DEVELOPMENT OF MANAGED LANE MODEL BASED ON MESO-SCOPIC SIMULATION APPROACH

NCDOT MUG Meeting

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Heejoo Ham, Citilabs
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OVERVIEW

• Managed Lanes?
• Mesoscopic Simulation Model
• Managed Lane Modeling
• Application of Model
• Model Validation by O-D Matrix Estimation
MANAGED LANES?

FHWA says “Managed Lanes are defined as highway facilities or a set of lanes where operational strategies are proactively implemented and managed in response to changing conditions.”

Source: Freeway Management System, Federal Highway Administration, US Department of Transportation
(http://ops.fhwa.dot.gov/freewaymgmt/mngd_lns_hov.htm)
TYPES OF MANAGED LANES (ML)

- High Occupancy Vehicles (HOV)
- High Occupancy Toll (HOT) Lanes
- Express Toll Lanes (ETL)
- Truck Only Toll (TOT)
- Open Road Tolling
- Dynamic Tolling
- Transit/Busway
- Pre-pay and/or Pay per use (toll booths)
- ITS Solutions (Traffic calming, speed advisories, incident management)
HIGH OCCUPANCY TOLL (HOT) LANES

Source: We Want Toll Lanes Done Right, The Transit Coalition (2012)
EXPRESS TOLL LANES (ETL)

Source: Florida Department of Transportation (2013)
Mesoscopic Simulation Model
Mesoscopic models try to find a middle group between macro and micro models.

Vehicles are analysed as “packets” of vehicles by studying fundamental variables (flow, speed, density).

Mesoscopic models techniques can study traffic flows over time (Dynamic).

Mesoscopic models the lowest-cost path for the traffic volume for each packet of vehicles.

Mesoscopic models compute congestion effect, through volume-capacity rations and also interaction among vehicles units (“packets of vehicles”).
COMPARISON OF SIMULATION MODELS

- Macro-meso-micro methods can be most easily distinguished by how they represent flow and evaluate congestion.
- Flow can be either continuous (streams) or discrete (vehicles/packets).
- Performance functions can be either aggregate (evaluated for a whole time interval) or disaggregate (evaluated for individual flow quanta).

<table>
<thead>
<tr>
<th>Typology of assignment models</th>
<th>Performance functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Representation</td>
<td>Aggregate</td>
</tr>
<tr>
<td>Continuous</td>
<td>MACRO</td>
</tr>
<tr>
<td>Discrete</td>
<td>MESO</td>
</tr>
</tbody>
</table>
During the “model period” the following variables are constant and do not change:

- Origin-destination flows (travel demand)
- Routing and path proportions
- Link flows (vehicle volumes)
- Link costs (congested times)
- Path costs (origin-destination skims)

These models process time-varying inputs and outputs.

- **Inputs:**
  - Time-varying origin-destination travel demand (flow per time segment)
  - Average link costs by time segment
  - Capacities (max flow/period by segment)

- **Outputs:**
  - Dynamic path/link flows (total entering vehicles by time segment) and path/link costs
  - Simulation-based record of actual trajectories
## COMPARISON BETWEEN STATIC & DYNAMIC ASSIGNMENTS

### Static Assignment
- A vehicle exists everywhere along its route during period
- Variables do not change over the duration of the period to be modelled
- Capacity constraints not strictly enforced; $V/C > 1$
- No link storage constraint
- Link volumes and costs are separable and independent
- Time = Link Travel Time + Junction Delay (if using)

### Dynamic Assignment
- Simulated packets can only be in one place at a time
- Model period divided into “time segments” with varying flow rates
- Capacity strictly enforced using “flow gates”
- Storage strictly enforced
- Simulation of queues affects preceding link volume, cost
- Time = Link Travel Time + Queue Time + Junction Delay (if using)
• The model duration is explicitly defined and divided into smaller time segments

The demand is assumed to be constant during each time segment
An internal random number generator randomly draws a departure time for each packet departing in a given interval.
EVENT-BASED SIMULATION

- Simulation processes events as they are encountered by packets moving along their paths.
- Packets can be in one of two states:
  - Moving on a link
  - In queue (waiting on a link)
- A vehicle may have to wait if:
  - Cars leaving a link exceed its exit flow capacity (Capacity Constraints)
  - Cars entering a link exceed its entrance flow capacity (Capacity Constraints)
  - There is no room for it on the next link (Storage Constraints)
- These criteria are evaluated by A-B-C movement.
- Turn capacity is also checked if output by a junction model (intersection analysis, e.g. HCM 2010).
- Constraint is the minimum of constraints at node.
MINIMUM HEADWAY and STORAGE

- Capacity and storage constraints are maintained by “gates” on each link
- In practice, minimum headway is used rather than maximum flow
- Consider a 2-lane freeway link with per-lane flow capacity of 1800 vehicles per hour and total flow capacity of 3600 vehicles per hour:
  - This is equivalent to a headway (or gap) of one sec/vehicle
  - So if a packet with two vehicles arrives at the gate, it cannot leave the link any sooner than two seconds after the packet ahead of it.
Mesoscopic Simulation Model

QUEUE PROPAGATION

Backing up (0:20:15)

Queue begins to form on link 104-105 due to flow constraint on 105-106

Queuing (0:38:07)

Flow to zone 2 continues unimpeded because it does not use link 104-105

Flow to zone 3 queues on link 100-104 because there is no room on 104-105

Blocked (1:04:27)

Flow rate to zone 2 is now the same as at the link 105-106 bottleneck

Link 100-104 fills, blocking flow to either destination on link 103-100
MESOSCOPIC MODELING APPLICATIONS

A mesoscopic model allows to complete new types of analyses:

- Quantify impact of upstream traffic congestion
- Measure queuing at intersection and merge points in a network
- Isolate secondary impacts from one intersection through another
- Evaluate the benefits of ITS (Intelligent Transportation System) projects
- Simulate alternative infrastructure, operational and policy changes to optimise
- Emergency evacuation plans and strategies
- Test strategies to improve arrival and departure from stadiums and other special event facilities
- ...

Managed Lane Modeling
PROCEDURE FOR MANAGED LANE MODELING

1. Model Settings
2. Skimming (Time & Toll) by each Time Segment
   - Toll Diversion Process
     - Willingness to Pay Curve or Logit Model
     - Free O-D Trips
     - Toll O-D Trips
3. Avenue Assignment by each Time Segment
4. Computation of V/C
5. Update of Toll Cost
   - Toll Cost Look-up Table or Exponential Function
MAJOR CONCERNS IN MODEL DEVELOPMENT

• Toll diversion model (Free vs. Toll)
  – Willingness-to-pay curve
  – Binary logit model

• Update of toll cost
  – Lookup table by V/C
  – Lookup table by density
  – Using exponential formula

• Toll update process in Avenue
  – Iteration-by-iteration basis
  – Time segment-by-time segment basis
TOLL DIVERSION TYPE 1: WILLINGNESS-TO-PAY CURVE

Toll Cents per Minute Saved = \( \frac{\text{Total toll cost (cents) for toll route}}{\text{Free route time (min)} - \text{Toll route time (min)}} \)

- Demand% is the share of toll trips.
TOLL DIVERSION TYPE 2: BINARY LOGIT MODEL (1/2)

\[ P_{toll} = \frac{1.0}{1.0 + e^{[\alpha(T_{toll}-T_{free})+\beta(C_{toll})]}} \times 100\% \]

Where,

- \( P_{toll} = \) toll trip proportion (%) for toll route
- \( T_{toll} = \) travel time (min) for toll route
- \( T_{free} = \) travel time (min) for free route
- \( C_{toll} = \) total toll cost ($) for toll route
- \( \alpha = \) coefficient for time
- \( \beta = \) coefficient for toll cost
TOLL DIVERSION TYPE 2: BINARY LOGIT MODEL (2/2)
DYNAMIC TOLL COST UPDATE TYPE 1: BY V/C

- Referred on the final report of “Managed lane modeling application for FSUTMS (Phase I)”
DYNAMIC TOLL COST UPDATE TYPE 2: BY LINK DENSITY (1/2)

- Referred on “Florida Department of Transportation District VI Standard Operating Guidelines”

<table>
<thead>
<tr>
<th>LOS</th>
<th>Road Density</th>
<th>Toll Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>A</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>C</td>
<td>19</td>
<td>26</td>
</tr>
<tr>
<td>D</td>
<td>27</td>
<td>35</td>
</tr>
<tr>
<td>E</td>
<td>36</td>
<td>45</td>
</tr>
<tr>
<td>F</td>
<td>&gt;45</td>
<td></td>
</tr>
</tbody>
</table>
DYNAMIC TOLL COST UPDATE TYPE 2: BY LINK DENSITY (2/2)

- Unit: Vehicles per Mile per Lane (VPMPL)

\[
\text{Link Density} = \frac{\text{Hourly Link Volumes} \div \text{Lanes}}{\text{Link Speed} \ (\text{mph})}
\]
DYNAMIC TOLL COST UPDATE TYPE 3: EXPONENTIAL FORMULA

\[ TOLL = 0.05 \times EXP\left(\frac{V}{C} \times 6\right) \]
**HOW TO UPDATE TOLLS** (1/2)

- Update of toll costs by an iteration-by-iteration process

```markdown
<table>
<thead>
<tr>
<th>Time Segment</th>
<th>Initial Toll</th>
<th>Road Density</th>
<th>Updated Toll</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0.25</td>
<td>22</td>
<td>$2.04</td>
</tr>
<tr>
<td>2</td>
<td>$0.25</td>
<td>18</td>
<td>$1.25</td>
</tr>
<tr>
<td>3</td>
<td>$0.25</td>
<td>26</td>
<td>$2.75</td>
</tr>
</tbody>
</table>

**< Iteration: 2 >**

<table>
<thead>
<tr>
<th>Time Segment</th>
<th>Toll from Iter# 1</th>
<th>Road Density</th>
<th>Updated Toll</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$2.04</td>
<td>20</td>
<td>$1.68</td>
</tr>
<tr>
<td>2</td>
<td>$1.25</td>
<td>27</td>
<td>$3.00</td>
</tr>
<tr>
<td>3</td>
<td>$2.75</td>
<td>24</td>
<td>$2.39</td>
</tr>
</tbody>
</table>
```

**ITERLOADINC = 0**

**MAXITERS = 2**

Managed Lane Modeling
## HOW TO UPDATE TOLLS (2/2)

- Update of toll costs by a time segment-by-time segment process

### Iteration Table

<table>
<thead>
<tr>
<th>Time Segment: 1</th>
<th>Iteration</th>
<th>Initial/current Toll</th>
<th>Road Density</th>
<th>Updated Toll</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>$0.25</td>
<td>20</td>
<td>$1.68</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>$1.68</td>
<td>16</td>
<td>$1.00</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>$1.00</td>
<td>19</td>
<td>$1.50</td>
</tr>
</tbody>
</table>

### Iteration Table

<table>
<thead>
<tr>
<th>Time Segment: 2</th>
<th>Iteration</th>
<th>Initial/current Toll</th>
<th>Road Density</th>
<th>Updated Toll</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>$0.25</td>
<td>28</td>
<td>$3.10</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>$3.10</td>
<td>23</td>
<td>$2.00</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>$2.00</td>
<td>25</td>
<td>$2.57</td>
</tr>
</tbody>
</table>

### Iteration Table

<table>
<thead>
<tr>
<th>Time Segment: 3</th>
<th>Iteration</th>
<th>Initial/current Toll</th>
<th>Road Density</th>
<th>Updated Toll</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>$0.25</td>
<td>22</td>
<td>$2.04</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>$2.04</td>
<td>24</td>
<td>$2.39</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>$2.39</td>
<td>20</td>
<td>$1.68</td>
</tr>
</tbody>
</table>

- \( \text{ITERLOADING} = 2 \)
- \( \text{MAXITERS} = 3 \)
MAJOR CONCERNS IN HIGHWAY NETWORK

• Review of short links
  – Use of true shape
  – Use of consolidating process in Cube

• Review for short of link storages
  – Use of packet animation in Avenue to see the traffic queue locations

• Review for short of link capacities
EXAMPLES OF NETWORK DIAGNOSTIC CHECK (1/2)

The ramps are adjusted by the true shape.
EXAMPLES OF NETWORK DIAGNOSTIC CHECK (2/2)

The short ramps cause the queues of vehicles due to the low storages.
Application of Model
CORRIDOR OF STUDY

- I-95 HOT facility in Miami
TOLL ENTRANCES IN I-95 HOT LANES

- Two southbound locations
- Two northbound locations
- It is assumed that each direction utilizes the same toll rate in both locations.
- The dynamic toll values are estimated based on the largest density for each directional road on the I-95 HOT corridor.
## MAJOR INPUT & OUTPUT DATA

<table>
<thead>
<tr>
<th>File Type</th>
<th>File Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input File</strong></td>
<td>DTA_Highway.NET</td>
<td>Input Cube highway network (*.NET)</td>
</tr>
<tr>
<td></td>
<td>SOV_TS_12.MAT</td>
<td>O-D vehicle trips for drive alone (DA) &amp; two persons (SR2) modes by 12 time segments</td>
</tr>
<tr>
<td></td>
<td>SR3_TS_12.MAT</td>
<td>O-D vehicle trips for three or more persons (SR3P) mode by 12 time segments</td>
</tr>
<tr>
<td></td>
<td>Truck_TS_12.MAT</td>
<td>O-D vehicle trips for truck mode by 12 time segments</td>
</tr>
<tr>
<td></td>
<td>NoWilling_to_Pay_Properties.dbf</td>
<td>Non-willing to pay proportions (%) for toll diversion process</td>
</tr>
<tr>
<td></td>
<td>TollCost_by_Density.dbf</td>
<td>Toll rates ($) by by road density (vehicles per mile per lane)</td>
</tr>
<tr>
<td><strong>Output File</strong></td>
<td>DTA_Managed_Lanes_Loaded.NET</td>
<td>Output loaded network (*.NET)</td>
</tr>
<tr>
<td></td>
<td>DTA_Managed_Lanes_Loaded.LOG</td>
<td>Packet log from assignemnt</td>
</tr>
</tbody>
</table>
REQUIREMENTS IN INPUT HIGHWAY NETWORK

- Link distance (mile)
- Link capacity (hourly or period)
- Link facility type
- Number of lanes
- Free flow speed (mph)
- Link storage (e.g. 220 vehicles per mile)
- Alpha and Beta for BPR function
- HOT corridor indicators
- Toll facility locations
- Initial toll costs
SETTING OF 12 TIME SEGMENTS

- Each time segment – 15 min
- 3 hours period (180 min)
- 12 time segments (=180/15)
OUTPUT – MAJOR OUTPUT FILES

- Skim matrices (Time & Tolls)
- SOV+HOV2 toll O-D trips
- SOV+HOV2 free O-D trips
- Loaded highway network
- Packet log
OUTPUT – LOADED NETWORK (1/2)

Toll Costs

Assigned Volumes
**OUTPUT – LOADED NETWORK (2/2)**

- Queues in HOT entrance
- Vehicles in Transit (VIT)
- Blocked vehicles
OUTPUT – VEHICLE ANIMATION (1/2)
OUTPUT – VEHICLE ANIMATION (2/2)

Northern HOT entrance

Southern HOT entrance
Application of Model

OUTPUT – VOLUME & QUEUE ANIMATION
Model Validation by O-D Matrix Estimation
STATIC & DYNAMIC O-D ESTIMATION

- Run Regional Model
- TDM Subarea Analysis for Project Area
- Subarea Network
- Static O-D Estimation for Model Period using Cube Analyst Drive
- Major Corridor Counts
- O-D Trips by Time Segment
- Land Use Data
- Dynamic O-D Estimation by Time Segments using Cube Analyst Drive
- Using All Counts
- Managed Lane Model Calibration & Validation
THANK YOU!

Any questions?

Heejoo Ham
hham@citilabs.com
generalsupport@citilabs.com