 minutes to traverse a link on a bike under ideal free flow conditions, then in the presence of vehicular traffic, it will take more time. Assume that BLOS for link \((i,j)\) for a bicyclist of type \(m\) is defined as \(LOS_{ijm}\). Then, the delay experienced by that bicyclist is given by:

\[
\text{Link Delay}_{ijm} = LDF_{ijm} \times \text{Bike Free Flow Time} \quad \forall (i,j) \in A \ \forall m \in M
\]

Equation 1

Where, the link delay factor (LDF) is defined as:

\[
LDF_{ijm} = 1 + LOS_{ijm} \quad \forall (i,j) \in A \ \forall m \in M
\]

Equation 2

In turn, \(LOS_{ijm}\) is defined as:

\[
LOS_{ijm} = \max \{ f(A_{ij}, P_i, P_j, M_m \times A_{ij}), 0 \}
\]

Equation 3

Where:
\(A_{ij}\) = Link specific variables,
\(P_i\) = Downstream node-specific variables,
\(P_j\) = Upstream node-specific variables,
\(M_m \times A_{ij}\) = Link-user specific interaction variables.

Table 1 shows an example of the LOS computation with the initial parameters set by the authors based on the literature review.
### Table 1: An Example showing Bicycle LOS computation

<table>
<thead>
<tr>
<th>Variables</th>
<th>Units</th>
<th>BIcyclist</th>
<th>Value</th>
<th>Effect</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Link-Level</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle Lane (yes/no)</td>
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<td>Bike Lane Width</td>
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<td>Value</td>
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<td>Decrease</td>
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<tr>
<td>Traffic Speed</td>
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<td>35</td>
<td>Increase</td>
<td>0.022</td>
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<tr>
<td>Curb Lane Volume</td>
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<td>Value</td>
<td>700</td>
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<td>0.002</td>
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<tr>
<td>Other Lane Volume</td>
<td>Vph</td>
<td>Value</td>
<td>1400</td>
<td>Not Good</td>
<td>0.00045</td>
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<tr>
<td>Parking Lane (yes/no)</td>
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<tr>
<td>% HV Volume</td>
<td>Ratio</td>
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<td>Increase</td>
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<td>Increase</td>
<td>0.019</td>
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<tr>
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<td>Value</td>
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<td>Increase</td>
<td>0.05</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables</th>
<th>Units</th>
<th>BIcyclist</th>
<th>Value</th>
<th>Effect</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Node-Level</strong></td>
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<td>Signal</td>
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<tr>
<td>Stop Sign</td>
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<td>Cross Street Width</td>
<td>Feet</td>
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<td>0.07</td>
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<td>LOS</td>
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<td>Value</td>
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<td></td>
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<tr>
<td>Free Flow Travel Time</td>
<td>Mins</td>
<td>Value</td>
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<td></td>
<td></td>
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<tr>
<td>Delayed FF Travel Time</td>
<td>Mins</td>
<td>Value</td>
<td>7.239</td>
<td></td>
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</tr>
</tbody>
</table>

### Link Volume Delay Function (Bicycle)

LDF does not account for the delay caused due to traffic congestion at a link. To account for these delays, a link volume delay function for bicycle is defined. The following factors affect delays experienced by bicyclists:

- **Auto volume** – high V/C ratio for autos implies a steeper bicycle VDF as they have to navigate through high congestion for mixed-traffic
- **Bike lane type** – easier to navigate through dedicated bike lane than mixed traffic
- **Total effective capacity** – effective capacity available to bikes conditional on the modeled traffic volumes
A link-based bike VDF that accounts for these factors was specified. Let the capacity of the link be $C$, the auto volume on that link be $V_a$, the bicycle free flow travel time be $t_0$, and the link delay factor be $LDF$. In addition, a few calibration parameters are also defined - $\alpha_b$, $\beta_a$, $\gamma$, $\theta$, $\mu$, $\nu$, $\zeta_b$. Now, the travel time on a link with bike volume $V_b$ is specified by a function $t(V_b)$ that is defined as:

$$t(V_b) = ACF \times \left( 1 + \frac{\zeta_b}{C_{eff}} \right)^{Exp_{eff}}$$  \hspace{1cm} \text{Equation 4}$$

Where,

$$Exp_{eff} = \max\{\gamma, \min\left(\frac{C}{V_a+\epsilon}, \beta_b\right)\}$$  \hspace{1cm} \text{Equation 5}$$

Effective capacity is calculated in the following way:

$$C_{eff} = \max\{C - V_a, \alpha_b C\}$$  \hspace{1cm} \text{Equation 6}$$

Auto Congestion Factor (ACF) is calculated in the following way:

$$ACF = LDF \times t_0 \times \left( 1 + \mu \left(\frac{V_a}{C}\right)^\nu \right).$$  \hspace{1cm} \text{Equation 7}$$

The cross impacts of auto congestion on bicycle LOS are incorporated into this VDF using the auto congestion factor (ACF).

**Link Volume Delay Function (Auto)**

In addition to examining how auto traffic affects bicycle congestion, one also needs to examine the effect bicycles have on auto congestion and link travel times. Auto travel times increase due to the presence of bicycles. Bicycles take up part of capacity, and since they move slower than autos, they take up even more capacity than their physical dimensions. The travel time delay that motorized vehicles experience because of the presence of bicycles can be accounted by the amount of effective car capacity bicycles take up.

Mathematically, this can be expressed as follows. Let the capacity of the link be $C$, the bike volume on that link be $V_b$, the auto free flow travel time be $t_0$, the link factor be $LF$, let Passenger Car Equivalent (PCE) for bike user $b$ and link type $l$ be $p_{b,l}$. In addition, calibration parameters $\beta_a$, $\zeta_a$ are also specified. The link factor is a parameter whose value is dependent on the link type (mixed-traffic, bike lane etc.). Now, the travel time on a link with auto volume $V_a$ is given by $t(V_a)$ and is specified as:

$$t(V_a) = t_0 \times LF \times \left( 1 + \zeta_a \left(\frac{V_a + \sum_{b \neq l} p_{b,l} V_b}{C}\right)^{\beta_a} \right).$$  \hspace{1cm} \text{Equation 8}$$
Iterative Implementation of Equilibrium Auto- Bicycle Assignment

The final goal of defining the LOS variables and VDFs is to study the effects bicycles have on vehicular traffic and vice-versa in a coherent equilibrium framework. This objective is met by iteratively assigning autos and bicycles onto the network with the linkages between them. Figure 1 explains the entire iterative framework for the mode choice and assignment procedure. In the first step, auto assignment is carried out assuming that there are no bikes on the network. After auto assignment, effective capacity and other VDF parameters are computed for the bike assignment based on auto volumes and travel times. After bike assignment, the bike volumes in PCEs are preloaded on the auto network for auto assignment. The process iterates between these two assignments until the stopping criteria (equilibrium) is obtained. If the stopping criterion is met, the LOS skims are passed on to the mode choice model.

It should be noted that a possible alternative way is to assign both auto and bicycle trips as different vehicle classes in one multi-class assignment procedure. However, a multi-class assignment would restrict the classes to share same VDF while it is evident that the VDFs for autos and bicycles are very different.

Overall, there are three levels of equilibration: (a) bike and auto assignment each one separately; (b) equilibrium between bike and auto assignments achieved by iterations with a feedback between them; (c) demand (mode choice) global equilibrium. For bicycle mode, skims are generated by 6 facility types and fed into the mode choice model. The sensitivity to bicycle time varies across different bike facility type which makes bicycles more attractive between Origin-Destination pairs which have higher proportion of travel time on bike friendly lanes.
Figure 1: Mode Choice and Assignment Framework Incorporating Bicycles
Conclusions

The paper presents an innovative approach to incorporate cycling as an explicit mode in the Ottawa-Gatineau model. The adopted approach overcomes the limitations of many existing travel models in practice that operate with greatly simplified bicycling LOS measures and do not model details associated with actual cycling routes and facilities. An iterative auto and bike assignment process with feedback of volumes from one to another is used until equilibrium is reached. This regional assignment model is integrated into the overall regional travel model that predicts the share of cycling trips versus other auto, transit, and other non-motorized modes for different types of trips and population segments. Extensive validation results for bike trips are available and will be included in the presentation and full paper.

The designed model framework addresses specifics of bicycling LOS and the associated cross-modal impacts which cyclists and motorised traffic have upon each other. The bicycle route choice model is designed to be sensitive to a wide range of LOS measures including time, speed, level-of-stress, pavement condition, vehicular traffic, area type effects etc. The proposed model is able to evaluate specific policies that affect cycling conditions, for example dedicated cycling lanes and/or related traffic regulations that cannot be evaluated with the current models. This is particularly important for the City of Ottawa (TRANS Member Agency) that is currently considering several large-scale programs to further promote bicycle use and improve conditions for bicycling.

A future improvement for the model would be inclusion of turn penalties to account for the interaction of bicycles and autos at the intersections. Turning bikes increase auto travel times and turning autos increase bike travel times. In addition, proportion of bikes (autos) turning also directly affect bike (auto) travel times. Lastly, turning and through traffic in other directions also adversely impact travel times. These turn penalties are inherently dynamic because they change with traffic volume.
References


