Framework for Multi-Resolution Analyses of Advanced Traffic Management Strategies

Mohammed Hadi, Thomas Hill, and Vladimir Majano
Agenda

- Introduction to Multi-Resolution Modeling (MRM)
- MRM Framework
- Case Study: I-95 Managed Lane Corridor
Role of Analysis Tools

- Identification of deficiencies in design and/or operations
- Support assessing system, corridor, and segment performance
- Impacts of influencing factors (incidents, weather, etc.)
- Assessment of advanced strategies
- Prioritization of alternatives
- Forecasting future conditions
- Off-line and real-time support of traffic operations and management
- Connected and automated vehicle modeling
- Hardware, software, and driver in the loop
### Planning for Operations (Source: FHWA)

<table>
<thead>
<tr>
<th>Transportation Planning Needs</th>
<th>OPERATIONAL ANALYSIS TOOLS/METHODS</th>
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</thead>
<tbody>
<tr>
<td>Needs Assessments/Deficiency Analysis</td>
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<tr>
<td>Preliminary Screening Assessments</td>
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<tr>
<td>Alternatives Analysis</td>
<td>•</td>
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<tr>
<td>Strategic ITS Planning</td>
<td>•</td>
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<tr>
<td>Project Scoring/Ranking/Prioritizing</td>
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<tr>
<td>Corridor and Environmental Analysis</td>
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<tr>
<td>Planning for Nonrecurring Congestion</td>
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<td>Performance Monitoring</td>
<td>•</td>
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<tr>
<td>Evaluations of Developed Projects</td>
<td>•</td>
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</tbody>
</table>
Traffic Analysis Handbook
A Reference for Planning and Operations

Systems Planning Office

2014

March 2014
Chapters
1. Introduction
2. Methodology
3. Analysis Area
4. Tool Selection
5. Data Collection
6. Analytical Tools
7. Microsimulation Analysis
8. Alternatives Analysis
9. Documentation

Applicable Traffic Analysis
- Corridor studies,
- Interchange Access Requests (IARs)
- Project Development and Environment (PD&E) studies.

Level of Analysis
- Generalized planning (sketch-level)
- Conceptual planning and Preliminary Engineering
- Design
- Operational
Chapter 4
Analysis Tool Selection

Traffic Tools used in Florida:
- Generalized Service Volume Tables (GSVT)
- LOSPLAN
- HCM/HCS
- Synchro and SimTraffic
- SIDRA INTERSECTION
- CORSIM
- VISSIM

Recommendations:
- Apply one set of tools consistently
- Select appropriate tools based on
  - Level of analysis effort
  - Degree of detail
  - Limitation of the tool
- More than one tool might be needed
Fig. 4-1 Categories of Traffic Analysis Tools

- Generalized Planning
- Conceptual Planning
- Preliminary Engineering, Design and Operational

Increasing Degree of Detail and Accuracy

- VISSIM / CORSIM
- SYNCHRO
- SIMTRAFFIC
- SIDRA
- HCM/HCS
- LOSPLAN
- GSVT

Deterministic/Analytical Tools
Microscopic Simulation Tools

Increasing Level of Analysis Effort and Complexity
## Table 4-1 Use of Traffic Analysis Tools

<table>
<thead>
<tr>
<th>Analysis Type</th>
<th>Level of Detail</th>
<th>Level of Analysis</th>
<th>Analysis Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketch Planning</td>
<td>Analyzing system elements to obtain general order-of-magnitude estimates of performance based capacity constraints and operational control</td>
<td>Generalized Planning</td>
<td>GSVT, LOSPLAN, HCM/HCS</td>
</tr>
<tr>
<td>Deterministic</td>
<td>Analyzing broad criteria and system performance based on geometric and physical capacity constraints; operational systems such traffic control and land use</td>
<td>Conceptual Planning &amp; Preliminary Engineering; Design: Operation</td>
<td>LOSPLAN, HCM/HCS, Synchro; SIDRA</td>
</tr>
<tr>
<td>Travel Demand Modeling</td>
<td>Analyzing regional travel demand patterns, land use impacts and long range plans. Outputs of demand models are applied in analytical and microscopic analysis</td>
<td>Conceptual Planning</td>
<td>Cube Voyager</td>
</tr>
<tr>
<td>Microscopic Simulation</td>
<td>Analyzing system performance based on detailed individual user interactions; geometry and operational elements</td>
<td>Preliminary Engineering; Design: Operation</td>
<td>CORSIM, VISSIM, SimTraffic</td>
</tr>
</tbody>
</table>
Which Tool is Appropriate?

- It depends on the project complexity, goals, time, budget and performance measures
- Tradeoff between resources versus decisions
- Review tool capabilities
## Table 4-2. Traffic Analysis Software by System Element

<table>
<thead>
<tr>
<th>Facility</th>
<th>Level of Analysis</th>
<th>Project Need</th>
<th>Performance MOE</th>
<th>Recommended Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Arterials</td>
<td>Generalized Planning</td>
<td>Determining a need for additional capacity</td>
<td>LOS</td>
<td>GSVT, LOSPLAN</td>
</tr>
<tr>
<td></td>
<td>Conceptual Planning</td>
<td>Determining number of lanes</td>
<td>LOS</td>
<td>LOSPLAN, HCM/HCS</td>
</tr>
<tr>
<td></td>
<td>Preliminary Engineering and Design</td>
<td>Determining how the facility will operate</td>
<td>Speed</td>
<td>HCS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Optimizing signals</td>
<td>Control delay, queue, V/C ratio</td>
<td>SYNCHRO/ SIMTRAFFIC</td>
</tr>
<tr>
<td></td>
<td>Operational</td>
<td>Coordinating traffic signals</td>
<td>Travel time, speed</td>
<td>SYNCHRO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evaluating existing signal timing plans</td>
<td>Travel time, speed</td>
<td>HCS, SYNCHRO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Checking the effect of technology application or traffic demand management strategy</td>
<td>Travel time, speed</td>
<td>SYNCHRO/ SIMTRAFFIC, VISSIM,CORSIM</td>
</tr>
</tbody>
</table>
Traffic Analysis Handbook (2014) does not include:

- Multi-Resolution modeling
- Traffic Analysis on Managed Lanes
- Multimodal Transportation Alternative Studies
Needs for Multi-Resolution Modeling Framework

- Modeling congested conditions
- Multi-modal modeling
- Support planning for operations and operational aspects of TSM&O
  - Managed Lanes & Dynamic Pricing
  - Advanced Signal Control
  - Smart Work Zones
  - ATDM
  - ICM
  - ITS
  - Other operational strategies
Multi-Resolution Modeling

Macroscopic
- Cube Voyager
- VISUM (DTA)
- HCM/HCS
- FITSEVAL

Mesoscopic
- Cube Avenue (DTA)
- Dynasmart (DTA)
- DynusT (DTA)
- DTALite (DTA)
- DIRECT (DTA)

Microscopic
- VISSIM (DTA)
- CORSIM
- AIMSUN

Dynamic Traffic Assignment (DTA)
Multi-Resolution Modeling Types

- **Isolated Models**
  - Regional Demand Model
    - Meso
    - Micro

- **Partial Multiresolution Models**
  - Trip tables from Regional Models feeding either Meso or Micro
  - Regional Demand Model
  - Meso-DTA
  - Micro-DTA

- **Full Multiresolution Models**
  - Interactions between Regional Demands to Meso and Meso to Micro
  - Regional Demand Model
  - Meso-DTA
  - Micro-DTA
Research Objectives

• Investigate the ability of combinations of tools in analyzing congestion and advanced strategies

• Recommend a framework for use in support of agency analysis and modeling processes

• Apply and assess the utilization of tools in the modeling of use cases
Proposed MRM Framework Components

Data Sources

- Regional Planning Model
  - FSUTMS

  Network Data
  Demand Data

- Additional Data Sources

  Signal Data*
  Other Data*

- ITSDCAP

- Data Archives and Analytics
Data Needs

• Data from multiple sources both conventional and new
• Increased emphasis on data from multiple days
  – Allow identifying different operational conditions (operational scenarios)
  – Allow identifying representative days
  – Allow isolating out unusual days and days with bad data
  – Allow identification of system reliability
Data from Multiple Sources

- Traffic operation detector and incident data
- Planning office data
- Private sector data
- AVI data (Bluetooth, Wi-Fi, ETC)
- Weather data
- Managed lane dynamic congestion pricing rates
- Work zone data
- Crash data (CAR System and Signal4)
- Signal control, ramp metering, and other ATDM parameters
- Freight data
- Transit data
- Freight data
- Connected/Automated vehicles, and connected travelers
Day-to Day Variation (I-95 Miami)
Phoenix Testbed Clustering

- **Centroid Hourly Traffic Volumes**
  - Graph showing traffic volumes per hour over time for different scenarios.

- **Centroid Hourly Traffic Speeds**
  - Graph showing traffic speeds per hour over time for different scenarios.

- **Centroid Number of Incidents**
  - Graph showing the number of incidents per hour over time for different scenarios.

- **Member Ratios in 4 Clusters (PM peak)**
  - Pie chart showing the percentage of members in each cluster during the PM peak.
Connected Vehicle Data

• J2735 standards specify a number of message types including BSM and Probe vehicle messages
• Only BSM Part 1 (every 1/10 sec) will be mandated by NHTSA
  – vehicle position, heading, speed, acceleration, steering wheel angle, and vehicle size
• BSM Part 2 have useful elements for DMA applications
  – precipitation, air temperature, wiper status, light status, road coefficient of friction, Antilock Brake System (ABS) activation, Traction Control System (TCS) activation, and vehicle type.
• Probe vehicle data message contains snapshots of vehicle information and sensor data collected from and sent to a vehicle’s on-board unit.
Proposed MRM Framework Components

Analytical
- FITSEVAL
- HCM Procedure
- ELTOD
- RealCost

Regional Planning Model
- FSUTMS

Data Analytics Tools
- ITSDCAP

Macro/Mesoscopic DTA
- DTALite
- VISUM
- Cube Avenue
- Dynameq
- DynusT
- Direct

Other Modeling Tools
- Mobility
- Safety
- Reliability

Microscopic Simulation
- VISSIM
- AIMSUN
- CORSIM
- Transmodeler

Analysis, Modeling, and Simulation Tools

Speed*, Counts*, OD Matrix*, TFM

Sub-Network Demand*
Analysis Tool Types

- Data processing and data-based analytics
- Regional demand forecasting models
- Land use
- Sketch planning
- Analytical models (called deterministic in FHWA documents)
- Macroscopic simulation models (with and without DTA)
- Mesoscopic simulation-based DTA
- Microscopic simulation (with and without DTA)
Modeling Tool Levels (Source: SHRP 2 L05)
Sketch Planning Tools

- Produce general order of magnitude estimates of travel demand and traffic operations in response to transportation improvements.
- Such tools are primarily used to prepare preliminary benefits and costs.
- Examples: TOPS-BC, IDAS, FITSEVAL
FITSEVAL

• A joint FDOT System Planning Office and FDOT ITS Section effort (accomplished 2008)

• Implemented using Cube script language

• Supports planning process in assessing benefits and costs associated with implementing ITS in given region

• Allows users to assess deployment options within the FSUTMS
ITS Evaluated by FITSEVAL

- Ramp Metering
- Incident Management Systems
- Highway Advisory Radio (HAR) and Dynamic Message Signs (DMS)
- Advanced Travel Information Systems (ATIS)
- High-Occupancy Toll (HOT)
- Toll Lanes
- Signal Control
- Transit Vehicle Signal Priority
ITS Evaluated by FITSEVAL (Cont’d)

- Emergency Vehicle Signal Priority
- Monitoring and Management of Fixed Route Transit
- Transit Information Systems
- Transit Security Systems
- Transit Electronic Payment Systems
- Smart Work Zones (SWZ)
- Road Weather Information Systems
Why Simulation

- Generate dynamic volumes, travel times, and other measure profiles
- Represent reality under congestion, queuing, and spillback
- Can restrict flow rates not in excess of capacity
  - Demand models allows V/C >>> 1
- Allow assessment impacts of time-variant recurrent and non-recurrent (incidents, work zones, etc.) congestion
- Simulate time-dependent dynamic control, pricing, and management strategies
  - Modeling using API facilities for more detailed modeling
- Can be extended to AV and CV modeling with different market penetrations
- Can be integrated with other applications
  - e.g., signal optimization, DTA, behavioral models (logit), environmental assessment, safety assessment, reliability assessment, etc.
Three Simulation Levels

- Macroscopic
- Mesoscopic
- Microscopic
Why Multi-Resolution

• Static assignment does not produce acceptable level of routing for microscopic simulation
• Traffic demands generated from demand models are not capacity constrained
• Impacts of recurrent congestion and queuing are not well modeled in demand models
• Non-recurrent event impacts are not modeled in demand models
• Strategies such as ML, pricing, and traveler information not well modeled in demand models
• TAZ need to be disaggregated and connectors may need to be reconnected
• Allow multi-scenario modeling (days of the year with different operational scenarios)
Previous Findings

• Sbayti and Roden (2010) compared the use of partial MRM versus full MRM

• In the partial MRM, a subarea from the demand forecasting model is converted to run in a microscopic simulation tool.
  • With this structure, the O-D demands that are departing and entering the boundaries of the sub-area are not capacity constrained.
  • From the macroscopic model's perspective, this results in links with volume to capacity ratios exceeding 1.0.
  • Microscopic models will have difficulty with the utilization of such inputs from the demand model
MRM Applications

- Typical applications use a top-down approach
  - Determine the initial demands and network configuration based on the approved regional demand forecasting process.
  - Use as inputs to mesoscopic simulation-based DTA to determine diversions and bottleneck and strategy impacts on traffic demands.
- Bottom-up applications approach can be used
  - e.g., estimate capacity with CV/AV and signal control using microscopic simulation and feed the results to mesoscopic simulation
- A combination of the two approaches may be needed
Challenges to Effective MRM

• Need for supporting tools that automate parts of the process
• Limited knowledge and experience, particularly with DTA-based mesoscopic tools.
• Some of the effective DTA-based tools are still academic and research tools
• Need for knowledge transfer and documentation
• Challenges in calibration large networks including demands (particularly for future years) and supply calibration and validation
• The need to disaggregate the zones and connectors coded in demand models
Strategic Travel Choices

• What kinds of travelers and choices do we need to represent? Example is below

INFORMED

REAL-TIME
INFO

UNINFORMED

UNFAMILIAR FAMILIARITY SEASONED

• Who are the travelers traversing the network?

• How do we apply DTA techniques, possibly combined with other behavioral models to model each subset of the traveler population?
Two Different Choice Categories

- Choices based on day-to-day learning and adaption
- Other choices (tourists, diversion due to incidents, work zones, response to VSL and queue warnings, etc.)
Data Analytic Functionality

• Aggregation and cleaning of data from multiple sources
• Grouping and clustering of data
• Performance measurements and dashboard
• Real-time information sharing
• Prediction of system performance and impacts
• Decision support tools
• Benefit-cost analysis of advanced strategies
• Transportation model support
Proposed MRM Framework Components

Support Environment

ISSTA
- Tool Assessment
- Conversion Tool
- OD Matrix Estimation
- Modeling Support
- Emission Modeling
- Output/Alternative Analysis

Zone Disaggregation
- Clustering
- NEXTA
- Signal Plan Conversion
- Signal Optimization
- AV/CV Modeling

Field Data*
- Speed*
- Traffic Counts*
- Travel Time*
- Other Parameters*
Supporting Tools

- Tool Assessment
- Conversion tools
- ODME
- Zone and connector disaggregation
- Traffic pattern clustering and aggregation
- Signal modeling support
- Calibration and convergence support
- Emission modeling
- Reliability modeling
- Safety modeling
- Decision support (output visualization and alternative analysis)
- Possibly land use tools (SHRP 2 C10 A and B projects)
Example of Tool Selection Criteria

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Cube Voyager</th>
<th>ELTOD</th>
<th>DTALite</th>
<th>Cube Avenue</th>
<th>VISSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assignment Type</strong></td>
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<tr>
<td>Shortest Path and Path Choice</td>
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<tr>
<td><strong>En-route Dynamic Routing (e.g., Dynamic Navigation System)</strong></td>
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<tr>
<td><strong>Specification of Fine-Grained Assignment Interval (e.g., 15-30 minutes)</strong></td>
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<tr>
<td><strong>UE Assignment Method</strong></td>
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<tr>
<td>Allows Fixing Paths for Parts of the Demands</td>
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<tr>
<td>Outputting and Using Interval-based Convergence Gap</td>
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<td><strong>Assignment of Individual Vehicles</strong></td>
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<td>Assignment of Multiple Demand Types</td>
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<tr>
<td><strong>Traffic Flow Model (TFM)</strong></td>
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<tr>
<td><strong>Model Type</strong></td>
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<td>Queuing and Spillback</td>
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</table>
Example of Tool Selection Criteria

<table>
<thead>
<tr>
<th>Automatic Calculation of Signal Timing</th>
<th>Lane-by-Lane Simulation</th>
<th>Merging/Weaving Simulation</th>
<th>ML and ACC/CACC Modeling</th>
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</thead>
<tbody>
<tr>
<td>Generalized Cost in Assignment</td>
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<tr>
<td>Willingness-To-Pay (WTP) Combined with Assignment</td>
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<tr>
<td>Link Access Restrictions/Prohibitions by Vehicle Type</td>
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<tr>
<td>Modeling Managed Lanes and Reversed Lanes</td>
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<tr>
<td>Fixed and Time-of-Day Pricing by User Types</td>
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</tr>
<tr>
<td>Dynamic Pricing</td>
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<tr>
<td>In Homogenizing of VOT and VOR</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Feedback to Regional Planning</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Capacity as a Function of Proportion of Vehicle Types</td>
<td></td>
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</tr>
</tbody>
</table>
Estimation of Other Measures

- Traditionally traffic modeling tools produced mobility measures: VMT, VHT, travel times, queues, etc.
- Increasing interest in other measures that predict safety performance for planning, planning for operations, and operations
- Prediction can be also at macroscopic, mesoscopic, and microscopic levels
  - Reliability
  - Safety
  - Emission
Why Modeling Reliability is important
Unreliability Modeling

• Seven factors cause travel times to be unreliable
  • Incidents
  • Inclement weather
  • Work zones
  • Special events
  • Traffic control device timing
  • Demand fluctuations
  • Inadequate base capacity

• SHRP 2 tool and methods: L02, L04, L07, L08, C11
Modeling of Advanced Management Strategy

- Active traffic and demand management (ATDM): Dynamically monitor, control, and influence travel, traffic, and facility demand of the entire transportation system and over a traveler's entire trip chain.
- Dynamic mobility applications (DMA) improve mobility and reliability based on emerging technologies such as AV and CV.
- Integrated corridor management (ICM): Improvement of operational efficiency based on coordinated operations between facilities and modes. Promotion of cross-network shifts.
Case Study: Application to Managed Lane Modeling
Stations 600561, 600711, and 600921 were recognized as potential bottlenecks.
Capacity

- Capacity is modeled as pre-breakdown flow before breakdown happens, and as queue discharge for after breakdown.
- Capacity of GPL is about 1,830 vphpl and of managed lane is 1,650 veh/hr/lane.
Calibration Impacts

- Calibrating capacity and jam density successfully replicated bottleneck locations and impacts

**Speed (MPH)**

Storage Density=190 veh/ln/mi  
Queuing Density=55 veh/ln/mi
DTA versus STA Results

Generalized Cost Function

- Divert to HOT (veh/15 min)
- Intervals
- Highway
- AVENUE
- Observed

[Graph showing the generalized cost function with intervals and vehicle divert rates for Highway, AVENUE, and Observed.]
Impact of VOT – Cube Avenue
**ML Modeling VOT Distribution**

- Best fit: Gen. Extreme Value *(Orange)*
- Distribution will be used in DTALite: Lognormal *(Blue)*.

\[
f(x; \mu, \sigma) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{1}{2} \left( \frac{x - \mu}{\sigma} \right)^2}
\]

- Average VOT: 12 $/hour.

<table>
<thead>
<tr>
<th>Goodness-of-Fit Statistics</th>
<th>Value of Time $ (VOT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$12</td>
</tr>
<tr>
<td>MAPE (%)</td>
<td>16.50</td>
</tr>
<tr>
<td>RMSE (veh/ln/15min)</td>
<td>73.94</td>
</tr>
</tbody>
</table>
## Impact of VOR Use

<table>
<thead>
<tr>
<th>Goodness-of-Fit Statistics</th>
<th>ELToD</th>
<th>Meso</th>
<th>Macro</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>With Consideration of VOR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMSE (veh/ln/15min)</td>
<td>12.00</td>
<td>8.23-9.18</td>
<td>10.77</td>
</tr>
<tr>
<td>MAPE (%)</td>
<td>2.29</td>
<td>1.89-1.96</td>
<td>2.27</td>
</tr>
<tr>
<td><strong>Without Consideration of VOR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMSE (veh/ln/15min)</td>
<td>54.30</td>
<td>40.34-46.22</td>
<td>37.03</td>
</tr>
<tr>
<td>MAPE (%)</td>
<td>13.36</td>
<td>9.03-11.29</td>
<td>8.68</td>
</tr>
</tbody>
</table>
Can Models Predict ML Shifts

### Goodness-of-Fit Statistics

<table>
<thead>
<tr>
<th></th>
<th>Fixed Pricing and Static Assignment (ELTOD)</th>
<th>Dynamic pricing with Dynamic Assignment (Avenue)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New Toll Policy</strong></td>
<td>RMSE (veh/ln/15min) = 51.42</td>
<td>RMSE (veh/ln/15min) = 25.15</td>
</tr>
<tr>
<td></td>
<td>MAPE (%) = 12.22</td>
<td>MAPE (%) = 5.87</td>
</tr>
<tr>
<td><strong>Old Toll policy</strong></td>
<td>RMSE (veh/ln/15min) = 67.39</td>
<td>RMSE (veh/ln/15min) = 31.04</td>
</tr>
<tr>
<td></td>
<td>MAPE (%) = 13.48</td>
<td>MAPE (%) = 5.90</td>
</tr>
</tbody>
</table>
Macro+Meso+Micro Modeling

• Waiting for I-95 Model from FDOT D6
Estimation of CV MP

The diagram illustrates the percentage change over time (Year) for minimum MP (Min MP), maximum MP (Max MP), and the MP difference. The x-axis represents the year, while the y-axis shows the percentage of CV change.
## Estimation of CV MP on Capacity

<table>
<thead>
<tr>
<th>Percentage of CACC Vehicles (%)</th>
<th>Lane Capacity (veh/ln/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2018</td>
</tr>
<tr>
<td>0</td>
<td>2092</td>
</tr>
<tr>
<td>40</td>
<td>2230</td>
</tr>
<tr>
<td>60</td>
<td>2500</td>
</tr>
<tr>
<td>80</td>
<td>2890</td>
</tr>
<tr>
<td>100</td>
<td>4000</td>
</tr>
</tbody>
</table>
Impact of CACC on ML Using Meso-based DTA
Impact of CACC on the Merging Segment Using Micro
Thank You!

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