A Framework for Network Sensitive Dynamic Activity-Travel Simulation

SimTRAVEL: Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land

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And Many Other Students and Post-Doctoral Researchers
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Research Effort

Goal

- Develop a set of methods, computational procedures, data models and structures, and tools for the integration of land use, activity-travel behavior, and dynamic traffic assignment model systems in a microsimulation environment.
  - Universally applicable framework, methods, tools, and data structures
  - Open-source enterprise

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Design Considerations

❖ Behavioral
  • Consistency in behavioral representation, and temporal and spatial fidelity
  • Explicit recognition of inter-relationships across choice processes
  • Example: Response to increase in congestion from home to work
    o Short term - Alter route and/or departure time
    o Medium term - Adjust work schedule/arrangements
    o Long term - Change home and/or work locations

❖ Computational
  • Individual models can take several hours to run a single simulation
  • Run times for integrated model systems could be prohibitive
  • Leverage advances in computational power
Design Considerations

- **Data**
  - Land use data available at the parcel level
  - Employment and residential data available at the unit-level (e.g., individual employer)
  - Higher-resolution network data with detailed attributes and vehicle classification counts by time-of-day
  - Detailed activity-travel data including in-home activity information

- **Policy**
  - HOV/HOT lanes, congestion pricing, parking pricing, fuel price shifts
  - Alternative work arrangements (flex-hours, telecommuting)

- **Beyond Interface**
  - Make connections across choice processes within a unified entity (as opposed to loose coupling)
Integrated Model System: Linkages

- **Land Use**
  - Location choices $\rightarrow$ Activity-travel patterns
  - Network conditions $\rightarrow$ Activity-travel patterns

- **Travel Demand**
  - Activity-travel patterns $\rightarrow$ Network conditions

- **Traffic Assignment**
  - Network conditions $\rightarrow$ Location choices
Integrated Model System: Overview

**Base Year Bootstrapping**
- Population Synthesis
- Land Use Model
- Activity Travel Simulation
- Dynamic Traffic Assignment and Simulation

**Convergence**?
- Y → TOD OD Trip Times
- N → Updated Travel Times

**Base Year Simulation**
- Population Synthesis
- Land Use Model
- Activity Travel Simulation
- Dynamic Traffic Assignment and Simulation

**Demand and Supply Convergence**?
- N → TOD OD Trip Times
- Y → Updated Travel Times

**Future Year n**
- Population Synthesis
- Land Use Model
- Activity Travel Simulation
- Dynamic Traffic Assignment and Simulation

**Demand and Supply Convergence**?
- N → TOD OD Trip Times
- Y → Updated Travel Times

**Future Year n + 1**
- Population Synthesis
- Land Use Model
- Activity Travel Simulation
- Dynamic Traffic Assignment and Simulation

**Demand and Supply Convergence**?
- N → TOD OD Trip Times
- Y → Updated Travel Times
Integrated Model Design

- **Base Year Simulation: Bootstrapping**
  - To obtain time-varying travel skims
  - Start with peak/off-peak skims from 4-step model
  - Apply model systems sequentially
  - Iteratively run until demand and supply models converge

- **Model Year Simulation: Integrated Model**
  - Location choices are simulated once for a model year
  - Activity-travel patterns are generated and vehicles are routed until both demand and supply side convergence is achieved
  - The converged time-of-day skims feed into the model simulation for subsequent year
  - This process is repeated on an annual time step
Integrated Model: Supply and Demand

Activity-Travel Model
- Trip and Vehicle Information
- Path is identified and trip is simulated
- Person pursuing activity at destination
- Trip and Vehicle Information

DTA Model
- Update O-D Travel Times
- New Link Travel Times
- Update Time-Dependent Shortest Path

1440 minutes
6 second interval
Feedback origin-destination travel times after each iteration
- Mimics learning process of individual from one day to the next
- Each iteration represents an adaptation of activity-travel schedule based on past experience
- Process is continued until “convergence” is achieved both on the demand and supply side
- Convergence offers consistency between
  - Input travel times used for travel choices in demand model
  - Output travel times from network assignment and microsimulation model
- How does one define “convergence” in the integrated modeling context?
Three Prime Processors of the System
PCATS-DEBNetS (Kitamura et al, 2008)

Decision Processor
- Decision to engage in some activity
- Determine destination and mode
- Given arrival time, determine activity duration
- Decision to engage in some activity

Event Manager
- Scanning Interval (1")
- Agent on Process Waiting List

Traffic Simulator
- Activity duration
- Agent on Actor List
- Travel
- Agent on Traveler List

Time Axis
Iterative Process: Convergence

- **Supply Side Convergence**
  - Well-established and incorporated into modeling paradigms
  - Compare OD travel times from one iteration to the next
  - Use of relative gap function

- **Demand Side Convergence**
  - No well-established criterion for convergence; simulation results are accepted as stochastic realizations of underlying process
  - Compare daily trip tables from one iteration to next to monitor convergence
  - Use successive averaging schemes as appropriate
Prism vertices generated by stochastic frontier models

A prism configured based on the fastest travel mode in the choice set

Travel mode availability by time of day and mode continuity checked within and across prisms
Alternative Integration Paradigms

- Alternative paradigms to integrated modeling of the urban system
  - Sequential approach
  - Dynamic continuous-time supply-demand interaction approach

- Implications for:
  - Consistency in activity-travel patterns
  - Ability to simulate real-time disruptions/events, interactions, and activity-travel plans
A CEMDAP-VISTA Integration (Lin et al, 2008)

- **Activity-travel simulator (CEMDAP)**
  - Interface: Link Volumes and Speeds
  - Update LOS
  - Activity-travel environment (LOS)

- **Synthetic population generator (SPG) and Input generation (CEMSELTS)**

- **Aggregate socio-demographics**

- **Individual activity-travel patterns**

- **Interface: Convert Person-Tours to O-D Trip Tables by Time of Day**

- **Synthetic population generator (SPG) and Input generation (CEMSELTS)**

- **Activity-travel simulator (CEMDAP)**

- **VISTA**
  - **Traffic Simulation**
    - Find 6 sec. traffic flows
    - Accounts for ramp metering, information provision, traffic incidents, etc
    - Output: Travel times per interval and road segment
  - **Optimal routing**
    - Finds optimal route for all OD pairs and departure times
    - Solve time-dependent shortest path
    - Accounts for non-travel time costs (tolls, stochasticity)
    - Output: Optimal route per OD pair and departure time
  - **Path Assignment**
    - Assign paths to each individual vehicle on the network
    - Output: Vehicle path
  - **Convergence Check**

- **After Convergence**
  - O-D Trip Tables by Time of Day
  - Link Volumes and Speeds
Why Dynamic Approach to Integration

Because Sean Doherty’s 2005 Fred Burggraf Award Winning Paper said the following:

(Survey) Responses indicate that a large portion of activities were planned impulsively, including almost 30% of all activities, or 20% of activity time. An even higher proportion of modifications and deletions were planned impulsively (45.3%), with about half of these impulsively changed during the activity.
Case Study Area: Maricopa County

- SimTRAVEL prototype run in both sequential and dynamic interactive modes
- Maricopa County, AZ
  - City of Chandler, Town of Gilbert and Town of Queen Creek
  - 505,350 persons, 167738 households
- Spatial resolution of analysis is TAZ
Case Study Area: Maricopa County
Sequential vs Dynamic Approach

- Behavioral Consistency: Gaps and Overlaps

![Household Schedule Diagram](image-url)
Sequential vs Dynamic Application

- Implications for behavioral consistency
  - Gap → fewer trips than dynamic approach
  - Overlap → more trips than dynamic approach

- Sequential approach generated 3002 more trips than dynamic approach for subarea population
  - Would have been more (far more?) dramatic if work locations were not confined to three-city subarea

- If the differences between skims and experienced network conditions is high
  - The difference in trips generated will be significant
Also, accounting deviation (gaps and overlaps) are higher for workers than non-workers

- In addition to affecting prisms, the arrival information of trips affects workers by having to readjust their fixed activities
- Nonworkers with less fixed activities that need to be adjusted in response to arrival time and hence the smaller deviation from 1440
Why Dynamic Approach to Integration

- Modeling network perturbations and understanding its impact on activity-travel engagement behavior
  - Incident delays
  - Traveler information systems
- Sequential approach cannot be used
- Dynamic approach with its event-based supply-demand interaction paradigm is best suited for such an analysis
Scenario Analysis

- Model testing involves evaluation of policies for the full population

<table>
<thead>
<tr>
<th>Scenario type</th>
<th>Conditions</th>
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<tbody>
<tr>
<td>Socio-economic scenarios</td>
<td>Change in population across the region</td>
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<td>Change in population in some parts of the region</td>
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<td></td>
<td>Change in employment density</td>
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<tr>
<td>Highway scenarios</td>
<td>Change in fuel price or value pricing scheme</td>
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<td></td>
<td>Change in link capacity (Example: link removal)</td>
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<td>Transit scenarios</td>
<td>Change in transit fares</td>
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<td></td>
<td>Change in transit service frequency</td>
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<tr>
<td>Travel demand management scenarios</td>
<td>Alternative work schedules</td>
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<td></td>
<td>Telecommuting</td>
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<td></td>
<td>Introducing HOV lanes</td>
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<tr>
<td></td>
<td>Introducing HOT lanes</td>
</tr>
</tbody>
</table>
Application Challenges

- Variety of Application challenges in use of integrated activity-travel demand and dynamic network supply models
  - Computational burden
  - Data structures and handling
  - Calibration and validation of models (model components) to ground truth conditions
  - Appropriate levels of sensitivity to changes in input conditions
  - Dealing with stochasticity across model runs (say, for policy analysis)

- All of these issues well known and discussed; not necessarily specific to integrated demand and supply models
  - What are some application challenges in the context of “integrated” models?

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Network Disruptions

- Class of events that alter the regular flow of traffic
  - Drop in capacity → Delays → Queues → Spillback → Activity-travel patterns

- Planned Disruptions
  - Roadway closures for maintenance or construction

- Unplanned Disruptions
  - Roadway incidents

- Important to understand impact of disruptions on activity-travel engagement
  - Unplanned disruptions → Emergency response services
  - Planned disruptions → Traveler information services
Network Disruptions

- No disruption
  - Establishes the baseline

- Disruption with no information provision
  - Individuals are unaware of the incident
  - Unrealistic but provides a bound for the expected impact

- Disruption with full information provision
  - All individuals are made aware of the incident after its onset
  - Routing and activity-travel engagement decisions are based on prevailing conditions
  - However, all decisions made pre-trip based on the information provision are “locked”
Network Disruptions

- Limitations of the current framework
  - No real-time “route-switching” or “activity re-planning” or “activity re-allocation” is accommodated
  - People already on the network at the onset of the disruption must proceed to the destination of the trip and use the specified route
  - No ability to cancel/skip activity, reallocate activity, move activity to later in day, or get off the disrupted route
Tracking Vehicles and Persons

- Much interest in capturing intra-household interactions
  - And extending to inter-household interactions when such data is available
- Joint and solo trip-making behavior
- Interactions between adults and children
- Task allocation among adults
- Vehicle allocation among adults
- Longer term location choices – joint decision-making
Tracking Persons and Vehicles

- Much interest in modeling vehicle fleet composition, vehicle type choice, and vehicle utilization
  - Key implications for greenhouse gas emissions and energy consumption
  - Allocation of vehicles among adults
  - Choice of vehicle for trip – solo and joint

- Accommodate day-level interactions between adults and children – rather straightforward
More challenging is representing interactions that happen during the day – particularly the impulsive variety.

At each decision point, scan for available persons in household to join an individual (adult) on activity/trip:
- May have common origin, or common destination, or both
- Spur-of-the-moment joint activities – come from different origins and meet at same destination
- Need to consider available time-space prism of all participating individuals

Distinguish between joint trip, joint activity, or both (e.g., parent takes child to soccer game)
Sensitivity to Accessibility

- Many aspects of activity-travel behavior affected by accessibility measures
- Accessibility measures typically include dimensions of travel time and travel cost
- Accessibility measures impact:
  - Longer term location choices
  - Medium term vehicle ownership/type choices
  - Daily activity travel choices including activity generation, destination, mode, time-of-day, party size (accompaniment), and route choice
Sensitivity to Accessibility

- Incorporation of land use intensity variables (square feet, number of employees) in accessibility measures
- Accessibility measures may vary by time of day due to temporal changes in land use intensity
  - Store opening and closing hours
- Thus accessibility measures should not only be network-sensitive, but should also be land-use sensitive
- Considerable progress with SCAG SimAGENT effort
Sensitivity to Price Change

- Need to capture effects of cost changes on activity-travel demand
- Ability to reflect effects of cost through logsums that affect higher level choices in nested logit tour-based models
- More challenging in dynamic continuous-time models
  - Convert pricing policies (fuel price change, vehicle mileage based fee) to equivalent time through value of time (VOT) measure
  - Activity-travel decisions made based on generalized cost (time) – impacts activity generation and destination choice
  - Can vary price by time of day
- Need to extend to corridor- or cordon- pricing policies
  - Very possible with dynamic supply-demand interaction approach
Sensitivity to Price Change

- SimTRAVEL uses time-of-day varying skims for simulating activity-travel choices
- Modify time-of-day varying skim at each time step based on OD specific price
  - New generalized travel time forms basis of activity generation and destination choices
  - DTA model routes trip and reports arrival time based on actual network conditions (travel times) experienced by traveler
  - Early arrival (actual experienced travel time is likely to be less than generalized travel time) leads to changes in activity duration
- Operational implementation and computational burden
  - Implement user equilibrium within DTA model to accurately reflect route choice (priced versus non-priced)
Conclusions

- Much progress in integrated transport-demand supply model development
- Greater levels of interaction or coupling between demand and supply model to reflect dynamics of behavior
  - Accurately reflect progression of time as experienced by traveler on network
  - Consistency in patterns of activity-travel behavior simulated
- Application challenges remain in multiple domains
  - Software architecture, data handling (Big Data), and computational burden
  - Enroute activity rescheduling, destination modification, task reallocation, and route switching (e.g., unexpected network disruption)
  - Tracking people and vehicles throughout the course of a day – accommodate spur-of-the-moment or impulsive activity engagement (ICT impact)
  - Reflecting sensitivity to accessibility measures and pricing policies incorporating time of day based changes in land use intensity and OD/time specific changes in price signals