Incorporation of Travel Time Reliability in Integrated Demand and Network Simulation Models

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SHRP 2 Projects

- C04 “Improving Our Understanding How Highway Congestion and Pricing Affect Travel Demand”
Topics to Discuss / Concepts

- ABM-DTA integration and 2-way linkage:
  - ABM-to-DTA
  - DTA-to ABM
  - Individual schedule consolidation
  - Pre-sampling

- Incorporation of travel time reliability:
  - Perceived time by congestion levels
  - Mean-variance methods
  - Schedule delay methods
  - Temporal utility profiles
Conventional Integration Scheme

- Trip tables
- 4-step demand model
- Static assignment
- LOS skims for all possible trips
Integration Issue DTA-to-ABM

- Microsimulation ABM
  - List of individual trips
  - Individual trajectories for the current list of trips
  - LOS for the other potential trips
- Microsimulation DTA
Possible Surrogate

Microsimulation ABM

List of individual trips

Microsimulation DTA

Aggregate LOS skims for all possible trips
Temporal equilibrium to achieve individual schedule consistency
Individual Schedule Consistency

\[ \text{Schedule} \quad \theta = \{ \pi_i \} \]

- Activity $i=0$
  - Trip $i=1$

- Activity $i=1$
  - Trip $i=2$

- Activity $i=2$
  - Trip $i=3$

- Activity $i=3$

\[ T_i \quad d_i \quad \tau_i \quad \pi_i \]

ABM-DTA
Schedule Adjustment Prototype

Find new schedule close to previous durations and departures

\[
\min \left\{ \sum_i \left( x_i \ln \frac{x_i}{d_i} + y_i \ln \frac{y_i}{\pi_i} \right) \right\}
\]

Daily consistency

\[
\sum_i (x_i + t_i) = 24
\]

Departure time

\[
y_i = \sum_{j \leq i} (x_j + t_j)
\]

Solution

\[
x_i = k \times d_i \times \prod_{j \geq 1} \frac{\pi_j}{y_j}
\]

ITM, Tampa, FL, April 28, 2012
Schedule Adjustment Extended

\[
\min_{\{x_i\}} \left\{ \left[ \sum_{i=0}^{I} w_i \times x_i \times \ln \left( \frac{x_i}{d_i} \right) \right] + \left[ \sum_{i=1}^{I+1} u_i \times y_i \times \ln \left( \frac{y_i}{\pi_i} \right) \right] + \left[ \sum_{i=0}^{I} v_i \times z_i \times \ln \left( \frac{z_i}{\tau_i} \right) \right] \right\}
\]

\[
y_i = \tau_0 + \left( \sum_{j=0}^{i-1} x_j \right) + \left( \sum_{j=0}^{i-1} t_j \right), \quad i = 1, 2, \ldots, I + 1
\]

\[
z_i = \tau_0 + \left( \sum_{j=0}^{i-1} x_j \right) + \left( \sum_{j=0}^{i} t_j \right), \quad i = 1, 2, \ldots, I
\]

\[x_i > 0, \quad i = 0, 1, 2, \ldots, I\]

\[
x_i = d_i \times \left\{ \prod_{j>i} \left[ \left( \frac{\pi_j}{y_j} \right)^{u_j} \times \left( \frac{\tau_j}{\tau_j} \right)^{v_j} \right] \right\}^{1/w_i}
\]
Weights for Schedule Adjustment

<table>
<thead>
<tr>
<th>Activity type</th>
<th>Duration</th>
<th>Trip departure (to activity)</th>
<th>Trip arrival (at activity location)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work (low income)</td>
<td>5</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Work (high income)</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>School</td>
<td>20</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Last trip to activity at home</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Trip after work to NHB activity</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Trip after work to NHB activity</td>
<td>1</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>NHB activity on at-work sub-tour</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Medical</td>
<td>5</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Escorting</td>
<td>1</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Joint discretionary, visiting, eating out</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Joint shopping</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Any first activity of the day</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Other activities</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Pre-Sampling of Trip Destinations

- Primary destinations are pre-sampled:
  - 300 out of 30,000 for each origin and travel segment,
  - 30 out of 300 for each individual and travel segment
- Stop locations are pre-sampled:
  - 300 out of 30,000 for each OD pair and travel segment
  - 30 out of 300 for each individual and travel segment
- Importance sampling w/o replacement from expanded set of destinations $300 \times 30,000$ and $30 \times 300$ to ensure uniform unbiased samples
- Efficient accumulation of individual trajectories in microsimulation process
LOS Skims for Outer Loop

- Individual trajectories by departure time period for the same driver (personal learning experience), if not:
  - Individual trajectories by departure time period across individuals (what driver can hear from other people through social networks), if not:
    - Aggregate OD skims by departure time period (Advice from navigation device)
Mode Choice Refinement: Driver vs. Passenger for HOV

- **Mode**
  - **Auto**
    - SOV
      - Non-toll, General Purpose lane
      - Toll, Managed lane
    - HOV2 driver, joint travel party
      - Non-toll, General Purpose lane
      - Toll, Managed lane
    - HOV3+ driver, joint travel party
      - Non-toll, General Purpose lane
      - Toll, Managed lane
    - HOV2 passenger (not assigned)
      - Non-toll, General Purpose lane
      - Toll, Managed lane
    - HOV3 passenger (not assigned)
      - Non-toll, General Purpose lane
      - Toll, Managed lane
  - **Transit**
    - ...
  - **....**
Trip Departure Time Choice Refinement (5 min resolution)

- Tour TOD choice model:
  - bi-directional and has 841 departure-arrival alternatives with 30 min resolution
  - Number of alternatives will quadruple with 15 min resolution

- Trip departure time choice model:
  - One-directional
  - 5 min resolution is feasible and results in under 100 ordered alternatives
  - Multiple Discrete-Continuous approach is being tested for Phoenix ABM (ASU)
Quantification of (Un)reliability

- Systematic variation of travel time is not unreliability:
  - Season
  - Day of week (weekdays vs. weekends)
  - Hour

- Random unpredictable variation on top of it is unreliability:
  - Day-to-day
  - Special events
  - Accidents
  - Weather, etc
Four Methods

- Perceived highway time by congestion levels
- Time-distribution-based measures (Mean-Variance)
- Schedule delay cost
- Temporal profiles for activity participation
Time-Distribution-Based Measures

- **(Mean-Variance)** Standard Deviation (symmetric)
- **(Buffer time)** Difference between 80-90-95\textsuperscript{th} and 50\textsuperscript{th} percentile (asymmetric)
- **(Risk measure)** Probability of delay of certain length (asymmetric)
- **(Lateness measure)** Average delay (asymmetric)
Reliability Ratio ($\rho$)

- $U = a \times \text{Time} + \beta \times \text{Cost} + \gamma \times \text{Reliability}$
  - $\text{VOT} = \frac{a}{\beta}$
  - $\text{VOR} = \frac{\gamma}{\beta}$
  - $\rho = \frac{\gamma}{a} = \text{VOR/VOT}$

- It is more complicated with non-linear models:
  - VOT, VOR, and $\rho$ becomes functions of time, cost, or distance
  - These variables must be fixed at certain values to calculate VOT, VOR, and $\rho$
### Recommended Weights for Perceived Time

<table>
<thead>
<tr>
<th>Travel time conditions</th>
<th>Weight</th>
<th>LOS</th>
<th>V/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Flow</td>
<td>1.00</td>
<td>A, B</td>
<td>Under 0.5</td>
</tr>
<tr>
<td>Busy</td>
<td>1.05</td>
<td>C</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>Light Congestion</td>
<td>1.10</td>
<td>D</td>
<td>0.7-0.8</td>
</tr>
<tr>
<td>Heavy Congestion</td>
<td>1.20</td>
<td>E</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td>Stop Start</td>
<td>1.40</td>
<td>F</td>
<td>1.0-1.2</td>
</tr>
<tr>
<td>Gridlock</td>
<td>1.80</td>
<td>F</td>
<td>1.2+</td>
</tr>
</tbody>
</table>
Schedule Delay Cost

- Linear
- Linear w/ fixed
- Non-linear

Cost, $

Early arrival, min
Preferred arrival time (PAT)
Late arrival, min
Schedule Delay Cost

- \( U = \alpha \times T + \beta \times SDE + \gamma \times SDL + \delta \times L \)
- In presence of random travel times:
  - \( f(T) \) – travel time distribution
  - \( E(U) \) – expected utility dependent on \( f(T) \) and departure time/PAT
  - Improvement of reliability in terms of \( f(T) \) can be evaluated in terms of \( E(U) \)
- Considerable body of literature:
  - SP estimates: \( \gamma \geq \alpha \)
## Summary of Defaults for $\rho$

<table>
<thead>
<tr>
<th>Population segment</th>
<th>Travel segment</th>
<th>Perceived congested time vs. free-flow</th>
<th>STD vs. mean time</th>
<th>Buffer 90th-50th vs. median time</th>
<th>Lateness against PAT vs. mean time</th>
</tr>
</thead>
<tbody>
<tr>
<td>High income (60K+)</td>
<td>To work</td>
<td>2.0</td>
<td>0.8</td>
<td>1.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>From work</td>
<td>1.5</td>
<td>0.6</td>
<td>0.7</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Non-work</td>
<td>1.2</td>
<td>0.4</td>
<td>0.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Low income (U60K)</td>
<td>To work</td>
<td>2.5</td>
<td>1.0</td>
<td>1.2</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>From work</td>
<td>1.2</td>
<td>0.3</td>
<td>0.4</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>Non-work</td>
<td>1.1</td>
<td>0.2</td>
<td>0.2</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Temporal Utility Profile for Activity Participation

\[ u(\tau_1, t - \tau_1) \]

\[ u(\tau_2, t - \tau_2) \]
Temporal Utility Profile for Activity Participation

\[ u(\tau_1, t - \tau_1) \]

\[ u(\tau_2, t - \tau_2) \]
Equivalence of Methods

- Perceived time
  - Piece-wise VDRF and fixed reliability ratio
- Mean-variance
  - Optimal departure time, Fosgerau, 2007
- Schedule delay
  - Fixed order of activities and constrained delays, Tseng & Verhoeff, 2008
- Temporal profile
  - Engelson, 2011
Reliability in Network Simulations

- Challenges:
  - Incorporate reliability in route choice
  - Generate OD reliability measures (skims)

- Methods:
  - Analytical (single run)
  - Simulation (multiple runs)
Traffic Physics at Link Level

- Volume-Delay-Reliability Function (VDRF):
  - Average time $t_a = f(v_a)$
  - STD (or other Reliability measure):
    $\sigma_a = g(t_a) = g[f(v_a)]$ or $\sigma_a = h(v_a)$

- Growing number of VDRF estimated:
  - $\sigma_a = g(t_a)$ – linear, slightly non-linear
  - $\sigma_a = h(v_a)$ – highly non-linear (convex)
Link-Level Functions (L03)

\[ y = 0.5549 \ln(x) + 0.0893 \]

\[ R^2 = 0.372 \]

![Graph showing the relationship between Standard Deviation (Minutes Per Mile) and Mean of Median Minutes Per Mile. The equation of the line is given as \( y = 0.5549 \ln(x) + 0.0893 \) with an \( R^2 \) value of 0.372.](image)
2 Implementation Frameworks for Mean-Variance Method

- **Single-run framework:**
  - One demand scenario
  - One network simulation
  - Travel time variation derived from a single equilibrium state (implicitly)

- **Multiple-run framework:**
  - One or several demand scenarios
  - Several network simulations
  - Travel time variation modeled explicitly
Single-Run Framework

- **Demand model (C04):**
  - Adding variance or standard deviation as LOS variable along with mean travel time and cost to mode choice and other travel choices

- **Network Simulation Model (L04):**
  - Adding variance or STD to route generalized cost along with mean travel time and cost
  - Generation of route variance or standard deviation skims for demand model
STD of Travel Time / Mile as Function of Mean Travel Time / Mile
(Seattle, GPS Traffic Choices Study, 2008)

(a) O-D Level; (b) Path Level; (c) Link Level
Construction of OD Trip Reliability Measures

- Link-level function does not solve the problem:
  - STD and buffer time measures are not additive
  - Variance is additive if link travel times are independent (not in general case)
- Route-level and OD Reliability Measures:
  - Robust statistical relationships between mean travel time and STD (path-based assignment)
  - Scaling procedures for link-level STD (link-based assignment)
Example of Scaling Procedures to Construct Route STD

- For elemental unit (mile):
  - \( \sigma = k \times t \)
  - \( k = \) coefficient of variation

- For entire OD route:
  - \( \sigma = k \times t \times (d)^\mu \)
  - \( d = \) distance
  - (independence) \(-0.5 \leq \mu \leq 0\) (perfect correlation)
Self-Calibration of $\mu$ in Link-Based Assignment

- For each OD pair based on the previous iterations:
  - $(d_{OD})^{-\mu(OD)} = \sigma_{OD}/(\Sigma_a \sigma_a) = \eta_{OD}$
- Assume link generalized cost function:
  - $c_a = t_a(v_a) + \rho \times \sigma_a[t_a(v_a)]$
- Scale reliability ratio for next iteration:
  - $\rho_{OD} = \rho \times \eta_{OD}$
Incorporation of Schedule Delay Cost
Equilibrium Assignment with Random Demand and Reliability

- Source of travel time variation is variable demand by scenarios $D(s)$
- Link travel time on given day is deterministic function $c(v)$
- Travelers do not know demand and link travel times on given day; they only know link and route mean and variance
- Travelers chose routes based on the mean-variance generalized cost function; probabilities are the same across days
Equilibrium Assignment with Random Demand and Reliability

- Average demand
- Demand scenarios (s)
- Link costs by path-building scenarios (u)
- OD shortest paths (u)
- Starting route probabilities by (u)
- Split demand by classes (u) for each scenario (s)
- Multi-class (u) assignment for each scenario (s)
- Link cost for each scenario (s)
- Link mean cost and variance across scenarios
- Class-specific skims (u) for each scenario (s)
- Mean and variance skims by class (u) across scenarios
- Update route choice probabilities (u)
Conclusions

- Methods to integrate microsimulation demand and network models:
  - Intermediate (temporal) equilibration for individual schedule consistency
  - Pre-sampling of locations to accumulate individual trajectories

- Methods to incorporate travel time reliability:
  - Perceived highway time by congestion levels – easy but just a surrogate
  - Mean-variance – main method substantiated in C04 and L04
  - Schedule delay cost & temporal activity profiles – more advanced methods that need further research and improved data

- Operational models / single-run framework:
  - Demand models include STD in generalized cost
  - Construction of STD measures at OD-route level to feed into demand model (robust stats or scaling)
  - Incorporation of reliability in route choice in (efficient) traffic assignment equilibrium (path-based or link-based)

- Operational models / multiple-run framework:
  - More promising and holistic way but more complicated
  - Ongoing L04 research (Scenario Manager)