Agent-Based Methods for Transportation Network Optimization

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## Agents and Their Behaviors

<table>
<thead>
<tr>
<th>Decision Type</th>
<th>Agents</th>
<th>Time Scale</th>
<th>Influenced By (Major Factors Only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving Behavior</td>
<td>Driver, Vehicle</td>
<td>Real-time</td>
<td>Real-time surrounding traffic conditions</td>
</tr>
<tr>
<td>En-Route Diversion</td>
<td>Driver, Vehicle</td>
<td>Real-time</td>
<td>Real-time congestion, traveler information, traffic management, toll</td>
</tr>
<tr>
<td>Pre-Trip Route Choice</td>
<td>Person</td>
<td>Daily, Short-term</td>
<td>Network knowledge, experience, information, traffic management, toll</td>
</tr>
<tr>
<td>Departure Time</td>
<td>Person</td>
<td>Short-term, Fixed</td>
<td>Schedule flexibility, dynamic tolls, information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for most work trips</td>
<td></td>
</tr>
<tr>
<td>Mode Choice</td>
<td>Household, Person</td>
<td>Mid-term</td>
<td>Modal performance, personal attributes, vehicle ownership</td>
</tr>
<tr>
<td>Destination Choice</td>
<td>Household, Person</td>
<td>Midterm (e.g. shopping) or Long-Term (work)</td>
<td>Spatial knowledge, information, network LOS, HH/personal attributes</td>
</tr>
<tr>
<td>Trip Frequency</td>
<td>Household, Person</td>
<td>Mid- to long-term, but partially adjustable daily</td>
<td>Activity patterns, household/personal attributes</td>
</tr>
<tr>
<td>Vehicle Ownership</td>
<td>Household</td>
<td>Mid- to long-term</td>
<td>Household attributes</td>
</tr>
<tr>
<td>Location Choice</td>
<td>Household</td>
<td>Long-term</td>
<td>Household attributes, land use</td>
</tr>
</tbody>
</table>
Theory and Methodology

Traditional: Rational Behavior Theory

- What agents SHOULD do
- Perfect information and rationality
- Optimizing behavior
- Maximizing utility, profit, welfare, etc.

Emerging: Descriptive Behavior Theory

- What agents ACTUALLY do
- Imperfect knowledge and learning
- Time-dependent behavioral dynamics
- Empirically-derived behavioral rules

Econometric Models and Mathematical Optimization
Equilibrium Analysis

Artificial Intelligence, Agent-Based Models, and Simulation-Based Optimization
Evolutionary Analysis
Descriptive Travel Behavior Theory

Information
- Experience
- Other sources

Learning
- Update knowledge

Knowledge
- Cognitive map
- Subjective beliefs

Perceived
- search cost

Subjective
- search gain

Search?

Yes

Search Dimensions
- Decide which dimension(s) to search

Search Scope
- Find an alternative departure time/mode/route...

Decision Rules
- Choose the new alternative or no behavior change

Travel Experience

Travel time,
- Travel cost,
- Schedule delay,
- Etc.

No

Repetitive behavior
Integrated Agent-Based Model

- System Supply and Operations
  - Agent: Agencies and Controllers

- Network, Control, and Policy

- Dynamic OD
  - Dynamic Routing
  - En-route diversion

- Agent-Based Behavioral Model
  - Agent: Individual

- Agent-Based Network Simulator
  - Agent: Vehicle

- Data: Traffic Counts, Speed, Travel Time, and Individual Behavior

- Calibration Validation

- System Operations, Planning, and Optimization; Energy and Emissions

- Simulated Network Performance

- Routing
  - Departure time
  - Mode choice
Simulation-Based Optimization

Simulation Based Optimization

- Jointly optimize multiple operations and planning strategies
- Use simulation models for evaluation and now for optimization too
- Multiple modes can also be jointly optimized with multiple objectives

**Optimization problem definition**
- objective functions, decision variables, constraints

**Design of Experiments (DoE)**
- e.g. LHS, CCD

**Transportation Network Simulation**
- Initial set of toll plan

**Construct Surrogate Models**
- Simulation outputs

**Model Validation**
- Surrogate model parameter tuning

**Model accuracy criteria satisfied?**
- No
- Yes

**Optimization based on surrogates**
- e.g. using GA to explore the response surfaces

**One-stage surrogate:**
- Polynomial
- RBF
- Kriging
- SVR

**Two-stage surrogate:**
- Suboptimal infill strategies
- Global infill strategies

- Generating infill toll plans
- e.g. mean travel time minimization using optimal toll rates with box constraints
- e.g. cross validation (CV)
- e.g. R-square, RMSE, NRMSE, NMAE, EGO

Simulation-Based Optimization
- Jointly optimize multiple operations and planning strategies
- Use simulation models for evaluation and now for optimization too
- Multiple modes can also be jointly optimized with multiple objectives
Active Corridor Traffic Management

[Map of the area with highlighted routes and labels such as DMS and Incident Scenario]
Congestion: Baseline Scenario

I-95 SB Basecase Scenario

5 AM 6 AM 7 AM 8 AM 9 AM 10 AM

Time (hour)

5 mph 15 mph 25 mph 35 mph 45 mph 55 mph

Space (mile)

DMS1 Exit 29
DMS2 Exit 30
DMS3 Exit 31
DMS4 Exit 32

Exit 29
Exit 30
Exit 31
Exit 32

Transportation Systems Research at University of Maryland
http://tep.umd.edu
Accident without ATM

I-95 SB Incident Scenario
Dynamic Pricing Optimization
Multi-Objective Optimization Results

Average Travel Time

Total Toll Revenue
China-Singapore Eco-City in Tianjin

**Multimodal Transportation Planning and Optimization**

- Target year 2020, area 30 km²
- Projected 350,000 residents
- Green transportation planning
- 145 TAZs, 556 nodes, 1,770 links
- 9 bus lines and 3 LRT lines
- 7 population groups, 7 activity pairs and 5 travel modes (Bus, rail, car, bike, walk)
- Transportation Planning goal: Public transportation and non-motorized modes > 90% mode share by 2020
Multimodal System Optimization

Optimal [Parking restriction + Car sharing incentive + Transit fare] for maximum user benefits

Base Case

Optimal strategy

Level of Service

- <= 20%
- <= 60%
- <= 80%
- <= 90%
- <= 100%
- > 100%
Key Challenges: Behavior Data

- Home
- Work

Legend:
- No use
- Low use
- High Use
Model Calibration and Validation

Level-of-Service Comparison

Traffic Count Comparison

<table>
<thead>
<tr>
<th></th>
<th>Freeways</th>
<th>Freeways + Arterials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Difference</td>
<td>11%</td>
<td>15%</td>
</tr>
<tr>
<td>(24 stations)</td>
<td></td>
<td>(62 stations)</td>
</tr>
</tbody>
</table>

Travel Time Comparison

<table>
<thead>
<tr>
<th></th>
<th>AM Peak</th>
<th>PM Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time Difference $</td>
<td>14%</td>
<td>12 %</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>(9 corridors)</td>
<td>(9 corridors)</td>
</tr>
</tbody>
</table>
Agency and User Support

SHA Agent-Based Model Web Reporting System

2010 Summary

Travel Times (min)

<table>
<thead>
<tr>
<th>Corridor 1</th>
<th>Corridor 2</th>
<th>Corridor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before ICC</td>
<td>45.4</td>
<td>53.3</td>
</tr>
<tr>
<td>After ICC</td>
<td>42.2</td>
<td>52</td>
</tr>
</tbody>
</table>

Corridor 1 Corridor 2 Corridor 3

Travel Times (min)

- select intersection
- select one link
- select one superlink
- select multiple links
- select area
- select all
Real-Time Decision Support

Decision-Maker
Model Transferability

Example: En-Route Diversion Model Transfer

Development Site
Boston

Application Site
Baltimore

50% : 120

Normal route
Diverting route
Dynamic msg. sign
Bluetooth detector
Closing Remarks

- Similarity between Energy and Transportation Grids: Agents, Networks, Critical Infrastructure, …
- Opportunity: Nonlinear and complex relationships between agent behavior and system performance
- Systematic identification of feasible behavior shifts that can produce significant system benefits
- Model development should be driven by data availability and analysis needs
- Big, exciting, but still imperfect data
- Decision-makers want more information, better information, and they want it now, in real time
Thank You!

Questions, Comments, and Suggestions are Welcome. Please Contact:

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