Integrating Urban Systems Modeling: From Land Use to Emissions

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Presentation Outline

- Urban form and transportation
- Integrated urban modelling
- Agent-based microsimulation & urban models
- An application: environmental impact modelling
URBAN FORM & TRANSPORT
The Transportation – Land Use Connection

Transportation and urban form are fundamentally linked. How we build our city directly determines travel needs, viability of alternative travel modes, etc.

Transportation, in turn, influences land development and location choices of people & firms.
Transportation - Activity System Interactions

(a) The Urban Activity and Transportation Systems

(b) System Interactions
ILUTE Microsimulation
(c) 2002 University of Toronto
Paul Salvini

INTEGRATED URBAN MODELLING

GTA 1986
Visualization of Auto AM Peak Travel Time to C

Colour Legend (values above and below scale are clipped):

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<th>Value (minutes)</th>
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Land Use Models

Formal models which try to capture the transportation - land use interaction are usually referred to as land use models, integrated land use - transportation models, or integrated urban models.

Such models have existed since the early 1960’s. They have had mixed success, with the result that relatively few urban areas currently use formal models.

Integrated urban models, however, are receiving increasing attention and are being actively developed and used in many U.S. & European cities.

* In some systems these are substitutable spatial interaction models.
What is an integrated model?

An integrated urban model is intended to represent the spatial evolution of a given study region system state over time as a function of various socio-economic, demographic and political processes. Key words:

- Spatial
- Time, evolution
- Socio-economic, demographic, political
Urban region system state

An urban region’s system state at any point in time is highly multi-dimensional. It usually includes:

• The spatial distribution of the resident population (and its attributes)
• The spatial distribution of the region’s employment & other out-of-home activity locations (and their attributes)
• Person travel within the region during a representative time period (e.g., a “typical” weekday)
• Flows of goods/services within the region during a representative time period
Why build integrated models?

Integrated models provide the opportunity to consistently and comprehensively explore the intended and unintended, interconnected consequences of transportation and land use policies in complex urban regions.

Without an integrated analysis of both land use and transportation, may well “miss” key system responses, and/or over/under-estimate the system responses which are being explicitly modelled.

Many “transportation” issues (especially wrt sustainability) have their origins (and perhaps their solutions as well) in land use design.
Example Application: Removing a Downtown Freeway

What would be the impact of tearing down the Gardiner Expressway? What if it wasn’t replaced? What transit options might exist?
What would be the impact on population & employment distributions? …
Example Application: Urban Greenbelt

What will be the impact of a greenbelt on:
- housing density & prices?
- employment concentration?
- transit viability?
- congestion?
- emissions?
- …
Operational Urban Models: Examples

- **TRANUS**  [http://www.modelistica.com/download.htm](http://www.modelistica.com/download.htm)
- **URBANSIM**  [http://www.urbansim.org](http://www.urbansim.org)
- **PECAS**  [http://people.ucalgary.ca/~jabraham/Papers/pecas/summary.html](http://people.ucalgary.ca/~jabraham/Papers/pecas/summary.html)
- **Others …**
Synthesis of Base Sample for \( t = t_0 \)

Endogenous Changes to Sample during this \( \Delta t \)

Disaggregate Behavioral Model

Behavior/System State at \( (t + \Delta t) \)

Exogenous Inputs this \( \Delta t \)
Agent-based microsimulation

• An *agent* is an autonomous entity that perceives the world around it, acts within its world, and (potentially) learns and adapts based on its experiences.

• *Microsimulation* is simulation at the very disaggregate level of individual decision-makers / agents. Aggregate system-level behaviour *emerges* out of the behaviour of the individual agents.

Agent-based microsimulation is what makes a disaggregate, behavioural approach to urban systems modelling feasible.
The Integrated Land Use Transportation Environment (ILUTE) Model System
Household-Level Models

Household-level models are required to “properly” deal with many system components:

• Housing location/type choice
• Automobile ownership
• Demographics/household structure/lifecycle stage evolution
• Activity/travel scheduling

Households:
• Acquire durable goods (housing, vehicles, etc.)
• Allocate household resources (money, vehicles)
• Allocate household activities/responsibilities to household members (serve-dependents, household “chores”, joint household activities)

Requests for resources, availability for tasks

Allocation of resources, assignment of tasks

Person 1
Person 2
Many *markets* are of interest within ILUTE (housing, labour, commercial real estate, etc.). Market interaction is a three-stage process:

1. **Become Active in the Market**
2. **Constrained Search**
3. **Bidding & Search Termination**

![Diagram](image-url)
ILUTE Overview

Observed Base Year Aggregate Distributions of Agents & Attributes (Census, etc.)

AGENT SYNTHESIS

Synthetic Agent Population $T = 0$

$T = T + \Delta T$

Demographic Update

Labour Market

Housing Market

Auto Ownership

Activity-Based Daily Travel (TASHA)

Commercial Vehicle Movements

Road & Transit Network Assignments

Transportation Emissions & Dispersed Pollution Models

Link & O-D Travel Times/Costs Link, Congestion Levels, Etc.

GHG Emissions

Exogenous Inputs @ time T:
- Interest rates
- Energy prices
- Vehicle technology
- Zoning
- In/out migration rates
- ...

Population Exposure to Pollutants by Location & Time of Day

Exogenous Input

Modelled Process

Under development

Major Output

Currently exogenous; to become endogenous

LEGEND

ILUTE
A new, IPF-based population synthesis procedure has been developed for the Greater Toronto-Hamilton Area.

- Handles a large number of attributes per agent by using a list-based data structure.
- Consistently generates persons, families, households and dwelling units.

See Pritchard & Miller, 2009 TRB Meeting
Demographic Updating

- A demographic updating procedure has been developed for the GTHA that updates household, family & person attributes each year in a simulation run.

- Observed rates by year, categorized by agent attributes are used.
Modelling Housing Markets

- **Policies**
  - Zoning
  - Interest Rates
  - Infrastructure Investment

- **Households**
  - Occupants’ decisions to move
    - Active households search among selected vacancies
      - Decision to buy/rent

- **Developers/Landlords**
  - Decision to build new housing
    - Developers’ decisions to build new housing
      - Type (structure/tenure)
      - Location
      - Number of units
      - Size/quality/price range
  - Decision to sell/lease
Housing Market Microsimulation Model

Supply
- Quantity Decision
- Location Decision

Demand
- Mobility Decision
- Location Choice Decision

Active Dwelling Pool
- Asking Price
- Active Dwelling Pool

Active Household Pool

Housing Market

Market Clearing

Transaction Price

OutMigration

InMigration

Household, Dwelling @
Historical Test Runs

We are currently running 20-year historical simulations to test & improve the model system.

1986 Census

1986 Initial State

Twenty-year simulation run, 1986-2006

1991 Census

1996 Census

2001 Census

2006 Census

Other time-series historical datasets (CMHC, TREB, TTS, …)
Predicted vs Observed Births, Deaths & Out-Migration

Birth, Death and Out-Migration Rates by Year

- ILUTE Births
- ILUTE Deaths
- ILUTE Out-Migration
- Census Births
- Census Deaths
- Census Out-Migration
Simulated Total Housing Starts, 1987-2006

Total New Stock in GTA

- CMHC Data
- ILUTE Forecast
Predicted Transaction Prices by Dwelling Type

- Detached
- Semi-Detached
- Attached
- Apartments
Modelling Daily Activity & Travel

TASHA (Travel/Activity Scheduler for Household Agents) has been developed at UofT. Key features include:

• Activity-based
• Household-based (only such model currently in existence)
• Microsimulation-based
• Agent-based, object-oriented
• Capable of interfacing with either conventional aggregate modelling systems or new disaggregate microsimulators at both “input” and “output” ends of the model (unique to this model)
Activity Episode Frequency, Start Time and Duration Generation

(a) Draw activity frequency from marginal PDF
(b) Draw activity start time from feasible region in joint PDF
(c) Draw activity duration from feasible region in joint PDF

Scheduling Activity Episodes into a Daily Schedule

<table>
<thead>
<tr>
<th>Work Project</th>
<th>Work</th>
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<tbody>
<tr>
<td>School Project</td>
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<tr>
<td>Other Project</td>
<td>Other</td>
</tr>
<tr>
<td>Shopping Project</td>
<td>Shop 1 Shop 2</td>
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</table>

Person Schedule:

At-home Work Shop 1 Other Shop 2 At-home

= “Gap” in Project Agenda
= Activity Episode
= Travel Episode

Trip-Chain (Tour) Based Mode Choice

Auto-Drive Chain
All trips made by auto-drive mode

Non-Drive Chain

Chain c
Trips 1, …, Tc

Trip Tc Mode
... Trip 2 Mode
Trip 1 Mode

Travel/Activity Scheduler for Household Agents (TASHA)
### 3 Conflicting With-Car Chains

<table>
<thead>
<tr>
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<th>Person 2</th>
<th>Person 3</th>
</tr>
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<tbody>
<tr>
<td>Work</td>
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### 3 Possible Vehicle Allocations

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<tbody>
<tr>
<td>Person 1</td>
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<td>Person 3</td>
</tr>
<tr>
<td>Car</td>
<td>Car</td>
<td>Car</td>
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</table>

Choose allocation with highest total household utility.

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### Household –Level Vehicle Allocation & Ridesharing in TASHA

- **Joint Trip**
- **Joint Activity**
- **Passenger**
- **Passenger’s Activity**
- **Serve Passenger Trip**
- **Drive**
- **Transit**
- **Passenger’s Activity**
- **Serve Passenger Trip**
- **Driver’s Activity**
Environmental Modeling with TASHA

• TASHA has been connected with:
  – MATSim road network simulator (auto link speeds, times, costs & volumes by hour of day)
  – EMME transit network assignment model (transit travel times and costs by time of day)
  – MOBILE6.2C emissions model (link emissions by type by link by time of day)
  – CALMET meteorological model (wind speed & direction by time of day)
  – CALPUFF dispersion model (pollutant concentrations by zone by time of day)

Dynamic population exposure to pollution by zone by time of day.
Emissions Modelling in ILUTE/TASHA

Persons & Households

Auto & Transit Travel Times/Costs

TASHA Activity/Travel Scheduler

Household Auto Ownership Model

Transportation Network Model

Activity Patterns & Trip Chains

Vehicle Allocation Model

Trips By Mode, Vehicle Type & Time of Day

Hot/Cold Soaks, Cold Starts, etc.

Emissions Model

Locations of People by Time of Day

Exposure to Pollution

Dispersion Model

Mobile Source Emissions
Auto Emissions by location and time of day

Link-based running emissions by time of day

Zone-based soak emissions by time of day

Dispersion of Emission Concentrations

Population Exposure to NO₂
\[ E = \sum_{i} T_i \times C_i \]

\( E = \text{Total personal exposure} \)
\( T_i = \text{Time fraction spent in } i\text{-th TAZ} \)
\( C_i = \text{Concentration in } i\text{-th TAZ} \)
We can also accumulate emissions by vehicle/person & household.
ILUTE

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THANK YOU! QUESTIONS?