Travel Demand Modeling

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Transportation Systems Analysis: Demand & Economics

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Review

● Discrete Choice Framework
  – A decision maker \( n \) selects one and only one alternative \( i \) from a choice set \( C_n = \{1, \ldots, J_n\} \)
  – Random Utility Model where

\[
U_{in} = V_{in} (\text{attributes of } i, \text{ characteristics of } n, \beta) + \varepsilon_{in}
\]

● Discrete Choice Models
  – Multinomial Logit
  – Nested Logit
    • Correlated Alternatives
    • Multidimensional Choice

Next… Travel Demand Modeling
Outline

- Introduction
- Approaches
  - Trip
  - Tour
  - Activity
- Emerging Approaches
Long Term Choices

- **Urban Development**
  - Firm location and relocation decisions
  - Firm investment in information technology

- **Mobility and Lifestyle Decisions**
  - Labor force participation
  - Workplace location
  - Housing
  - Automobile ownership
  - Information technology ownership and access
  - Activity program
Activity and Travel Pattern Choices

- Activity sequence and duration
- Priorities for activities
- Tour formation
- Telecommunications options
- Access travel information
  - Traffic conditions
  - Route guidance
  - Parking availability
  - Public transportation schedules
- Reschedule activities
- Revise travel plans
Modeling Framework

- **Long Term**
  - Land Use and Economic Development
  - Household & Individual Behavior
    - Lifestyle and Mobility Decisions
    - Activity and Travel Scheduling
    - Implementation and Rescheduling
- **Short Term**
  - Transportation System Performance

Massachusetts Institute of Technology
The Fundamental Modeling Problem

- Adequately represent a decision process that has an inordinate number of feasible outcomes in many dimensions

- Example - Activity Schedule

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of activities</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Sequence</td>
<td>10!</td>
<td></td>
</tr>
<tr>
<td>Timing</td>
<td>10 per activity</td>
<td>100</td>
</tr>
<tr>
<td>Location</td>
<td>1000 per activity</td>
<td>10,000</td>
</tr>
<tr>
<td>Mode</td>
<td>5 per activity</td>
<td>50</td>
</tr>
<tr>
<td>Route</td>
<td>10 per activity</td>
<td>100</td>
</tr>
<tr>
<td><strong>Total Number of Activity Schedule Alternatives</strong></td>
<td>10^{17}</td>
<td></td>
</tr>
</tbody>
</table>

- Simplify
- Achieve valid results
Simplifying the Problem

- Discrete time intervals
- Individuals defined by socioeconomic variables
- Divide space into zones
- Categories of activities
- Depiction of travel patterns
  → trips, tours, activity schedules
Approaches to Modeling Travel

- Trip-based
- Integrated trip-based
- Tour-based
- Activity schedule
Representing Activity/Travel Behavior

**Schedule**

- **Time**
  - H: Home
  - W: Work
  - S: Shop
  - D: Dinner out

**Tours**

**Trips**
Trip-Based: The 4-Step Model

Trip Purpose
- Home-based work (HBW)
- Home-based shop (HBS)
- Home-based other (HBO)
- Non-home-based (NHB)

Behavioral Steps
1. Trip Generation (Frequency)
2. Trip Distribution (Destination)
3. Modal Split (Mode)
4. Assignment (Route)
The 4-Step Model: Trip Generation

● Trip Production
  • Household Size, Household Structure, Income, Car Ownership, Residential Density, Accessibility

● Trip Attractions
  • Land-use and Employment by Category (e.g. Industrial, Commercial, Services), Accessibility

● Cross Classification, Regression, Growth Factor
The 4-Step Model: Trip Distribution

- Trip matrix

<table>
<thead>
<tr>
<th>Generations</th>
<th>Attraction</th>
<th>O</th>
<th>O</th>
<th>O</th>
<th>∑T_{ij}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T_{11}</td>
<td>T_{12}</td>
<td>T_{13}</td>
<td>...</td>
<td>T_{1j}</td>
</tr>
<tr>
<td>2</td>
<td>T_{21}</td>
<td>T_{22}</td>
<td>T_{23}</td>
<td>...</td>
<td>T_{2j}</td>
</tr>
<tr>
<td>3</td>
<td>T_{31}</td>
<td>T_{32}</td>
<td>T_{33}</td>
<td>...</td>
<td>T_{3j}</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>i</td>
<td>T_{i1}</td>
<td>T_{i2}</td>
<td>T_{i3}</td>
<td>...</td>
<td>T_{ij}</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>J</td>
<td>T_{11}</td>
<td>T_{12}</td>
<td>T_{13}</td>
<td>...</td>
<td>T_{Jj}</td>
</tr>
</tbody>
</table>

\[ \sum_i T_{ij} = D_1 \quad D_2 \quad D_3 \quad ... \quad D_j \quad ... \quad D_J \quad \sum_i \sum_j T_{ij} = T \]
The 4-Step Model: Trip Distribution

● Gravity Model

\[ T_{ij} = \alpha_i O_i \beta_j D_j f(C_{ij}), \quad i = 1 \ldots I \text{ and } j = 1 \ldots J \]

\[ \sum_j T_{ij} = O_i, \quad i = 1 \ldots I \]

\[ \sum_i T_{ij} = D_j, \quad j = 1 \ldots J \]

- Where,
  - \( f(C_{ij}) \) = Function of the generalized cost of travel from \( i \) to \( j \) and
  - \( \alpha_i \) and \( \beta_j \) are balancing factors

Solve iteratively for \( T_{ij}, \alpha_i \) and \( \beta_j \)
The 4-Step Model: Modal Split

- **Logit**

  \[
  P(\text{auto}) = \frac{e^{V_{\text{auto}}}}{e^{V_{\text{auto}}} + e^{V_{\text{transit}}}}
  \]

- **Nested Logit**

  \[
  P(\text{NM}) = \frac{e^{\mu_{\text{NM}}}}{e^{\mu_{\text{NM}}} + e^{\mu_{\text{M}}}}
  \]
The 4-Step Model: Assignment

- Route Choice
  - Deterministic: Shortest Path, Minimum Generalized Cost
  - Stochastic: Discrete Choice (e.g. Logit)
- Equilibrium
  - Supply Side
  - User Equilibrium vs. System Optimal
Limitations of the Trip-Based Method

- Demand for trip making rather than for activities
- Person-trips as the unit of analysis
- Aggregation errors:
  - Spatial aggregation
  - Demographic aggregation
  - Temporal aggregation
- Sequential nature of the four-step process
- Behavior modeled in earlier steps unaffected by choices modeled in later steps (e.g. no induced travel)
- Limited types of policies that can be analyzed
Complexity of Work Commute (Boston)

**Simple Commute**
(no other activities)
- home ➔ work

**Complex Commute**
(includes non-work activities)
- home ➔ daycare ➔ work
- home ➔ bank ➔ work

### All Adults
- 64% Complex
- 36% Simple

### Females with Children
- 77% Complex
- 23% Simple

### Males with Children
- 60% Complex
- 40% Simple

Complex Responses to Policies
Example: Peak-Period Toll

Potential Responses to Toll

(a) Change Mode & Pattern
(b) Change Time & Pattern
(c) Work at Home

Modeling Travel at the Level of the Individual

● Classic 4-step
  – Trip Frequency
  – Destination Choice
  – Mode Choice
  – Route Choice

● Beyond 4-step
  – Time of Day
  – Integrated Trips
  – Tours
Integrated Trip-Based Framework (e.g., MTC, STEP)

- Auto ownership
  - Home Based Work trips
- Home Based Other trips
- Non-Home Based trips
 Highlights of Integrated Trip-Based System

● Key features
  – Disaggregate choice models
  – Models are integrated, via conditionality and measures of inclusive value, according to the decision framework

● Key weakness
  – Modeling of trips rather than explicit tours
Tour-Based Framework (e.g. Stockholm)

- Work Tours
  - Business
  - Shopping
  - Personal Business
  - Other

- Other Tours
Highlights of Tour-Based System

● Key features
  – Explicitly chains trips in tours
  – Validated and widely applied

● Key weaknesses
  – Lacks an integrated schedule pattern
  – Doesn’t integrate well the time dimension

● Data requirements
  – Same as for trip-based models
Basics of Activity-Based Travel Theory

- Travel demand is derived from demand for activities
- Tours are interdependent
- People face time and space constraints that limit their activity schedule choice
- Activity and travel scheduling decisions are made in the context of a broader framework
  - Conditioned by outcomes of longer term processes
  - Interacts with the transportation system
  - Influenced by intra-household interactions
  - Occurs dynamically with influence from past and anticipated future events
Activity Schedule System

Activity and Travel

Activity Pattern

Tours
Activity Pattern

- Replaces trip and tour generation steps of trip and tour-based models
- Models number, purpose and sequence of tours
  - Tours are interdependent

Example of Activity Patterns

Portland, OR

Table removed due to copyright restrictions.

Tours

- Primary Tour
  - Primary and secondary destinations
  - Timing
  - Modes

- Secondary Tours
  - Primary and secondary destinations
  - Timing
  - Modes
Model Structure

Activity Pattern
primary activity/tour type, 
#/purpose secondary tours

Primary Tours
timing, destination 
and mode

Secondary Tours
timing, destination 
and mode
Highlights of Activity Schedule System

● Key feature
  – Integrated schedule

● Key weaknesses
  – Larger choice set
    • Unrealistic behaviorally
    • Computationally burdensome
  – Incomplete representation
    • Coarse representation of schedule
    • Coupling constraints
Portland Activity-Based Model
[570 Pattern Alternatives]

Day Activity Pattern

Home Based Tours
- Time of day
- Primary destination
- Primary mode

Work-Based Subtour

Location of Intermediate Stops
## Preliminary Application Results

### $0.50/mile Peak Period Toll

- **Shift in patterns**

### Type of Pattern by primary activity

<table>
<thead>
<tr>
<th>Type of Pattern by primary activity</th>
<th>% before</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>62.2%</td>
<td>-2.0%</td>
</tr>
<tr>
<td>Maintenance</td>
<td>25.0%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Leisure</td>
<td>12.8%</td>
<td>3.3%</td>
</tr>
<tr>
<td>All patterns</td>
<td>100.0%</td>
<td></td>
</tr>
</tbody>
</table>

Preliminary Application Results

$0.50/mile Peak Period Toll

- Shift in work patterns

<table>
<thead>
<tr>
<th>Type of Work Pattern</th>
<th>% before</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>At home</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 sec tours</td>
<td>1.3%</td>
<td>11.5%</td>
</tr>
<tr>
<td>1+sec tours</td>
<td>4.0%</td>
<td>6.2%</td>
</tr>
<tr>
<td><strong>Simple work tour</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 sec tours</td>
<td>30.7%</td>
<td>-1.2%</td>
</tr>
<tr>
<td>1+sec tours</td>
<td>17.0%</td>
<td>-3.6%</td>
</tr>
<tr>
<td><strong>Complex work tour</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 sec tours</td>
<td>32.6%</td>
<td>-2.3%</td>
</tr>
<tr>
<td>1+sec tours</td>
<td>14.3%</td>
<td>-4.7%</td>
</tr>
<tr>
<td><strong>Total work patterns</strong></td>
<td>100.0%</td>
<td>-2.0%</td>
</tr>
</tbody>
</table>

Preliminary Application Results

$0.50/mile Peak Period Toll

- Shift in work tour mode and chaining

<table>
<thead>
<tr>
<th>Type of work tour</th>
<th>% before</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive alone simple</td>
<td>36.6%</td>
<td>-20.3%</td>
</tr>
<tr>
<td>Drive alone chained</td>
<td>39.2%</td>
<td>-17.3%</td>
</tr>
<tr>
<td>Other simple</td>
<td>13.6%</td>
<td>47.4%</td>
</tr>
<tr>
<td>Other chained</td>
<td>10.6%</td>
<td>54.9%</td>
</tr>
<tr>
<td>Total work tours</td>
<td>100.0%</td>
<td></td>
</tr>
</tbody>
</table>

Preliminary Application Results

$0.50$/mile Peak Period Toll

- Tour purpose and time-of-day effects

<table>
<thead>
<tr>
<th>Percent change in total number of home-based tours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>A.M. Peak</td>
</tr>
<tr>
<td>P.M. Peak</td>
</tr>
<tr>
<td>Midday</td>
</tr>
<tr>
<td>Outside Peak</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Trends in Transportation Demand Modeling

● **DATA:**
  Massive OD Surveys → Small-Scale Detailed Surveys

● **MODELING METHODS:**
  Aggregate Models → Disaggregate Models
  Static → Dynamic
  Canned Statistical Procedures → Flexible Estimation of Models

● **APPLICATION/FORECASTING:**
  Mainframe → User-friendly GIS, powerful PC Systems
  Aggregate Forecasting → Disaggregate Forecasting (microsimulation)

● **BEHAVIORAL REPRESENTATION:**
  Homogeneous → Heterogeneous (including demographics, attitudes and perceptions)
  Trips → Activity Schedules
Emerging Travel Modeling Approaches

● Activity and Trip-Chaining Models
  – Activity time allocation
  – Life cycle, household structure and role
  – Temporal variation of feasible activities over the day
  – Distribution of travel levels of service during the day

● Increased Travel and Information Choices
  – “No travel” options (tele-commuting, tele-shopping, etc.)
  – Information causes changes in departure time, mode and route choice
  – Choice set formation