Micro-simulation of Bicycles for Planning and Design

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Executive Summary

- Wide-area micro-simulation is an important planning and design tool for visualization and analysis
- TransModeler, specifically, micro-simulates bicycles rigorously, integrating state-of-the-art research on bicycles’ traffic dynamics
Outline

- Outputs of micro-simulation
- Role of micro-simulation
- TransModeler for micro-simulation
- TransModeler for bicycle micro-simulation
Outline

- Outputs of micro-simulation
  - Analysis
  - Visualization
- Role of micro-simulation
- TransModeler for micro-simulation
- TransModeler for bicycle micro-simulation

Micro-Simulation for Analysis

<table>
<thead>
<tr>
<th>Bicycle Mode Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bicycle Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Build</td>
</tr>
</tbody>
</table>
### Micro-Simulation for Analysis

<table>
<thead>
<tr>
<th>Bicycle Mode Share</th>
<th>0%</th>
<th>3%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Infrastructure Dimension</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Build</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Build</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Demand Dimension**

Provides a rigorous way to succinctly show impact on transportation system of outreach programs and infrastructure programs.
Micro-Simulation for Analysis

Value of the analysis hinges on rigor

Outlook

- Outputs of micro-simulation
  - Analysis
  - Visualization
- Role of micro-simulation
- TransModeler for micro-simulation
- TransModeler for bicycle micro-simulation
Micro-Simulation for Visualization

Provides something real for stakeholders to react to, rather than arguing abstract hypotheticals.
Micro-Simulation for Visualization

Value of the visualization hinges on reality

Provides something real for stakeholders to react to, rather than arguing abstract hypotheticals

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  - Transportation Modeling: Travel Demand vs. Micro
  - Micro-simulation as a tool for analysts
- TransModeler for micro-simulation
- TransModeler for bicycle micro-simulation

Transportation Modeling

- Travel Demand Modeling
  vs.
- Micro-simulation
Transportation Modeling

- Travel Demand Modeling

**vs.**

- Micro-simulation

### Why do micro-simulation?

- Used to forecast traffic volumes
- Used for large areas, such as a region or state
- Traffic on a road is treated in aggregate: travel times are a function of traffic volume
- Demand is generally time-invariant
Micro-simulation helps to build understanding of the level-of-service impacts on communities of transportation projects.
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    - Micro-simulation as a tool for analysts
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Micro-Simulation Modeling

How does micro-simulation modeling benefit communities and stakeholders?
Micro-Simulation Modeling

By giving analysts the means to:
- Ask and answer “what if?” questions
- Prioritize funding and projects
- Base decision-making on state-of-the-art analysis
- Engage the public through dynamic and compelling visualization

Outline
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  - TransModeler for bicycle micro-simulation
TransModeler is trip-based
TransModeler is trip-based traffic micro-simulation on a GIS platform.
TransModeler is trip-based traffic micro-simulation on a GIS platform

Outline

- Outputs of micro-simulation
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  - GIS platform
  - Traffic Micro-simulation
  - Trip-based
- TransModeler for bicycle micro-simulation
TransModeler’s GIS platform

- Bring in parcel data, land use, bodies of water, georeferenced aerial images, extrude building footprints in 3D
  - Reproduce existing and build geometry accurately
  - Integrate all of your geospatial data and insights
- Use digital elevation map (DEM) data to set segment grades
  - To say the least, hills are important to cyclists

TransModeler’s GIS platform

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Grade of 1.89

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Agents in traffic, on their on trips, interact with the road, the traffic control, and each other

Agents in traffic, on their on trips, interact with the road, the traffic control, and each other
TransModeler’s Traffic Micro-simulation

Agents in traffic, on their own trips, interact with the road, the traffic control, and each other.

Radius of 20 ft, curvature of (1/20 ft) * 1000 ft = 50 in

Segment layer

Maximum speed is constrained by the radius.

<table>
<thead>
<tr>
<th>Radius (ft)</th>
<th>Maximum Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>
TransModeler’s Traffic Micro-simulation

1,000 ft long

30 ft of elevation gain, from USGS DEM

TransModeler’s Traffic Micro-simulation

Effect on Acceleration

Impact of grade on maximum acceleration (ft/s²)

3% Grade

Effect on Max. Speed

<table>
<thead>
<tr>
<th>HPR (ft/s²)</th>
<th>Grade ≤ 2 % (mph)</th>
<th>2 to 9 % (mph)</th>
<th>9 to 2 % (mph)</th>
<th>2 to 4 % (mph)</th>
<th>Grade &gt; 4 % (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>140.0</td>
<td>120.0</td>
<td>120.0</td>
<td>119.0</td>
<td>100.0</td>
</tr>
<tr>
<td>1.97</td>
<td>50.0</td>
<td>60.0</td>
<td>50.0</td>
<td>60.0</td>
<td>50.0</td>
</tr>
<tr>
<td>2.47</td>
<td>20.0</td>
<td>50.0</td>
<td>45.0</td>
<td>35.0</td>
<td>25.0</td>
</tr>
<tr>
<td>3.29</td>
<td>25.0</td>
<td>20.0</td>
<td>15.0</td>
<td>10.0</td>
<td>5.0</td>
</tr>
<tr>
<td>3.96</td>
<td>25.0</td>
<td>20.0</td>
<td>10.0</td>
<td>7.5</td>
<td>5.0</td>
</tr>
</tbody>
</table>
TransModeler’s Traffic Micro-simulation

Agents in traffic, on their on trips, interact with the road, the traffic control, and each other.

<table>
<thead>
<tr>
<th>Lane Width Factor</th>
<th>Change in Desired Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.0</td>
<td>0.0</td>
</tr>
<tr>
<td>11.0</td>
<td>-1.9</td>
</tr>
<tr>
<td>10.0</td>
<td>6.6</td>
</tr>
</tbody>
</table>
TransModeler’s Traffic Micro-simulation

Agents in traffic, on their on trips, interact with the road, the traffic control, and each other.
TransModeler’s Traffic Micro-simulation

Agents in traffic, on their on trips, interact with the road, the traffic control, and each other.

Vehicles actuate and extend actuated traffic signals.
TransModeler’s Traffic Micro-simulation

Agents in traffic interact with the road, the traffic control, and each other signaling to move left.

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TransModeler’s Trip-Based Demand

- Every vehicle has an origin, destination, departure time, and attributes, such as vehicle type and proclivity for speeding, which are all drawn from probability distributions.
- Vehicles route themselves on their dynamic, stochastic shortest path.
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Finally, some bicycles!
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Bicycles on the GIS Platform

- Bike lanes
- Configuring signal detector actuation
Bicycles on the GIS Platform

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- Configuring signal detector actuation
Bicycles on the GIS Platform

- Bike lanes

Sensor is configured not to measure or detect Non-Motorized Vehicles (NMV), including bicycles.

This sensor is being actuated by this motorized vehicle.
This is the big stuff, the complicated stuff: how vehicles, motorized and not, interact with each other.
Bicycle Traffic Micro-Simulation

- Lateral Movement Within a Lane
- Stopped Gaps
- Desired Speed
- Following Distance & Acceleration
- Lane Changing Gap Acceptance
- Critical Distance
Bicycle Traffic Micro-Simulation

- Lateral Movement Within a Lane
- Stopped Gaps

Bicycles and Motorcycles - Lateral Movement

<table>
<thead>
<tr>
<th>Class</th>
<th>Outside Lane</th>
<th>Lower</th>
<th>Upper</th>
<th>Beta</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td></td>
<td>0.50</td>
<td>4.00</td>
<td>0.250</td>
<td>10.0</td>
</tr>
<tr>
<td>8K</td>
<td></td>
<td>0.30</td>
<td>2.50</td>
<td>0.200</td>
<td>10.0</td>
</tr>
</tbody>
</table>

\[ w_l = L + \frac{1 - e^{-\beta v_l}}{1 + e^{-\beta v_l}} (U - L) \]

Cyclists have a ‘bubble’ around them – a function of speed – that determines whether they can pass each other in the same lane.
Bicycle Traffic Micro-Simulation

- Lateral Movement Within a Lane
- **Stopped Gaps**
- Desired Speed
- Following Distance & Acceleration
- Lane Changing Gap Acceptance
- Critical Distance
- Grade
- Lane Choice

**Gaps between Stopped Vehicles**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mean (ft)</th>
<th>Standard deviation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-motorized vehicle in front</td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Motorized vehicle in front</td>
<td>6.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Bicycle Traffic Micro-Simulation

- Lateral Movement Within a Lane
- Stopped Gaps
- Desired Speed
  - Following Distance & Acceleration
  - Lane Changing Gap Acceptance
  - Critical Distance

*Desired Speed* determines the amount of space left between vehicles at a stop – affects the storage capacity of a segment.
Desired speed is generally defined as a deviation from the speed limit – bicycles operate in a different paradigm.
Bicycle Traffic Micro-Simulation

- Lateral Movement Within a Lane
- Stopped Gaps
- Desired Speed
- **Following Distance & Acceleration**
- Lane Changing Gap Acceptance
- Critical Distance

### Bicycles and Motorcycles - Forward Movement

<table>
<thead>
<tr>
<th>Class</th>
<th>Lower (ft)</th>
<th>Upper (ft)</th>
<th>Beta</th>
<th>Distance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BK</td>
<td>9.00</td>
<td>25.00</td>
<td>0.500</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Maximum speed passing non-motorized vehicle in the same lane (mph): 25.0
Maximum speed passing non-motorized vehicle in the next lane (mph): 25.0

### Distance Headway Thresholds and Variance of Acceleration

<table>
<thead>
<tr>
<th>Percentage (%)</th>
<th>Distance (ft)</th>
<th>Decelerating (ft/s²)</th>
<th>Constant (ft/s²)</th>
<th>Accelerating (ft/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.0</td>
<td>5.0</td>
<td>-0.10</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>50.0</td>
<td>5.0</td>
<td>-0.10</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>20.0</td>
<td>5.0</td>
<td>-0.10</td>
<td>0.00</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Bicycle Traffic Micro-Simulation

Configuration of the acceptable following distance while traveling and speeds at which to pass a bicycle.

Additionally, a motorist will shift over to pass a cyclist in a narrower lane that impinges on a cyclist’s ‘bubble’.
Bicycle Traffic Micro-Simulation

- Non-motorized Vehicles and Following Distance
- Configuration of acceleration profile used when attempting to achieve desired following distance
- Desired Speed
- Following Distance & Acceleration
- Lane Changing Gap Acceptance
- Critical Distance
### Bicycle Traffic Micro-Simulation

- **Lateral Movement Within a Lane**
- **Stopped Gaps**

#### Gap Acceptance Model

<table>
<thead>
<tr>
<th></th>
<th>NHV/Lead</th>
<th>NHV/Lag*</th>
<th>Motorized/Lead</th>
<th>Motorized/Lag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum (ft)</td>
<td>3.28</td>
<td>4.32</td>
<td>5.56</td>
<td>13.12</td>
</tr>
<tr>
<td>Followed slower (fps)</td>
<td>0.051</td>
<td>0.046</td>
<td>0.046</td>
<td>0.030</td>
</tr>
<tr>
<td>Followed faster (fps)</td>
<td>0.137</td>
<td>0.137</td>
<td>0.152</td>
<td>0.305</td>
</tr>
<tr>
<td>Followed speed (fps)</td>
<td>0.076</td>
<td>0.081</td>
<td>0.163</td>
<td>0.315</td>
</tr>
<tr>
<td>Sigma ($)</td>
<td>3.281</td>
<td>4.321</td>
<td>3.381</td>
<td>4.921</td>
</tr>
</tbody>
</table>

- NHV = Non-Motorized Vehicle

Lane-changing takes into account the types, speeds, and locations of the vehicles in the neighboring lane.
Bicycle Traffic Micro-Simulation

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- Stopped Gaps
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Bicycle Traffic Micro-Simulation

- Lateral Movement Within a Lane

  Distance upstream of a movement not accessible from a reserved bike lane that a cyclist moves out of the bicycle lane

- Stopped Gaps
- Desired Speed
- Following Distance & Acceleration
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Bicycle Traffic Micro-Simulation

- Work to be done:
  - Very high density situations are difficult to properly simulate:

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    - Trip-based demand
Bicycles as Trip-Based Demand

- Vehicles calculate shortest path across specified link travel times and turning movement delays
- These costs can be generalized to reflect the perceived cost to a cyclist
  - Presence of bicycle lane or cycletrack
  - Segment grades
  - Volume of traffic

Some research exists (e.g. Hood, Sall, & Charlton 2011) and more would be nice on bicycle path choice: what is a cyclist's cost function?
Bicycles as Trip-Based Demand

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Conclusion

TransModeler’s bicycle micro-simulation can be used as a tool for the visualization and analysis of cycling-related transportation projects.
Conclusion

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Conclusion
Thank you

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