Corridor-Level Queuing Prediction Model

August 8, 2012

Jeffrey Taylor & Dr. Xuesong Zhou
University of Utah
Overview

• Key Modeling Concepts
• Methodology
  – Queue model
  – Stochastic inputs
• Corridor Analysis Spreadsheet
Key Modeling Concepts

• Simplified corridor representation

• Modeled as self-contained system
  – Stochastic capacity, demand (inflow, outflow)
  – Vertical queue model for internal dynamics
  – User-specified conditions (weather, incidents, special events, etc.)
Key Modeling Concepts

• Sampling-based approach
  – Generate many random instances, representing a day or scenario
  – Use sampled travel time to construct distribution

• Vehicle trajectory-based approach
  – “Simulate individual vehicle trajectories based on stochastic bottleneck capacity”
Model Assumptions

1. First-In-First-Out (FIFO) conditions along corridor
2. Vertical/point queue model can be used to describe the queues along the corridor
3. Ramps (merge and diverge links) are located before vertical queue
4. Queue discharge rates and net ramp flow rates are constant over prediction horizon

Implicit Assumptions:
1. Travel time variability attributed primarily to variation in supply and demand, queues
2. FIFO, vertical queue is reasonable approximation to internal traffic flow dynamics
Methodology

• Corridor is a series of potential bottlenecks

• Given stochastic bottleneck capacity, net ramp flow rates, and number of vehicles on each link
  – Simulate the end-to-end travel time for a sample of probe vehicles passing through corridor under varying supply/demand conditions
Methodology

• Step 1: Calculate arrival time at bottleneck
• Step 2: Calculate number of vehicles behind queue
• Step 3: Calculate delay
• Step 4: Update end-to-end travel time
Notation

FFTA = Free-flow time of arrival to queue
n = Number of vehicles on link when probe vehicle entered corridor
V = Vehicles preceding probe vehicle
L = Queue length (# of vehicles)
W = Waiting time in queue (min)
Fnet = Net flow at ramps (veh/hr)
m = Index for bottlenecks
Methodology

• Step 1: Calculate arrival time (FFTA) at bottleneck

\[ FFTA_m = FFTA_{m-1} + W_{m-1} + FFTT_m \]
Methodology

• Step 2: Calculate number of vehicles behind queue

\[ V_m = \max(0, n_m + F_{net} m \times FFTA_m + V_{m-1}) \]

\[ n_m = \text{Density}_m \times \text{LinkLength}_m \]

\( V_m \) = Number of Vehicles Before Probe Vehicle

\( V_{m-1} \) = Vehicles before probe from previous link

\( n_m \) = Vehicles already on link at start time
Methodology

- Step 3: Calculate delay

\[ L_m = \max(0, V_m - Cap_m \times FFTA_m) \]

\[ W_m = L_m / Cap_m \]
Methodology

• Step 4: Update end-to-end travel time

\[ FFTA_m = FFTA_{m-1} + W_{m-1} + FFTT_m \]
Queue Prediction Spreadsheet
Component Worksheets

- Inputs
- Random Number Generation
- Calculations
- Histograms
- Outputs
- Vehicle Trajectory Data
- MOEs & Visualization
Inputs

- Density, capacity, and ramp flow rates
  - Different conditions
- Link attributes
  - Length, FFTT, Ramp flags, condition flags/probabilities

<table>
<thead>
<tr>
<th>Link ID</th>
<th>Length (mi)</th>
<th>FFTT (min)</th>
<th>Incident Prob. (%)</th>
<th>Ramp Flag</th>
<th>Density (vpmpl)</th>
<th>Capacity (vphpl)</th>
<th>Ramp Flow Rate (vphpl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>-1</td>
<td>100</td>
<td>1800</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>-1</td>
<td>100</td>
<td>1800</td>
<td>300</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>100</td>
<td>1800</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>-1</td>
<td>100</td>
<td>1800</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>-1</td>
<td>100</td>
<td>1800</td>
<td>300</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>100</td>
<td>1800</td>
<td>300</td>
</tr>
</tbody>
</table>
Random Number Generation

• Secondary input for simulation
  – Three variables per link * # of probe vehicles
  – Normal distribution N(0,1)

• Used to randomly generate input density, capacity, and ramp flows for each link
  – Translated to Log-Normal distribution
Calculations

• For each probe vehicle, entering each link
  – Calculate FFTA, Preceding vehicle count, Queue length, Waiting time, and Link travel time
  – Update variables at next link/bottleneck
Histograms

• Analyze inputs and outputs
  – Inputs: Density, capacity, ramp flow
  – Outputs: Delay, travel time

• Future revisions
  – Dynamic histogram bins
## Outputs

- Mean & variance for density, capacity, ramp flow rate, and travel time
- Corridor modeling checks

### Table

<table>
<thead>
<tr>
<th>Link ID</th>
<th>Length (mi)</th>
<th>FTT (min)</th>
<th>Incident Prob. (%)</th>
<th># Lanes</th>
<th>Ramp Flag</th>
<th>Sample Density (vppmi)</th>
<th>Sample Capacity (vphp)</th>
<th>Sample Ramp Flow (vphp)</th>
<th>Sample Travel Time (min)</th>
<th>Basic Corridor Modeling Checks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MEAN</td>
<td>VAR</td>
<td>MEAN</td>
<td>VAR</td>
<td>MEAN</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>98.4</td>
<td>336.5</td>
<td>1789.0</td>
<td>165142</td>
<td>300.4</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>100.1</td>
<td>384.9</td>
<td>1815.1</td>
<td>159367</td>
<td>-306.6</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>99.9</td>
<td>438.7</td>
<td>1757.8</td>
<td>156386</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>98.4</td>
<td>368.5</td>
<td>1774.1</td>
<td>183617</td>
<td>257.8</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>100.4</td>
<td>361.0</td>
<td>1750.7</td>
<td>128742</td>
<td>-320.4</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>99.1</td>
<td>367.0</td>
<td>1802.2</td>
<td>162314</td>
<td>0.0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>101.7</td>
<td>372.0</td>
<td>1747.0</td>
<td>152356</td>
<td>290.6</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>100.8</td>
<td>365.2</td>
<td>1832.8</td>
<td>154325</td>
<td>-307.0</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>99.7</td>
<td>499.1</td>
<td>1776.0</td>
<td>150249</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>99.7</td>
<td>499.1</td>
<td>1774.2</td>
<td>153685</td>
<td>256.6</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>99.0</td>
<td>398.1</td>
<td>1754.6</td>
<td>172272</td>
<td>-196.0</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>100.0</td>
<td>365.9</td>
<td>1759.8</td>
<td>158558</td>
<td>0.0</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>100.3</td>
<td>381.0</td>
<td>1772.2</td>
<td>128858</td>
<td>322.2</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>100.5</td>
<td>402.9</td>
<td>1750.0</td>
<td>150962</td>
<td>-303.8</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>97.9</td>
<td>372.6</td>
<td>1853.4</td>
<td>177352</td>
<td>0.0</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>100.6</td>
<td>415.0</td>
<td>1781.2</td>
<td>163912</td>
<td>316.1</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>98.8</td>
<td>372.2</td>
<td>1794.5</td>
<td>127847</td>
<td>286.6</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>98.8</td>
<td>388.7</td>
<td>1788.2</td>
<td>158537</td>
<td>0.0</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>102.1</td>
<td>377.9</td>
<td>1820.8</td>
<td>166987</td>
<td>300.8</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>101.4</td>
<td>392.0</td>
<td>1782.1</td>
<td>164140</td>
<td>-303.3</td>
</tr>
</tbody>
</table>
Outputs

<table>
<thead>
<tr>
<th>Travel Time Reliability Performance Measures</th>
<th>Travel Time Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure</td>
<td>Value</td>
</tr>
<tr>
<td>Buffer Index</td>
<td>1.27</td>
</tr>
<tr>
<td>Buffer Time (min)</td>
<td>135.85</td>
</tr>
<tr>
<td>Planning Time Index</td>
<td>12.12</td>
</tr>
<tr>
<td>Travel Time Index</td>
<td>5.33</td>
</tr>
<tr>
<td>Misery Index</td>
<td>14.15</td>
</tr>
</tbody>
</table>

Corridor Travel Time

Avg. & Percentile Travel Time

![Graph showing travel time distribution and percentile analysis.]
Outputs/Visualization
Thank You!

Questions?