DEVELOPMENT, CALIBRATION AND APPLICATION OF SIMULATION-BASED DYNAMIC TRAFFIC ASSIGNMENT TO GREATER CHICAGO NETWORK USING DYNASMART-P

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Outline

- Introduction to Simulation-based DTA
- Greater Chicago Network
- Calibration and Validation of DYNASMART-P
  - Supply side
  - Demand side
- Applications
  - Weather-responsive traffic estimation and prediction
  - Congestion management
Introduction to Simulation-based DTA
What is DYNASMART-P?

- **DY**namic **N**etwork **A**ssignment-**S**imulation **M**odel for **A**dvanced **R**oadway **T**elematics (**P**lanning version)

- It is an intelligent transportation network design, planning, evaluation, and traffic simulation tool.
State of Practice in Network Modeling

- Most agencies use static assignment models, often lacking formal equilibration, with very limited behavioral sensitivity to congestion-related phenomena (incl. reliability).

- Some agencies use traffic micro-simulation models downstream from assignment model output, primarily for local impact assessment.

- Time-dependent (dynamic) assignment models continuing to break out of University research into actual application—market growing, still fragmented, with competing claims and absence of standards:
  - existing static players adding dynamic simulation-based capabilities,
  - existing traffic micro-simulation tools adding assignment (route choice) capability, often in conjunction with meso-simulation
  - standalone simulation-based DTA tools
State of Practice in Network Modeling

- Applications to date complementary, not substitutes, for static assignment; primary applications for operational planning purposes: work zones, evacuation, ITS deployment, HOT lanes, network resilience, etc...
- Existing commercial software differs widely in capabilities, reliability and features; not well tested.
- Equilibration for dynamic models not well understood, and often not performed
- Dominant features, first introduced by DYNASMART-P in mid 90’s:
  - Micro-assignment of travelers; ability to apply disaggregate demand models
  - Meso-simulation for traffic flow propagation: move individual entities, but according to traffic flow relations among averages (macroscopic speed-density relations): faster execution, easier calibration
  - Ability to load trip chains (first tool with this capability, essential to integrate with activity-based models)
Greater Chicago Network
Data Overview

• Five categories of data required for DYNASMART-P
  – Network data
  – Control data
  – Demand data
  – Scenario data
  – System data

First three groups are critical for setting up the network

Last two group are critical for scenario analysis
Sources of data

- **Network:**
  CMAP TransCAD network converted to DYNASMART-P using DYNASMART-P utility (DynaBuilder)

- **Control:**
  Signal locations based on TranCAD network
  Other control locations inferred by spatial reasoning logic, confirmed by Google Earth
  Timing plans have been coded in DSPEd
  - Actual timing plans not available
  - Actuated Control signal timing plans specified by default

- **Transit:**
  Bus routes and frequencies
  - Not implemented to this network, yet

- **Demand:**
  Static demand matrix provided on daily basis and hourly factors

  Link counts obtained from IDOT loop detectors (in 5 minutes intervals)
Greater Chicago Network

- ~40,000 links
  - 144 links are tolled
  - 1,400 freeways
  - 200 highways
  - 2,000 ramps
  - (96 of them are metered)
  - 36,400 arterials

- ~13,000 nodes
  - 2155 signalized intersections

- 1,961 zones
  - 1,944 internal
  - 17 external

- Demand period
  - 5am -10am hourly demand
  - 355 unique link counts
  - Observation Interval: 5 min
Calibration and Validation of DYNASMArt-P
Location of traffic data for traffic flow calibration
Calibrating parameters in the traffic flow model / Procedure

**Step 1.** Plot the speed vs. density graph, and set initial values for all the parameters, i.e. breakpoint density \(k_{bp}\), speed-intercept \(v_f\), minimum speed \(v_0\), jam density \(k_{jam}\), and the shape parameter \(\alpha\), based on observations.

**Step 2.** For each observed density \(k_i\), calculate the predicted speed value and the parameters initialized in Step 1.

**Step 3.** Compute the squared difference between observed speed value \(v_i\) and predicted speed value, for each data point, and sum the squared error over the entire data set.

**Step 4.** Minimize the sum of squared error obtained in Step 3, by changing the values of model parameters.
Calibrating parameters in the traffic flow model for different weather conditions

![Speed-Density Data](image1.png)

![Speed-Density Calibrated Relationship](image2.png)
Calibration and Validation of DYNASMART-P II - Demand side

Time-dependent OD Estimation / Methodology

**Input**

- Static/historical OD matrix for the planning time horizon
- Time-dependent traffic counts on selected observation links

**Bi-level Optimization**

**Upper Level Problem**

- Minimizing deviation from static demand and observation with specific weights by changing estimated demand given link proportions

**Lower Level Problem**

- Finding link proportions by DTA given a time dependent OD

**output**

- Time-dependent OD matrices over the time horizon with a chosen time interval (5 minutes)
Calibration and Validation of DYNASSMART-P II - Demand side

Time-dependent OD Estimation for large scale networks / Results

\[ RMSE_{\text{Demand}} = \sqrt{\sum_{i=1}^{I} \sum_{j=1}^{J} \left( \sum_{k=1}^{H} d_{i,j,k} \right) - \delta_{i,j}} \]

\[ RMSE_{\text{Flows}} = \sqrt{\sum_{l=1}^{L} \sum_{t=1}^{T} \left( M_{l,t} - O_{l,t} \right)^2} \]

<table>
<thead>
<tr>
<th>Number of Trips</th>
<th>RMSE Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOV*</td>
<td>RMSE\text{Demand}</td>
</tr>
<tr>
<td>Historical OD matrix</td>
<td>4,145,413</td>
</tr>
<tr>
<td>New time-dependent OD matrix after Iteration 1</td>
<td>4,179,062</td>
</tr>
<tr>
<td>New time-dependent OD matrix after Iteration 2</td>
<td>4,157,199</td>
</tr>
<tr>
<td>New time-dependent OD matrix after Iteration 3</td>
<td>4,141,043</td>
</tr>
</tbody>
</table>

* SOV: Single-occupancy vehicle

** Deviation is zero because RMSE\text{Demand} in this case represents the deviation between the static OD matrix and itself.
Calibration and Validation of DYNASMART-P II - Demand side

Time-dependent OD Estimation / Results

### Link 14681

![Graph showing cumulative link counts for Link 14681 over time](image1)

### Link 14506

![Graph showing cumulative link counts for Link 14506 over time](image2)

### Observed vs. Simulated

![Graph showing observed vs. simulated link counts over time](image3)

![Graph showing observed vs. simulated link counts over time](image4)
Calibration and Validation of DYNASMART-P

VALIDATION OF WEATHER SENSITIVE DYNASMART-P

\[ \text{RMSE}_{\text{Speeds}} = \sqrt{\frac{\sum_{l=1}^{L} \sum_{t=1}^{T} [MS_{i,t} - OS_{i,t}]^2}{LT - 1}} \]

\[ \text{RMSE}_{\text{Flows}} = \sqrt{\frac{\sum_{l=1}^{L} \sum_{t=1}^{T} [M_{i,t} - O_{i,t}]^2}{LT - 1}} \]

<table>
<thead>
<tr>
<th>SNOW Scenario: 2010-01-07 (Chicago)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMSE Speeds</strong></td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>With Weather Features</td>
</tr>
<tr>
<td>Without Weather Features</td>
</tr>
</tbody>
</table>

Relative difference : 37%    Relative difference : -5%
Applications

I - Weather-responsive traffic estimation and prediction
Objectives

- Reduce the impact of *inclement weather events* and mitigate congestion
- Determine weather-related advisory and controls based on predicted traffic conditions and anticipatory road weather information
- This calls for integrated real-time *Weather-Responsive Traffic Management* (WRTM) and a *Traffic Estimation and Prediction System* (TrEPS)
Offline WRTM

- Historical weather and traffic count data from different days can be used to simulate various real-world scenarios.
- Many different What-If scenarios can be tested and evaluated.
- Successful scenarios can be added to the WRTM strategy repository to be used as an initial input for real-time implementation in DYNASMART-X via Scenario Manager.
Description of 5 Scenarios

1. **Clear Day:** Maximum visibility with zero precipitation.
2. **Snow:** Visibility ranges from 0.5 to 2.0 miles, snow intensity ranges from 0.03 to 0.10 inches per hour, network-wide.
3. **Snow with VMS – Variable Speed Limit:** Speed reduction strategies are implemented on freeway corridors.
4. **Snow with VMS – Detour:** Vehicles are detoured from some heavily impacted links to alternative routes.
5. **Snow with VMS – Detour plus Variable Speed Limit:** Vehicles are detoured from some heavily impacted links to alternative routes and Speed reduction strategies are implemented on freeway corridors.
Application I- Weather-responsive traffic estimation and prediction

Weather data during simulation with snow

Snow Intensity

Visibility
Weather Impact on density

Clear Day

Snow
Lake Shore Dr North bound between Belmont and Fullerton

Clear Day

Snow

Density

Speed

Volume
WRTM Strategies

VMS - VSL

VMS – Detour

Application I- Weather-responsive traffic estimation and prediction
5:30 am Density

Clear

Snow

Snow + Detour

Snow + VSL

Snow + Detour + VSL
7:00 am Density
8:00 am Density

Clear

Snow

Snow + Detour

Snow + VSL

Snow + Detour + VSL
9:00 am Density

Clear

Snow

Snow + Detour

Snow + VSL

Snow + Detour + VSL

Density:

0  15  30  45  60  75
10:00 am Density

Clear

Snow + Detour + VSL

Snow

Snow + Detour

Snow + VSL
11:00 am
Density

Clear

Snow + Detour + VSL

Snow + Detour

Snow + VSL
Application I- Weather-responsive traffic estimation and prediction

A Closer Look: Link Densities and Speeds
Kennedy Expy between Pulaski Rd and N Cicero Ave (west bound) 
(Density)
Kennedy Expy between Pulaski Rd and N Cicero Ave (west bound) (Speed)

- **Clear**
- **Snow**
- **Snow + Detour**
- **Snow + VSL**
- **Snow + Detour + VSL**
Kennedy Expy between Pulaski Rd and N Cicero Ave (west bound) (Volume)
Application I- Weather-responsive traffic estimation and prediction

- A **validated offline WRTM** strategy can provide a predefined input to be used for **online WRTM**.

- **Variable Speed Limit (VSL)** is a more general strategy which can be implemented for an entire corridor and can be **evaluated offline**.

- **Detour (VMS2)** is a strategy that should always be considered. However, its effectiveness should not be tested offline as it is more **case-dependent**.

- This calls the need for an **online implementation** with **Detector Measurement data** and **Weather Prediction** in order to predict near-future events based on prevailing real-world conditions and make **proper interventions** using **online WRTM** strategies.
Applications

II- Congestion management
What is the Problem?
What is the Problem?

- Congestion is growing in major cities
- Highly congested neighborhoods (e.g. CBD) suffer from gridlock phenomena in peak periods
- Need for a more efficient utilization of existing infrastructure
Application II- Congestion management

Objectives

- Improve mobility and accessibility
- Congestion mitigation
- Finding an effective and practical solution
Application II- Congestion management

City-wide Traffic Flow Relations

Traffic Control

- Network Flow
- Network Speed
- Network Density
Application II - Congestion management

City-wide Traffic Flow Relations

Transportation Planning

- Mobility
- Accessibility
- Vehicle Accumulation

Graph: Number of Completed Trips vs. Vehicle Accumulation in the Network

Data:
- Mobility: 20,000, 30,000, 40,000
- Accessibility: 20,000, 30,000, 40,000
- Vehicle Accumulation: 0, 10,000, 200,000, 400,000, 600,000, 800,000
City-wide Traffic Flow Relations

Number of completed trips (accessibility)

Number of vehicles in the network (vehicle accumulation)
What is the idea?

The idea is to monitor and control aggregate vehicle accumulation in the network in order to maximize the accessibility and mobility.
Application II- Congestion management

How can we do it?

London, UK
How can we do it?

Zurich, Switzerland
Application II- Congestion management

How can we do it?

Chicago, USA
Application II- Congestion management

Downtown Chicago
Application II- Congestion management

Vehicle Accumulation vs. Network Flow

Chicago CBD

![Graph showing Vehicle Accumulation vs. Network Flow](image-url)
Application II - Congestion management

Gridlock formation

Gridlock (5% EnRoute)  Gridlock (20% EnRoute)
Application II- Congestion management

Where they came from?

Spatial distribution of Origin-Destination demand in the network

Spatial distribution of Origin-Destination demand associated with vehicles trapped in the gridlock
Effect of traveler information

![Graph showing the effect of traveler information on average network flow versus average network density. The graph includes lines for 5%, 10%, 20%, and 30% EnRoute percentages.]
Application II- Congestion management

Effect of demand management
We have identified 41 signals in the periphery of downtown Chicago.

Restricting the accumulation of vehicles in downtown via modifying the signal timings on the periphery of downtown and/or pricing.

Similar analysis will be performed in a multi-modal network to understand the impact of modes interaction and its effect on the network-wide mobility and accessibility.
Summary
Simulation-based DTA tools overcome many of the known limitations of static assignment tools used in current practice.

DYNASMART-P provides a platform for integrating activity-based models with network assignment and performance simulation.

A Calibrated greater Chicago network is prepared in DYNASMART. Calibration includes both demand and supply side.

Two Applications of DYNASMART-P were reviewed including:
- Weather-responsive traffic estimation and prediction
- Congestion management.
Thank You

Questions ?