Knoxville’s Hybrid Trip-Based / Tour-Based Model

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Tennessee Model Users Group Meeting
March 10, 2010
Agenda

- Background & Motivation
- Overview of Model Design
  - Review of Traditional and Activity-Based Models
  - New Hybrid Model Design
- Details of Two Innovations
  - Double Destination (Origin-Destination) Choice
  - Mode-Destination Choice Hierarchy
- Results
  - Comparison with Trip-based Model
  - New Policy Variables and Sensitivity
- What’s Next?
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❖ Background & Motivation
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❖ Results
   ➢ Comparison with Trip-based Model
   ➢ New Policy Variables and Sensitivity
❖ What’s Next?
Background: Knoxville

- **Knoxville Area**
  - Population: 863,000
  - Area: 3,425 sq. mi.
  - Network: 6,626 lane miles
  - TAZ: 1019 zones
Background: Knoxville

- Knoxville Area
- Multinucleated
- Topography
Background

2000  Household Travel Survey
2002  New Trip-based Model
2005  Model Peer-Review
2007  *External Cordon Line Survey*
2008  Land Use Model (ULAM)
2008  *Household Travel Survey*
2008  KAT On-board Ridership Survey
2009  *New Hybrid Trip/Tour-based Model*
Motivation

- Model Peer Review
  - Noted poor distribution and k-factors
- Policy and Planning Interests
  - Built environment / land use interactions
  - Importance of transit and walking
  - Future tolling / pricing scenarios?
Peer Review Recommendations

- **Additional Data Collection:**
  - New external survey: **Completed**
  - Household survey update with outlying counties: **Completed**
  - On-board survey: **Completed**
  - Commercial vehicle/freight survey

- **Further Model Refinements:**
  - Land use modeling: **ULAM model developed**
  - Enhanced network detail & zone structure: **Ongoing Refinement**
  - Mode choice model development: **Completed**
  - Freight model refinements: **New three-class truck model**
  - Use Census data to improve modeled commuting: **Completed**
  - Destination choice modeling & removal of k-factors: **Completed**
Guiding Principles of New Model Update

- **Focus on the Foundational:**
  - How many trips / how much VMT is affected?

- **Focus on Current, “Hot Button” Planning Issues:**
  - Effects of Built Environment / Land Use
  - Importance of Transit Ridership and Walking
  - Future Tolling Options

- **Focus on Effectiveness:**
  - How much realism / policy sensitivity will be gained for how much money and model run time?
Knoxville Model Update Background

- **Key goals:**
  - Improved fundamentals of travel behavior
  - Sensitivity to new planning / policy issues
  - Reasonable model run times
  - Reasonable development costs and timeframe

- **A new solution**
  - Based on peer-reviewed, published research
  - Multiple nominations as a Best Paper at a national conference
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Limitations of Traditional Models

- Serious theoretical problems
  - Physically impossible travel patterns
  - Aggregation bias / inaccuracy
  - Reliance on fudge factors

- Lack of policy sensitivity
  - Insensitivity to gas prices, tolls, parking fees
  - Insensitivity to urban design / built environment
  - Insensitivity of timing of travel to congestion
  - Insensitivity of destinations to transit service
Why not Activity-Based Models?

- So, why didn’t we recommend a shift to activity-based modeling?
  - They clearly improve the fundamentals of the travel forecast.
    - They eliminate aggregation bias in traditional models and the inconsistencies related to non-home-based trips.
  - They offer improved sensitivity and planning capabilities related to all the current, “hot-button” planning issues.
First Tour & Activity-Based Models
Tour & Activity-Based Models Completed (8)
Tour & Activity-Based Models Under Development (+6)

- Seattle, since 2008
- Portland, 1998
- Boise, 1995
- Sacramento, 2007
- San Francisco, 2001
  Bay Area, since 2006
- Denver, since 2009
- Dallas-Ft.Worth, 2006
- Columbus, 2006
- Atlantas, since 2007
- New York, 2004
Three Tour & Activity-Based Models
NOT in use?!!

- Activity/Tour-based Model Complete and In Use (5)
- Activity/Tour-based Model Complete and NOT In Use (3)
- Activity-based Model Under Development (6)
  - Other MPO’s (374)

Bernardin Lochmueller & Associates

KNOXVILLE REGIONAL TRANSPORTATION PLANNING ORGANIZATION
What’s the Problem?

After 10 years, only 5 activity-based models are in use by MPOs.

- 99% of MPOs (381 of 385) still use more or less traditional models
- 3 MPOs have a tour/activity-based model that they do *NOT* use!
- Atlanta has been building an activity-based model for almost 8 years and still isn’t close to completion
What’s the Problem?

- Activity-based models generally cost several times as much as traditional models to develop (~$1 mill vs. $250k, not including data)
- Their application costs in computer hardware, computing time and staff costs are often even more disproportional
  - Typically run on machines with more than 10 processors (one requires a 64 processor machine)
  - Computing times for an average result still require about two weeks! (1-2 days / run x 10 runs for an average)
Why not Activity-based?

- Although they address the fundamentals and current issues,
- They are **not cost effective**!
### Cost-Effectiveness

#### Activity-Based
- 2-3 years to develop
- $600-800k (+ data) consultant fees
- Runs in 1-2 days
- On computers with 10+ processors

#### Knoxville’s Hybrid
- 9 months to develop
- under $300k (+ data) consultant fees
- Runs under 4 hours
- On standard dual core machines

- Importance of **data** and agency support for any advanced modeling
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A New, Alternative Model Design

- Methodology
  1. A hybrid *disaggregate* / *aggregate* system
     - To maximize model fidelity and minimize run time
Variables

- TAZ
- Accessibility
- Network
- Travel Times
- Flow Averaging
- Link Flows

Models

- Population Synthesizer
- Vehicle Availability Choice
- Activity / Tour Generation
- Tour Mode Choice
- Stop Location Choice
- Stop Sequence Choice
- Departure Time Choice
- HOV and Toll Choices
- Traffic Assignment

Disaggregate Models
Aggregate Models
Hybrid **disaggregate / aggregate**

- **Disaggregate population**
  - individual households choose activities and modes

- **Deterministic outcomes**
  - no simulation = no simulation error
  - average forecasts from a single model run

- **Aggregate spatial and temporal models**
  - some bias / insensitivity to demographics
  - reasonable run times
A New, Alternative Model Design

- **Methodology**
  1. A hybrid *disaggregate* / *aggregate* system
     - To maximize model fidelity and minimize run time
  2. *Disaggregate* vehicle & tour mode choices
  3. Departure time choice
Variables

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Models

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  - Vehicle Availability Choice
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- Aggregate Models
  - Stop Location Choice
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  - Traffic Assignment
Vehicle Availability Choice

- Ordered response logit model
- Each individual household chooses how many vehicles to own / lease
  - No aggregation bias
  - Vehicle ownership levels respond to
    - Demographics (household size, income, number of workers, students, etc.)
    - Gas Prices
    - Transit Availability
    - Urban Design (pedestrian environment / grid vs. cul-de-sac design)
Disaggregate Tour Mode Choice

- Mode choices made by individual households
  - No aggregation bias
  - Consider the probability of transit use for:
    - 100 households with an average of 2.2 cars per household
    - 5 households with no cars, 15 hh with one car, 50 hh with two cars, 20 hh with three cars, 5 hh with four cars, 5 hh with five cars

- Mode choices consistent for whole tours
- Each tour type has very distinct mode shares
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Disaggregate Models

Aggregate Models

Variables

- Models

Disaggregate Models

Aggregate Models
Departure Time Choice

- Each tour type has a distinct temporal distribution
- Demand by 15-minute intervals based on:
  - Travel time during period (peak-spreading)
  - Bias variables interacted with sinusoidal functions:
    - Origin / Destination Accessibilities (urban vs. rural)
    - Return factor (ratio of employment to population at origin vs. destination)
    - SOV vs. HOV trip
Departure Times by Time of Day

- The models reproduce the temporal distribution of trips
A New, Alternative Model Design

- Methodology
  1. A hybrid *disaggregate* / *aggregate* system
     - To maximize model fidelity and minimize run time
  2. *Disaggregate vehicle & tour mode choice*
  3. *Departure time choice*
  4. Feedback of *ACCESSIBILITY* as well as travel time
     - To introduce sensitivity to ‘lower level’ choices in ‘upper level’ decisions
Variables

Network

TAZ

Accessibility

Travel Times

Flow Averaging

Link Flows

Models

Disaggregate Models

Population Synthesizer

Vehicle Availability Choice

Activity / Tour Generation

Tour Mode Choice

Aggregate Models

Stop Location Choice

Stop Sequence Choice

Departure Time Choice

HOV and Toll Choices

Traffic Assignment
Accessibility

- What is Accessibility?
  - How easy is it to get somewhere else

- A simple example:

\[
Accessibility_i = \ln \left[ \sum_{zones(j)} Emp_j \times \exp(\beta \times time_{ij}) \right]
\]

most accessibilities used were similar

- The average cost (expected disutility) of a trip from this zone [by a mode, etc]
Accessibility

- Accessibility can be used to fix some of the important shortcomings of the four-step model.

- How’s this work?
  - The four-step model is limited because it is sequential (memory, but no foresight).
  - Accessibility introduces expectation or foresight into the models to produce a reasonable simultaneity of considerations.
Accessibility

What does Accessibility (the expected cost of a trip) affect?

- The likelihood of making a trip
  - land use / built environment effects; induced trip-making
- The mode used for a trip
  - expected cost by transit vs. car
- The destination of the trip
  - Trip chaining effects: convenience = the expected cost of a further trip (next trip in the chain) from a destination
  - Residential location effects on trip length
Network TAZ Flow Averaging

Traffic Assignment HOV and Toll Choices Stop Sequence Choice Stop Location Choice Departure Time Choice HOV and Toll Choices Traffic Assignment

Stop Location Choice

Activity / Tour Generation Tour Mode Choice

Vehicle Availability Choice

Population Synthesizer

Disaggregate Models Aggregate Models

Variables Models

TAZ

Accessibility

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Link Flows
Travel Cost Elasticity

- Found elasticities of out-of-home activities with respect to accessibility of 0.13 - 0.16
  - Lower tour-making by residents of rural (lower-accessibility) areas,
  - Decreased tour/stop-making in response to congestion (decreased accessibility),
  - Induced tour/stop-making in response to added network capacity (increased accessibility),
  - Induced tour/stop-making in response to new land use developments in other nearby zones (increased accessibility)
Network

TAZ

Flow Averaging

Stop Location Choice

Activity / Tour Generation

Tour Mode Choice

Vehicle Availability Choice

Population Synthesizer

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Variables

Models
Residence Effects on Trip Length

- When people choose their residence location, they also choose how far they are willing to travel.
- We allowed travelers’ willingness-to-travel, and hence, trip lengths to vary as a function of the accessibility of their residence location.
  - The willingness-to-travel of residents of the most urban (most accessible) areas was about 10% lower than the regional average.
  - The willingness-to-travel of residents of the most rural (least accessible) areas was about 200% higher or twice the regional average for most activity types.
Cost Elasticity from Accessibility

- Including accessibility in both activity generation and stop location choice reflects *fewer, but longer* rural tours; *more shorter urban* tours
A New, Alternative Model Design

❖ Methodology

1. A hybrid \textit{disaggregate} / \textit{aggregate} system
   - To maximize model fidelity and minimize run time

2. \textit{Disaggregate tour mode choice}

3. \textit{Departure time choice}

4. Feedback of \textit{ACCESSIBILITY} as well as travel time
   - To introduce sensitivity to ‘lower level’ choices in ‘upper level’ decisions

5. A ‘\textit{double destination choice}’ framework
   - Produce trips consistent w/ tours & trip-chaining behavior
Accessibility

TAZ

Network

Travel Times

Flow Averaging

Link Flows

Variables

Disaggregate Models

Population Synthesizer

Vehicle Availability Choice

Activity / Tour Generation

Tour Mode Choice

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Stop Sequence Choice

Aggregate Models

Departure Time Choice

HOV and Toll Choices

Traffic Assignment

Models
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The Problem

- Trip distribution or destination choice is the largest source of error in traditional travel models (Zhao & Kockelman, 2002)

- Gravity models typically explain only about 10%-30% of the variation in destination choices
Understanding the Problem

- Traditional trip-based models are commonly criticized for lack of consistency with tours, but what does this mean?
  - Open tours which are physically impossible
  - Inconsistency with tour cost minimization which is behaviorally implausible
An example of a possible trip table from a gravity model with seven trips (H-a, H-c, a-H, a-c, b-b, b-c, c-c):

- There is no way that all seven of these trips can be arranged into one or more tours.
- Real travelers could not produce the travel pattern in this trip table, but a four-step model can!
- For instance, one traveler doesn’t return home!
Tour Cost Minimization

- Stops Locations (trip ends) which Minimize Tour Costs:
  - Will be closer to home (radial dimension)
  - Will be closer to each other (angular dimension)

- In the Four-Step Model:
  - Home-based trips minimize radial costs, but **NOT** angular
  - Non-home-based trips minimize angular costs, but **NOT** radial
The Traditional (Sequential) Solution

- Proposed by Shiftan (1998), used in all tour / activity-based models in U.S.

\[
\text{ATT} = H_b + ba - H_a
\]

\[
\text{ATT} = H_c + ca - H_a
\]
The New Problem

- Building tours sequentially
  - Requires computationally intensive simulation
  - Takes as many steps as stops
  - Results in long model run times
A New Simultaneous Solution

- First choose all stop locations (where to go)
- Then choose how to sequence them (where to go from)
New Simultaneous Approach

- **Advantage**: only two steps regardless of how many stops = fast run times!
- **Challenge 1**: how to insure that sequences form closed tours?
- **Challenge 2**: how to include the cost of non-home-based trips in the choice of stop locations?
Traveler Conservation Constraint

- Requiring that whoever goes in, comes out results in consistency with tours

\[ \sum T_{hij} = D_{hj} = T_{hj} = O_{hj} = \sum T_{hjk} \quad \forall h, j \]
An example of a possible trip table with a Traveler Conservation Constraint for seven trips (H-a, H-b, a-H, a-H, a-c, b-a, c-a):

- These trips could be produced by either the tours:
  - H-a-H & H-b-a-c-a-H
  - H-b-a-H & H-a-c-a-H

- It can be proved that any trip table with identical row and column sums is consistent with some set of tours.
New Simultaneous Approach

- **Advantage:** only two steps regardless of how many stops / tours = fast run times!
- **Challenge 1:** how to insure that sequences form closed tours?
- **Challenge 2:** how to include the cost of non-home-based trips in the choice of stop locations?
Independence

In traditional models, two equidistant, equal-size destinations are equally probable.
What about Accessibility?

What if one is more accessible to other possible destinations?
Complementarity

Maybe the more accessible one is more probable - because you have to go a nearby destination anyway, and so it’s convenient.

Higher accessibility means the expected cost of a possible subsequent trip is lower.
ACDC Models attempt to minimize both dimensions of tour costs:

- Stops will be closer to home (radial dimension)
- Stops will be closer to each other (angular dimension)

\[
\ln \gamma S_j + \beta_c e_{kj} + \beta_{AS} A_j^S + \beta_{AC} \ln \sum_k d_{jk} B_k e^{c_{jk}}
\]

\[
P_{j|h} = \frac{e^{\ln \gamma S_j' + \beta_c e_{kj'} + \beta_{AS} A_j'^S + \beta_{AC} \ln \sum_k d_{jk'} B_k e^{c_{jk'}}}}{\sum e^{\ln \gamma S_j' + \beta_c e_{kj'} + \beta_{AS} A_j'^S + \beta_{AC} \ln \sum_k d_{jk'} B_k e^{c_{jk'}}}}
\]
Policy Analysis & Planning

What happens if a new development occurs?
In current models, all the other destinations get equally less probable.
Policy Analysis & Planning

In ACDC models, nearby destinations are affected more than distant ones.

Complements get more probable – new trips to old destinations!
Sensitivity Analyses – Real World Example

- Comparison of gravity and ACDC models for a new development to illustrate spatial competition and trip-chaining effects.
  - A new factory employing 1,000 workers in Loudon county indirectly attracts 125 daily non-work stops to the county.
Sensitivity Analyses

- Loudon County factory’s effect on shopping stops
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Choice Hierarchy

- In traditional four-step models, mode choice was modeled conditional on (after) destination choice (because the focus was on choice riders and commuting in larger MPOs).
- Instead, we modeled stop location or destination choice conditional on (after) mode choice
Choice Hierarchy

- This reverse choice hierarchy reflects the fact that *many travelers are more likely to change destinations than switch modes*
  - Even for work tours, the data suggests that in Knoxville, people are more likely to change jobs than change their travel mode to work
  - This may not be as unreasonable as it seems, considering captive riders, dependent on the bus to get to work
- Imposing the traditional hierarchy may be a source of "optimism bias" in transit forecasts
Optional Levels of Detail

- According to TRB’s SR288, **no mode choice** in
  - 75% of small MPOs
  - 10% of large MPOs
- Traditional hierarchy **requires** transit network
- Knoxville - reverse hierarchy **with** transit network
- Evansville - reverse hierarchy **without** network
  - Instead of transit accessibility variables based on transit network travel times (waits, transfers, etc.)
  - Evansville will use proxy variables such as % of TAZ within walk to bus and # of buses per hour
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Improved Accuracy

- Care must be taken in making fair apples-to-apples comparisons between traditional and advanced models

- Knoxville’s trip-based & hybrid models:
  - Different survey data, 2000 vs. combined 2000+2008
  - Essentially same
    - Network
    - TAZ
    - Counts
    - Through Trips
Better origin-destination patterns

- Guaranteed physically possible
- 33% increase over the ability of the previous model to explain observed trips in the household surveys
- Able to reproduce commuting patterns from Census without the use of fudge factors
Commuting

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<td>1,755</td>
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</tbody>
</table>
Knoxville Hybrid Performance

- Better origin-destination patterns
  - Guaranteed physically possible
  - 33% increase over the ability of the previous model to explain observed trips in the household surveys
  - Able to reproduce commuting patterns from Census without the use of fudge factors
  - Better forecasting
Network Assignment

- Improved accuracy versus base year counts

<table>
<thead>
<tr>
<th>Volume Range</th>
<th>Acceptable Range</th>
<th>% Error</th>
<th>% Error</th>
<th>% RMSE</th>
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<tr>
<td></td>
<td></td>
<td>Trip-based</td>
<td>Hybrid</td>
<td>Trip-based</td>
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<td>1,001 to 2,000</td>
<td>±200%</td>
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<td>2.8</td>
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<td>40,001 to 50,000</td>
<td>±15%</td>
<td>8.6</td>
<td>-2.5</td>
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<td>50,001 to 60,000</td>
<td>±10%</td>
<td>3.7</td>
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<tr>
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<td>±10%</td>
<td>-3.5</td>
<td>-6.0</td>
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<tr>
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<td>±10%</td>
<td>2.9</td>
<td>-5.2</td>
<td>33.0</td>
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</table>
Knoxville Hybrid Performance

- Better origin-destination patterns
  - Guaranteed physically possible
  - 33% increase over the ability of the previous model to explain observed trips in the household surveys
  - Able to reproduce commuting patterns from Census without the use of fudge factors
  - Better forecasting

- Better roadway volumes
  - 10% decrease in %RMSE (32.95 vs. 29.85)

- Better response properties & policy sensitivity
Agenda

- Background & Motivation
- Overview of Model Design
  - Review of Traditional and Activity-Based Models
  - New Hybrid Model Design
- Details of Two Innovations
  - Double Destination (Origin-Destination) Choice
  - Mode-Destination Choice Hierarchy
- Results
  - Comparison with Trip-based Model
  - New Policy Variables and Sensitivity
- What’s Next?
Realism & Policy Sensitivity

- The hybrid model design offers:
  - Guarantee of physically possible travel patterns
  - Sensitivity to gas prices, parking costs and tolls
  - Transit, bicycle and pedestrian travel
  - Sensitivity to urban design / built environment
  - More realistic representation of seniors, the poor…
  - More accurate commuting patterns, traffic impacts and travel times
  - Ability to predict shifts in the timing of travel
  - Improved truck and external models
Agenda

- Background & Motivation
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- What’s Next?
Knoxville Applications

- Possible tolling / pricing scenarios?
- Scenario planning with multiple land use scenarios from ULAM land use model
  - To support East Tennessee Quality Growth (ETQG) initiative
  - To investigate livability and sustainable mode usage
Knoxville Land Use Modeling
Historic Trend/Status Quo Scenario

Historical Growth
2000 - 2007
Sustainable Growth Scenario
Land Use Allocation Results for Sustainable Scenario
Potential Travel Demand Model
Scenario Performance Measures

- **Vehicle Miles of Travel (VMT)**
  - Current Model Projects -1.5% less VMT for Sustainable Growth Scenario

- **Vehicle Hours of Travel (VHT)**

- **Total Daily Vehicle Hours of Delay**

- **% of Lane Miles Congested**

- **Mode Share**
  - Shift to Transit for Transit Oriented Design
  - Shift to Pedestrian/Bike for Mixed Use Development Patterns
Pros & Cons of the Hybrid

 consulate:  
- Limited *disaggregate* results for data-mining  
- Limited ability to model *intra-household* interactions  
- Limited ability to deal with *complex scheduling* issues  

 consulate:  
- Consistency with *tours* and *trip-chaining* behavior  
- Improved *accuracy* vs. trip-based  
- Improved *policy sensitivity* vs. trip-based  
- Reasonable *run times* and development costs
Final thoughts

- There’s no one “right” way of modeling travel behavior for every region.
- There are a variety of different advanced model designs each with different pros and cons.
  - This approach has some advantages, in terms of computational efficiency / run time and development costs,
  - And it allows incremental improvements from existing models
  - But it does not offer all the advantages of activity-based models
- The ‘double destination choice’ framework allows for a new set of options for model designs.
Related Publications


Thank You!

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