Simultaneous Off-Line Demand and Supply Calibration of Dynamic Traffic Assignment Systems

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Second Transportation Research Symposium
10th February 2006, Northeastern University
Motivation

• Dynamic traffic assignment (DTA) systems
  – Demand, supply processes and interactions
    • Several complex model components, algorithms
  – Large number of inputs and parameters

• Model parameters must reflect reality
  – Calibration aims at reducing error between system output and observed data
Literature Review

• Individual model component calibration
  – Demand
    • OD estimation (e.g. [4, 3, 1])
  – Supply
    • Sensor data fit locally (e.g. [12])
    • Limited applications of network-wide estimation (e.g. [9, 10])

• System-level calibration
  – Two-step process (e.g. [7, 6, 11, 5])
Methodology

\[
\text{Minimize } \sum_{h=1}^{H} \left[ z_1(M_h, \hat{M}_h) + z_2(x_h, x^a_h) \right] + z_3(\beta, \beta^a)
\]

subject to:

\[
\hat{M}_h = f \left( x_1, \ldots, x_h, \beta, G_1, \ldots, G_h \right)
\]

• Advantages

  – Direct use of simulator output
  – Flexibility to include general traffic data
  – Simultaneous demand-supply estimation
  – Simultaneous OD estimation across time intervals
Problem Dimensions

• Complex DTA function $f$
  – Highly non-linear and non-analytical (simulator)
  – Potentially noisy
    • Unreliable gradients

• Very large scale in $x$, $\beta$
  – Demand parameters (OD flows) typically dominate
Solution

• Box Complex [2]
  – Span search space; locate potential optima

• SNOBFIT [8]
  – Stable Noisy Optimization by Branch and Fit
  – Refine search through local quadratic fitting

• Population-based global search
  – Gradient-free approach
Case Study

• Objectives
  – Demonstrate and evaluate calibration approach
    • Simultaneous temporal demand estimation
    • Simultaneous demand-supply estimation
    • Impact of speed data
  – Validate solution algorithm
    • Examine performance: sensitivity analysis
Network

- "Actual conditions": MITSIM
  - Flexible scenarios
  - 50 minutes (10 intervals)
  - Sensor data: counts, speeds

- Calibration
  - DynaMIT
  - Demand variables: OD flows, route choice
  - Supply parameters: capacities, speed-density function parameters
DynaMIT Overview

• Demand simulation
  – Dynamic OD flow estimation and prediction
  – Route choice and response to information

• Supply simulation
  – Queuing
  – Traffic dynamics

• Interactions
Estimators and MOE

- Reference estimator
  - Known demand, local supply parameter fitting
- Network-wide estimators

<table>
<thead>
<tr>
<th>Estimated Parameters</th>
<th>Calibration Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Counts</td>
<td>Counts+Speeds</td>
</tr>
<tr>
<td>Supply (known Demand)</td>
<td>$S_c$</td>
<td>$S_{cs}$</td>
</tr>
<tr>
<td>Supply and Demand</td>
<td>$SD_c$</td>
<td>$SD_{cs}$</td>
</tr>
</tbody>
</table>

$$RMSE = \sqrt{\frac{1}{S} \sum_{i=1}^{S} (y_i - \hat{y}_i)^2}$$

$y_i, \hat{y}_i$: observed and fitted sensor data
$S$: total number of data points
Base Case

- Representative demand, supply situations
  - Route choice
  - Weaving and merging behavior
  - Incident
  - OD flow profiles:
## Base Case Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Sensor Data Used for Calibration</th>
<th>Counts</th>
<th>Counts + Speeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RMSE$_c$</td>
<td>RMSE$_s$</td>
</tr>
<tr>
<td>S</td>
<td></td>
<td>15.89 (7.6)</td>
<td>2.86 (25.7)</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>15.87 (7.7)</td>
<td>3.02 (21.6)</td>
</tr>
</tbody>
</table>

Reference: RMSE$_c$ = 17.19, RMSE$_s$ = 3.85

S : Network-wide supply calibration
SD : Joint supply-demand calibration

( ) : Percent improvement over Reference

RMSE$_c$ : root mean square error, counts
RMSE$_s$ : root mean square error, speeds
Base Case Results

Estimated vs. “True” OD Flows
Base Case Results

Simulated vs. Actual Sensor Flows

![Graph showing simulated vs. actual sensor flows.](image)
## Sensitivity Analysis

<table>
<thead>
<tr>
<th>Factor</th>
<th>Levels</th>
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<tbody>
<tr>
<td></td>
<td>-1</td>
</tr>
<tr>
<td>Route choice</td>
<td>-0.01 (Time-insensitive)</td>
</tr>
<tr>
<td>OD spatial</td>
<td>Lower main flow</td>
</tr>
<tr>
<td></td>
<td>Higher side flow</td>
</tr>
<tr>
<td>OD temporal</td>
<td>Historical</td>
</tr>
<tr>
<td></td>
<td>(No variance)</td>
</tr>
<tr>
<td>Desired speed</td>
<td>Slower</td>
</tr>
</tbody>
</table>

### Run Table

<table>
<thead>
<tr>
<th>Run</th>
<th>Route Choice</th>
<th>OD: Spatial</th>
<th>OD: Temporal</th>
<th>Desired Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Base)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>2</td>
<td>-1</td>
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<td>0</td>
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<tr>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>-1</td>
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<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>-1</td>
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<td>7</td>
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<td>8</td>
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<td>0</td>
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<td>-1</td>
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<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Sensitivity Analysis Results

Fit to Sensor Counts

![Bar Chart](chart.png)
Sensitivity Analysis Results

Fit to Sensor Speeds

![Graph showing Sensitivity Analysis Results]
Conclusion

- Network-wide supply calibration
- Speed data significant
- Simultaneous demand-supply estimation feasible, efficient
- Approach robust under various demand, supply conditions
- Current research: Application to real networks
References


References (cont’d)


References (cont’d)


