Agent-based demand models

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## Why use models?

<table>
<thead>
<tr>
<th>Forecasting</th>
<th>Manage complexity, when eyeballs are insufficient, different people have different intuitions</th>
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</thead>
<tbody>
<tr>
<td>Scenario testing (alternative land uses, networks, policies)</td>
<td>Understanding travel behavior</td>
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<tr>
<td>Project planning/corridor studies</td>
<td>Influence decisions</td>
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<tr>
<td>Growth management/development regulation/public facility adequacy</td>
<td>Estimation in the absence of data</td>
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History

1950 - 60s

- Interstate construction era
- Extremely simple models
  
  Very few TAZs
  
  Only major highways
- Focus on trips to downtown
- Models to identify capacity requirements on highways
1970 - 80s

• Refinement of model
• More detailed structure
  Increased zonal structure
  Different type of roadways included
• Expanded focus on suburban movement
1990s

- Transit networks incorporated into the models
- Models used to analyze policy scenarios
- Focus on suburban movement
- Shifting trips from car to other modes
2000s

- Disaggregation (individuals, households)
- Increased complexity in models (trips, tours, time of day)
- Greater focus on integration with other aspects such as land use
Modeling Approaches

- Traditional four-step modeling
- New Approaches
  - Activity-based modeling
  - Agent-based modeling
  - The new approaches typically use micro-simulation
Four-step modeling

1. **Trip Generation**
   - How many trips originate or destined for zone i

2. **Trip Distribution**
   - Number of trips between origin zone i and destination zone j

3. **Mode Choice**
   - The trips between zone i and j using a certain mode

4. **Network Assignment**
   - The route chosen by mode from zone i to j
Current Twin Cities Travel Demand Forecast Model

Exogenous Models (Socio-Economic Forecasts)  Trip Generation Model  Network Models

Trip Distribution Model

Mode Choice Model

Temporal Distribution Model

Assignment Models

Source: http://www.dot.state.mn.us/trafficeng/modeling/workshop/C06-Forecasting.pdf
Criticisms

- Trip is the basis of analysis

  Trips analyzed as a function of zonal attributes, ie, reason for traveling not included

  Each trip is analyzed independent of the other trips

    Trip scheduling not considered

  Activity participation of individuals/household constraints not considered
• Aggregate (zonal) level of analysis

  Heterogeneity of travelers not considered

• Sequential approach

• Theoretical mis-specifications
• Traditional focus on
  Home to work trips
  Higher volume roadways
• Endogenous/Exogenous inputs
• Incorporation of feedback routine
• Static and deterministic nature of supply and demand in the model

  Can not handle the dynamic nature of traffic

• Limited policy analysis

  Congestion Pricing

  Toll Lanes

  Evacuation Scenarios
Micro-simulation

Refers to a broad range of tools used in modeling systems

Micro refers to the simulation done at the micro or disaggregate level - ex. individuals, households
• System characteristics for microsimulation

Dynamic nature

Complex behavior

Path dependent processes

Open system

Existence of significant uncertainties

Transportation definitely fits these conditions!
• Typically used to generate inputs in disaggregate modeling

Usually difficult to obtain data for disaggregate modeling

• Creates micro-level outputs that can be aggregated to any level

Better understanding of policy scenarios
• Considered to be computationally more efficient than conventional models

• Many applications in transportation
Activity based models

• Considers travel to be a derived demand

  This is the fundamental difference between these models and conventional four-step models!

• Travel decisions are components of a broader process

  Model the demand for activities rather than modeling trips
What does ‘derived demand’ mean?

Travel is not undertaken for its own sake

Travel is a demand that arises from people’s desire to participate in activities

Trips connect the spatially separate activities that individuals participate
People undertake activities based on their desires to participate in activities subject to constraints

- Capability constraints
- Coupling constraints
- Authority constraints
- Time Constraints
• It is NOT easy to model the demand for activities

• But we know that

Households moderate activity demand and influence activity decisions

The influence varies by household structure - size, age, gender etc.

Households with children have significantly more constraints and demands
• Activity based models provide a holistic framework that understands and incorporates the relationships between activity and travel behavior

• Individual decision making typically accomplished using micro-simulation and then aggregated for travel forecasting
Methodologies

• Computational Process Models

Explicitly models the process used by individuals to make decisions

Examples:

CARLA, SCHEDULER, STARCHILD - Treat activity generation as given and focuses on scheduling

ALBATROSS, AMOS - Focus on both activity generation and scheduling

PCATS, CATGW - Focus on both activity generation and scheduling within continuous time domain
• Hazard based duration models

Models the conditional probability of an activity terminating (referred to as failure) at time $t$, provided that it hasn’t been terminated prior to $t$.

• Approach generally used to model duration of activities and time spent at home between two trips
Discrete and Discrete-Continuous Choice Models/Econometric Choice Models

Has already been applied in conventional 4-step models in mode choice routine (nested logit formulation)

Applied to interrelated activities (tours) and travel
- Subdivided into three classes

  Trip-based models
  - ex. San Francisco MTC model

  Tour-based models
  - ex. Netherlands National LMS model

  Daily schedule models
  - ex. Portland daily activity schedule models
Concept of tours and daily schedule

Trip based models:
Six separate one-way trips

Tour based models:
Two separate tours;
one primary home tour
one secondary work tour

Daily schedule models:
Combines the tours
Agent-based models

• Another approach to travel demand forecasting

• Typical agent-based models come from different fields such as genetics, artificial intelligence, cognitive science, social science
• Activity-based demand models use sophisticated methods
  Much better than traditional models

• However there is a degree of aggregation involved especially in traffic assignment level
  Aggregate OD matrices feeding into dynamic traffic assignment models
Typical elements

• Agents
  Like “people” who have characteristics, goals and behavioral rules

• Environment
  Space where agents live

• Interaction rules
  Describe how agents and environment interact
• The agent-based model evolves once the micro-level elements are specified

Once initial conditions are specified, agents behave according to their characteristics, learning and behavioral rules

• Macro-level properties emerge from the evolutionary process
TRANSIMS

- **TRAN**sportation **AN**alysis **SIM**ulation **S**ystem
- Integrated travel demand model
- Developed by Los Alamos National Laboratory
- Long term effort to redesign the modeling process from the ground up
- Can be considered as a framework handling different modules
- Modules utilize micro-simulation techniques and activity-based approach
• Goal is to provide planning agencies with a tool to
  Handle increased policy sensitivity
  Detailed vehicle-emissions estimates
  Improved analysis and visualization capabilities
<table>
<thead>
<tr>
<th>Module</th>
<th>Inputs</th>
<th>Outputs</th>
</tr>
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<tbody>
<tr>
<td>Population Synthesizer</td>
<td>Census data files, TIGER line files</td>
<td>Synthetic Persons</td>
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<tr>
<td></td>
<td></td>
<td>Synthetic Household</td>
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<tr>
<td></td>
<td></td>
<td>Vehicles</td>
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<tr>
<td>Activity Generator</td>
<td>Synthetic Population, Household Activity Survey, Network Data</td>
<td>Activities</td>
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<tr>
<td>Route Planner</td>
<td>Activities, Link travel time, Vehicles, Transit Data, Network Data</td>
<td>Traveler Plans</td>
</tr>
<tr>
<td>Traffic Micro-</td>
<td>Network data, Vehicles, Transit data, Traveler plans</td>
<td>Traveler Events,</td>
</tr>
<tr>
<td>simulator</td>
<td></td>
<td>Snapshot data, Summary data</td>
</tr>
<tr>
<td>Emissions Estimator</td>
<td>Vehicles, Micro-simulation Outputs, External data sets, Network data</td>
<td>Emissions Inventory</td>
</tr>
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</table>
MATSIM

- **Multi-Agent Transportation SIMulation**
- Developed by two groups based in Europe

*Transportation Planning* at the Institute for Transport Planning and Systems (IVT), Swiss Federal Institute of Technology Zurich, led by Prof. Dr. Kay W. Axhausen

*Transport Systems Planning and Transport Telematics* at the Institute for Land and Sea Transport Systems, Technische Universität Berlin, led by Prof. Dr. Kai Nagel
• Agent-based approach similar to the approach used in TRANSIMS

  Was developed since TRANSIMS was difficult to obtain outside the US

• Differences between MATSIM & TRANSIMS

  File formats

  Handling of agents & activity chains

  Faster traffic flow simulation

  Traffic assignment routines
Summarizing

- Activity-based and agent-based models provide a new approach to travel demand modeling
- Both models superior in performance to conventional four-step models
- Much more applicable to evaluating current demand management scenarios such as congestion pricing, parking cost etc.
• However many agencies still use the conventional models for forecasting and scenario evaluation

Data requirements for inputs and calibration

Existing modeling softwares haven’t been able to accommodate the model requirements

Many more models to estimate and higher run times compared to traditional model

Staff skills and comfort level

The list goes on....
U of M research on Agent-based models
• MATSIM & TRANSIM utilize the theory behind agent-based demand models

Similar to activity-based demand models, activities are the unit of analysis.

Analysis is conducted at the individual/agent level all the way through assignment.

But they still use some aspects of traditional models - for example, TRANSIMS uses the shortest path algorithm.
Agent-based route choice models

Zhang & Levinson (2004); Zhu & Levinson (2007)

Goal was to develop a route choice model utilizing the behavioral framework of individuals

Agents defined in the model

- Traveler
- Node
- Arc or link
Traveler Characteristics

Value of time: influence route choice decision

Travel budget: decide job location choice

Knowledge: learn both through experience and from node, spread along travel route
• **Node Characteristics**

  **Number of jobs**: available position for traveler to compete

  **Knowledge**: pooled knowledge from visiting travelers
• Rules

Travelers form knowledge and exchange this knowledge through nodes.

Travelers choose route with bounded rationale.

Travelers change job location once they suffer losses and their ability to move is limited.
Model Framework

Model Initialization → Trip Generation Network

Network Origin-Destination Estimator → OD Table

Policy Module → Agent-based Route Choice

Agent-based Route Choice → Link Flow

Equilibrium

Equilibrium Yes → MOE Statistics

Equilibrium No → Toll Strategy
Network Traffic Generation

Randomly moving forward

Travel

Cost > Budget

Accept current node as destination

Everyone has a destination

Initial OD Table

No

Yes

ARC

New Link Flow

Current

Cost > Budget

Yes

No

Any adjacent node with less cost and available position

Yes

No

Competing with other travelers and moving if success

Moving possibility for any traveler

New OD Table

Yes

No

OD Initialization

Initial OD Table

No

Yes

OD Updating

No

Yes

Everyone has a destination

Initial OD Table
Initialization

Moving Forward One Step

Exchanging Shortest Path Information

All travelers arrive at destination?

Yes

Update route choice of each traveler

New link flow updated according to route choice

Equilibrium

No

Nodes

N shortest path from other nodes to current nodes

Shortest path from origin to current node

Path with least general cost

Yes

MOE of network

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Information Exchange

Exchanging Information

Vertices
Centroids
Traveler's Knowledge
Node's Knowledge

Diagram showing the exchange of information between nodes 1, 2, 3, 4, and 5.
Model Application

- Chicago Sketch Network
  - 387 centroids
  - 933 nodes
  - 2950 links
  - 1.13 million traveler agents
Figure 4: Error in Link Flow between ARI and OBA assignment on CHS

Figure 5: Relative Error in Link Flow between ARI and OBA assignment on CHS
Conclusions

• The agent-based route choice model simulates how individuals make route choice decisions

• Incorporates the behavioral framework of individuals considering the acquisition and processing of spatial information

• Model seems realistic even when applied to large networks
• Biggest advantage over traditional model
  
  Ability to track the evolutionary decisions of travelers

• Accounts for heterogeneity in travelers
  
  Allows for evaluation of policy measures such as congestion pricing (tolls)
Extra Slides
Assignment from a conventional 4-step model
Assignment outputs from TRANSIMS
Activity-based Modeling Approach

- Disaggregate analysis usually at individual level

  Generation of representative population

- Output - simulated daily travel itinerary
  Individual’s activities
  Location
  Sequence
  Travel between activities
• Trips then aggregated typically to zonal level (Monte-Carlo procedure)

• Zonal level trips then assigned to the network
ACTIVITY & TRAVEL DECISION FRAMEWORK

Urban Development

Household Decisions
- work, residence, auto ownership, activities
- sequence, location, mode
- route, speed

Activity & travel scheduling

Mobility & lifestyle

Implementation & route scheduling

Transportation System Performance

Source: Ben-Akiva