Integrating Land Use, Transportation and Air Quality Modeling

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From the RFA:

“How might models that project changes in land-use and activity locations be improved to better reflect and integrate lifestyle, economic production, and public policy factors that drive vehicle miles traveled? How might spatial redistribution of activities and changes in land-use influence investments in transportation infrastructure and technology? Conversely, how might investment choices in transportation infrastructure and technology influence changes in spatial distribution of activities and land-use change?”
1) Obtaining realistic predictions of travel and air quality outcomes from integrating models will require more than loosely coupling existing land use and transportation models. It will require fundamental integration at a behavioral level – otherwise, important patterns of behavioral substitution will be missed.
2) Behavioral integration can be most effectively pursued using a disaggregate approach that combines household long-term choices regarding residential location, workplace, and auto-ownership, with short-term choices of daily activity pattern, scheduling, mode and destination in an activity-based framework.
Behavioral and Operational Components

Behavioral
  • Latent lifestyle choices
  • Substitution across long and short-term choices
  • Endogeneity and self-selection issues
  • Econometric estimation methods

Operational
  • Integration of activity-based models with urban simulation models of land use
  • Integration with traffic assignment models
  • Integration with current and emerging emissions models
  • Testing of integrated platform on alternative scenarios
Key Behavioral Hypotheses

- Household residence location choices are interdependent with the workplace choices of household workers.
- Household residence location choices are interdependent with vehicle ownership.
- Expectations of daily travel patterns influence longer-term choices of residence, workplace and auto-ownership, and these longer-term choices condition daily activity scheduling and travel.
Key Behavioral Hypotheses

- Treating long-term household choices and short-term activity and travel behavior in an integrated way can be facilitated by representing these choices as dimensions of a latent lifestyle choice.

- An integrated approach to modeling household lifestyle choices (residence, workplace, auto ownership, and daily activity and travel patterns) can produce more realistic substitution patterns, and ultimately better predictions of VMT and other factors that directly influence emissions.
Key Behavioral Hypotheses

• An accurate knowledge of spatial cognitive maps of decision makers in residential choice models will allow for a more realistic representation of perceived neighborhoods and the appropriate consideration of the spatial extent of choice factors impacting residential location choice.

• Careful representation of the endogeneity produced by interactions or aggregation of individual choices is critical to the ability of disaggregate behavioral models to produce plausible aggregate sensitivity and substitution patterns.
Selected Research Publications
(all of the publications on the following slides site the EPA Grant)

Behavioral Integration and Econometric Methods


Behavioral Integration and Econometric Methods


Selected Research Publications

Behavioral Integration and Econometric Methods


Behavioral Integration and Econometric Methods


Assessing Uncertainty

Selected Research Publications

Integrated Land Use and Transportation Model Applications
San Francisco, Salt Lake City, Paris, Detroit


Selected Research Publications

Public Participation

Visualization
Moving the Research into Practice in the Puget Sound Region

Puget Sound Regional Council

A special acknowledgement to Maren Outwater and others at the PSRC for their close collaboration on this work
Proposed Role of Models in Planning

Stakeholders

- Goals
- Objectives
- Policies
- Scenarios
- Evaluation
- Visualization
- Indicators
- Models
Why do we need integrated disaggregate models?

New Policies in VISION 2040
- Environment
- Economy
- Development Patterns
- Public Services
- Transportation
- Housing

New Solutions in Transportation 2040
- Demand Management
- Operational Solutions
- Tolling/pricing

New Impacts to be Measured
- Transportation Efficiency
- Growth Management
- Economic Prosperity
- Environmental Stewardship
- Quality of Life
- Equity
What Is UrbanSim?

UrbanSim is an integrated planning and analysis of urban development, incorporating the interactions between land use, transportation, and public policy.

![Diagram of UrbanSim system]

- **Services**
- **Governments**
- **Transportation**
- **Land**
- **Housing**
- **Developers**
- **Floorspace**
- **Households**
- **Labor**
- **Business**

- Flow of consumption from supplier to consumer.
- Regulation or pricing.
PSRC Integrated Model System Design

Simulates persons and households at a parcel level
Why the move to UrbanSim

Current models (DRAM/EMPAL) restricted in using plans as inputs
  • Plans need detailed measures of land
  • Requires density limitations in Urban Growth Area
  • Limited feedback with the travel models

Expanded and more flexible forecast output
  • Can fit forecasts to different geographies
  • Annual forecasts instead of 10-year increments
  • Greater forecast detail (households, jobs, built data, market values)

Micro-simulation supports next generation of travel demand models
  • Modeling individual households and persons, activities instead of trips

Open-source, collaborative approach
  • Created at UW, other MPOs implementing and researching improvements
Why the move to Activity Models

Current models (trip-based) do not represent transportation strategies well
  • Demand management strategies need linked activities (tours)
  • System management strategies need vehicle simulations
  • Tolling strategies require distributed values of time

Expanded and more flexible forecast output
  • Can distribute benefits and costs for equity analysis
  • Greater forecast detail (trips, tours, stops, temporal and spatial detail)

Micro-simulation supports next generation of operational models
  • Modeling individual vehicles for operational and air quality analysis
UrbanSim Geography

DRAM / EMPAL: Forecast Zones

UrbanSim: Individual Parcels or Gridcells
## Primary UrbanSim Databases

Five primary inputs and outputs

<table>
<thead>
<tr>
<th>Parcels</th>
<th>Buildings</th>
<th>Households</th>
<th>Persons</th>
<th>Jobs</th>
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<tr>
<td>Parcel id</td>
<td>Building id</td>
<td>Household id</td>
<td>Person id</td>
<td>Job id</td>
</tr>
<tr>
<td>Zones, cities, zip code, etc.</td>
<td>Parcel id</td>
<td>Building id</td>
<td>Household id / Job id (if worker)</td>
<td>Building id</td>
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<tr>
<td>1.18 million parcels</td>
<td>1.0 million buildings</td>
<td>1.28 million households</td>
<td>3.2 million people</td>
<td>1.85 million jobs</td>
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</table>
UrbanSim Models

Land Development Models
- Process Pipeline Events
- Real Estate Price Model
- Expected Sale Price Model
- Development Proposal Choice Model
- Building Construction Model

Household Location Models
- Household Transition Model
- Household Relocation Model
- Household Location Choice Model

Employment Location Models
- Employment Transition Model
- Employment Relocation Model
- Employment Location Choice Model

Workplace Location Models
- Economic Transition Model
- Home-based Job Choice Model
- Workplace Location Choice Model
- Job Change Model
Land use plan assumptions:
  • Type of development (residential, commercial, …) and density

Transportation system:
  • Accessibility measures from zone to zone, jobs 10-30 minute travel times

Critical area buffers:
  • Restrictions on parcels near streams, wetlands, slopes, shorelines, floodplains, etc.

Planned / Pipeline Developments:
  • Predetermine number of housing units, non-residential SQFT on parcels, year

Costs factors:
  • Land development variables
Model Design for Integrated Activity Models

CUSPA

Model Design for Integrated Activity Models

Transport Planning
- Transport Networks
- Parcel Attributes (Transport Development)
- Mobility Choice Simulator
- Person Day Simulator
- Special Generators (e.g., airport)
- OD Matrices

UrbanSim
- Parcel Attributes (Land Development)
- HH/Person day-tour-trip list
- Trip Aggregator
- Commercial movements
- Network traffic assignment
- Network performance (skims)

AB Household Travel Demand Simulator

Transport Model System

Opus Framework

Reporting and Query Subsystem
Incremental Approach to Implementation of Activity Models

Develop activity generator
- Assess changes in trip-making from tolling and growth management strategies
- Assess impacts on climate change and transportation efficiency

Link with current trip-based models
- Necessary to use in current transportation plan update
- Validation of activity generator with current models

Complete remaining activity model components
- Destination choice
- Mode choice
- Time of day
# Implementation Timeline

**Rest of 2008**

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- **Activity Generator Development and Calibration**
- **Activity Model Design**
- **Activity Model Development (into 2009)**
Destination 2030 Update and Regional Growth Strategy

Transportation Concepts & Strategies
- Pricing
- TDM
- System Mgmt
- Strategic Capacity Investment

Screening
- V2040 Regional Growth Strategy
  - Growth Distribution
- MPPs
  - Policy Analysis
- Impacts
  - EIS Impacts

Consistent/Inconsistent

Alternatives Analysis
- Alt. 1
  - UrbanSim
  - Criteria
  - V2040 RGS
  - V2040 MPP Analysis
- Alt. 2
  - Environmental Review
- Alt. 3
  - Regional Econ. Strategy
- Alt. 4
  - Public Comment

Preferred Alternative

Draft Plan
CUSPA
Refinements in UrbanSim and OPUS to Support Integration with Activity-based Models

- Flexible Geography and Data Structures
  - Shift to parcel and building level of detail
- New and Significantly Modified Models
  - Residential Location
  - Workplace Choice
  - Real Estate Development
- Assessing Uncertainty
  - Bayesian Melding
  - Current testing on Alaskan Way Viaduct project
- Visualization
Creating New Models in OPUS

- **Models can be implemented in the new GUI**
  - Most models can be implemented from Model Templates
  - When using templates, no coding required
  - Model specification and estimation is interactive
  - Drop a new model into a model list, and run!

- **Model Templates:**
  - Simple Model
  - Allocation Model
  - Regression Model
  - Choice Model
  - Agent Location Choice Model
New Model System Based on Parcels and Buildings
Advantages of Parcel Geography

- Parcels are clear behavioral units
- Parcels reflect original data sources
- Buildings map to parcels directly
- Land use regulations apply to parcels directly
- Parcels aggregate cleanly to other geographies
- Easier to interpret and diagnose models
Disadvantages of Parcel Geography

- **Variable size and shape**
  - Mitigate initially by using centroids for spatial calculations

- **Boundaries change over time**
  - Working on geometric subdivision and aggregation (demo later in presentation)
  - In the mean time, subdivide parcels but new sub-parcels share original centroid
Household and Employment Location Models
Using Employment as the example

Transition Model
- Annual regional control totals – change in jobs by sector
- Jobs losses
- New jobs to the region

Relocation Model
- Probability of each job changing location - by sector
- Jobs uprooted
- Jobs that stay put

Location Choice Model
- Jobs searching for a space in a building…’cubicle’
- Select one job at a time
- Sample possible locations
- Select new location
## Advances in Household Location Choice Using Time-Space Prism Accessibility

### Base Model

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### Accessibility Models

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<th>Work-to-home</th>
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| Log-likelihood            | -3997.1 | -3964.4 | -3953.0 | -3950.1 |
| Likelihood ratio          | 0.29922 | 0.30496 | 0.30695 | 0.30746 |
# Work at Home Choice Model

(Individual worker)

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<td>worker's education</td>
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<td>presence of children &lt; 13yr</td>
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<td>emp within 30 minutes’ drive</td>
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## Workplace Choice Model
(individual worker matched to individual job)

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Validation of Workplace Choice Model

Individual-level New Logit model
RMSE 1440

Previous aggregate gravity model
RMSE 2558
New Real Estate Development Models

• **Key elements**
  • Parcel-based unit of analysis
  • Development project templates
  • Development constraints
  • Return on investment calculations
  • Infill
  • Redevelopment
  • Building schedules
Example of Land Use Plan and Land Development Constraints

Example parcel
• 2.5 acres / 107,000 SQFT size
• Min Units 4.5, Max Units 8.7

Traits of each parcel factor into its attractiveness to location, development models:
• Price
• Proximity to downtown, jobs
• Vacant or built, etc.
Development Templates:
Can represent any land use mix, density, size
How Land Development is Modeled

Template #1
- Units Per Acre: 6
- Total Units: 14
- Min Parcel size: 87,000 SQFT
- Max Parcel size: 350,000 SQFT
- Land Use: SF Resid
- ROI: $440,000

Template #2
- Units Per Acre: 8.5
- Total Units: 20
- Min Parcel size: 87,000 SQFT
- Max Parcel size: 283,000 SQFT
- Land Use: SF Resid
- ROI: $536,000
How Land Use Plans Are Modeled

Land use plans converted to an overlay in GIS containing:

- Min and Max Housing Units (per Acre)
- Min and Max Floor Area Ratio

Every parcel assigned to a specific part of the GIS overlay:

- Constraints transferred to parcels
Assessing Uncertainty: Bayesian Melding

• Developed rigorous methodology for assessment of uncertainty in integrated land use and transport models based on Bayesian Melding (published in Transportation Research A, 2007)

• Currently testing an application to the question: what would happen if the Alaskan Way Viaduct adjacent to the waterfront in the Seattle CBD were demolished? It is at risk of collapse in the next earthquake.

• Note: the following results are PRELIMINARY, and will self-destruct in 10 minutes.
Some claim that alternatives which do not have comparable traffic capacity will cause massive failure of traffic in CBD and on I5.

Others claim that we should replace it with surface street and transit, and reclaim the waterfront. It won’t cause much traffic impact because people adapt.

How much would a low-capacity alternative affect travel times over 10 years?
Assessing Uncertainty with Bayesian Melding
Assessing Uncertainty with Bayesian Melding

Likelihood and posterior distribution

\( y_k \) is sqrt of observed quantity in zone \( k \)

\[
y_k | \Theta_i \sim N(\hat{a} + \hat{\mu}_{ik}, \hat{\sigma}_i^2)
\]

\[
\omega_i \propto p(y|\Theta_i) = \prod_{k=1}^{K} \frac{1}{\sqrt{2\pi\hat{\sigma}_i^2}} \exp \left[ -\frac{1/2(y_k - \hat{a} - \hat{\mu}_{ik})^2}{\hat{\sigma}_i^2} \right]
\]

\[
p(\Psi_k) = \sum_{i=1}^{I} \omega_i N(\hat{a}b + \Psi_{ik}, \hat{\sigma}_i^2), \quad k = 1, \ldots, K
\]
Assessing Uncertainty with Bayesian Melding

Quantity of interest: Travel times on selected routes

1. Observed # households, # jobs per group in 2005
2. Observed data in 2000
3. 1 iteration per year 2000–2020
4. Predictions for 2020
5. Simulated data about households, jobs, people’s workplaces
6. Accessibilities measures
7. Travel model (Emme)
8. Input parameters, traffic network (PSRC)
9. Observed travel times of selected commutes in 2005
10. 1 iteration per 5 years 2005, 2010, 2015, 2020
Assessing Uncertainty with Bayesian Melding

7 Famous Commutes Tracked by WSDOT Loop Sensor Data
Systematic bias in travel times predicted by travel model was corrected

$$\log(T) \sim N(\log(T_{sim}) - 0.25, 0.16^2)$$
Assessing Uncertainty with Bayesian Melding

How much difference in travel time on those famous commutes if we remove the Viaduct in 2010 and simulate land use and transport to 2020?

On distant routes < 1 minute, On others closer to 2-3 minutes
Assessing Uncertainty with Bayesian Melding

<table>
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<td>21.5</td>
<td>13%</td>
<td>22.4</td>
<td>13%</td>
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</tbody>
</table>

On shorter routes close to Viaduct, these translate to 9 – 16% increases in travel time.
Assessing Uncertainty with Bayesian Melding
Open Platform for Urban Simulation
(open source software)

The preceding applications are implemented in OPUS

Planning a major release next month:
www.urbansim.org
New Tools for Visualization

Interactive Visualization of Simulated Urban Spaces by Using Procedurally Generated Content

Online ID: #vis-1278
Acknowledgments

EPA R831837: Integrating Land Use, Transportation, and Air Quality Modeling. Science to Achieve Results Program


NSF EIA-0121326: Interaction and Participation in Integrated Land Use, Transportation, and Environmental Modeling. Information Technology Research Program