Integrated ABM-DTA System for Chicago Metropolitan Region

Project Team

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1. Background

State of the Art & Practice

- All ABMs in practice are currently based on SUE assignments:
  - Until recently DTA could not handle large networks
  - Until recently D-Transit-A was not available
- ABM-DTA integration is recognized as one of the most important avenues
- First ABM-DTA integration projects:
  - SHRP 2 C10:
    - Sacramento, Jacksonville, Tampa
  - MPO-sponsored:
    - CMAP, SANDAG, JTMT

Directions / Original Thinking

- Methodology:
  - Behavioral foundation of integrated model
  - Bring ABM and DTA to a common denominator
  - Make ABM-DTA interactions disaggregate
  - Equilibration schema
- Technical implementation:
  - Make ABM and DTA efficient for a large region
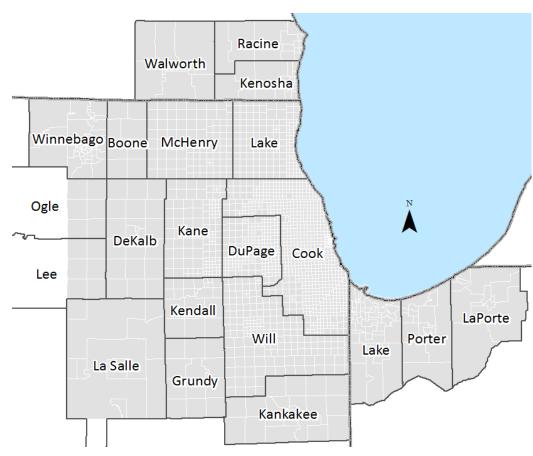 - Make interface and data transfer efficient

Conceptual Aspects to Keep in Mind

Modeling Phase	ABM	DTA
Planning & scheduling	Activity generation, tour formation, trip scheduling	Routing
Real-time implementation and response	Missing in classic ABM, the gap will be filled in the current project by dynamic individual schedule adjustment algorithm	Vehicle movement simulation and en-route decisions
Learning & adaptation	Missing in classic ABM, the gap will be filled in the current project by dynamic generation of destination choice samples	Dynamic generation of route choice sets?

Challenge of CMAP Region

- Population: 10.5m
- 21 counties
- 2K TAZs
- 17K MAZs

Coordinated Travel & Regional Activity Modeling Platform (CT-RAMP)

- Completed CT-RAMP ABMs:
  - MORPC, 2004
  - TMPO, 2006
  - ARC, 2009
  - MTC, 2010
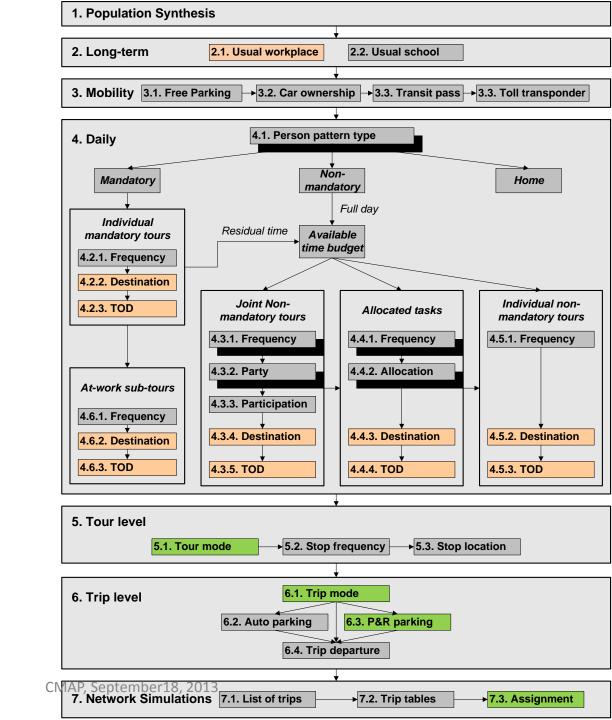 - SANDAG, 2011
  - CMAP, 2013
  - SERPM, 2013

- CT-RAMP ABMs under development:
  - MAG
  - PAG
  - MORPC
  - NOACA
  - OKI
  - JTMT

CMAP
CT-RAMP
ABM

Standard CT-RAMP components

Developed for CMAP Pricing ABM

Developed for CMAP Transit ABM

1. Population Synthesis

2. Long-term   2.1. Usual workplace   2.2. Usual school

3. Mobility   3.1. Free Parking → 3.2. Car ownership → 3.3. Transit pass → 3.3. Toll transponder

4. Daily

4.1. Person pattern type

Mandatory   *Non-mandatory*   *Home*

Full day

Individual mandatory tours

Residual time   *Available time budget*

4.2.1. Frequency

4.2.2. Destination

4.2.3. TOD

Joint Non-mandatory tours   *Allocated tasks*   *Individual non-mandatory tours*

4.3.1. Frequency   4.4.1. Frequency   4.5.1. Frequency

4.3.2. Party   4.4.2. Allocation

At-work sub-tours

4.3.3. Participation

4.6.1. Frequency

4.6.2. Destination   4.3.4. Destination   4.4.3. Destination   4.5.2. Destination

4.6.3. TOD   4.3.5. TOD   4.4.4. TOD   4.5.3. TOD

5. Tour level

5.1. Tour mode → 5.2. Stop frequency → 5.3. Stop location

6. Trip level

6.1. Trip mode

6.2. Auto parking   6.3. P&R parking

6.4. Trip departure

7. Network Simulations   7.1. List of trips → 7.2. Trip tables → 7.3. Assignment
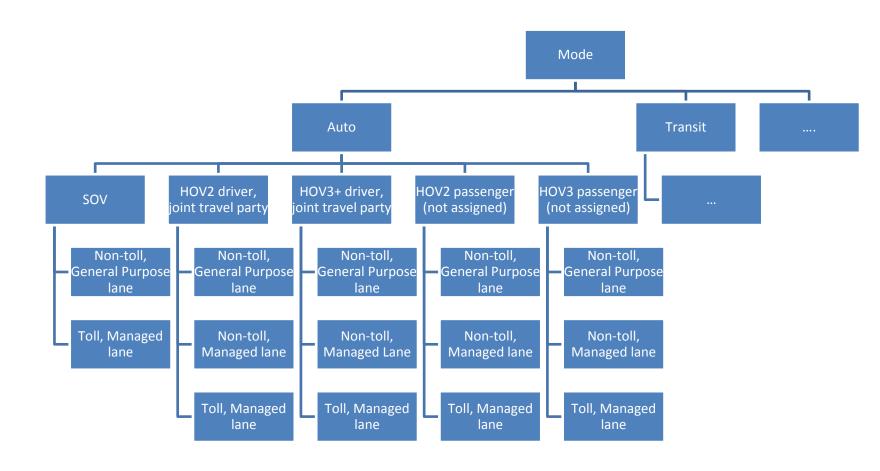
2. ABM Improvements

Needed Improvements for ABM

- Driver and passenger roles in mode choice to translate person trips into vehicle trips

- Trip departure time choice with enhanced temporal resolution (5 min)

- Route type choice as part of mode choice (2 versions):
  - Detailed (controlled by ABM)
  - Aggregate (relies on DTA route choice)

Mode Choice Refinement: Driver vs. Passenger for HOV

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 MAG (Phoenix) ABM

Mode vs. Route Choice: ABM or DTA?

- Largely terminological and no a priori rules:
- Frequently discussed:
  - Include toll roads and Managed Lanes as "modes" (route types)?
  - Distinguish between transit modes (local bus, express bus, BRT, LRT, commuter rail) or rely on route choice?

Mode vs. Route Choice

Mode / route type choice:

- Pros:
  - Unlimited segmentation (person, HH, purpose, individual VOT)
  - Non-linear non-additive utility function
  - Probabilistic
  - Easy to calibrate

- Cons:
  - Multiple route type combinations
  - ("Leaks") Route type choice difficult to enforce ("must use at least one toll or ML" link)
  - More LOS variables to store

Network route choice:

- Cons:
  - Limited segmentation (unless implemented individually)
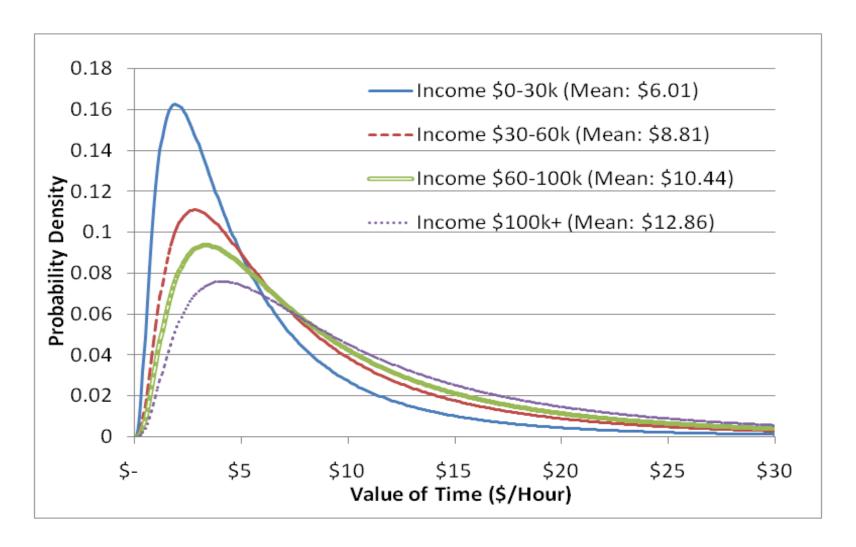 - Additive utility function by links
  - AON
  - Tricky to calibrate

- Pros:
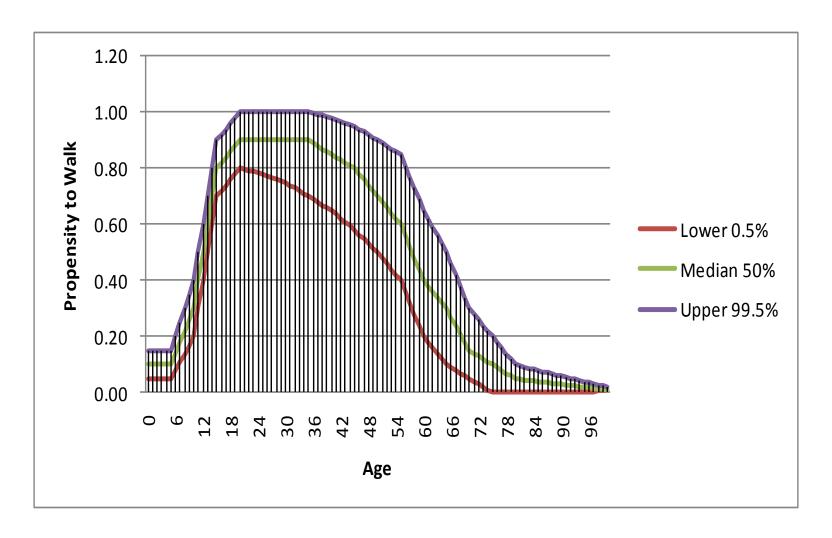 - Efficient way to handle multitude of route type combinations

Mode vs. Route Choice: Recent Recognition

- Better user segmentation (car occupancy, VOT):
  - Mitigates differences between probabilistic and AON choices
  - Eliminates needs for mode choice constants and hence route type choices
- Individual randomized features in CT-RAMP:
  - VOT
  - Propensity to walk

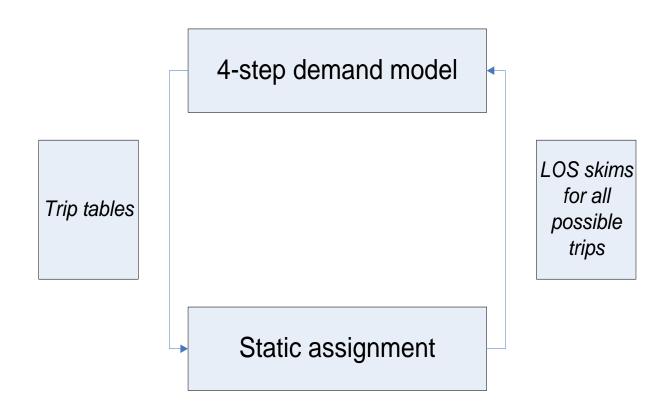# Probabilistic VOT

Probabilistic Propensity to Walk

Legend:
- Lower 0.5%
- Median 50%
- Upper 99.5%

X-axis: Age
Y-axis: Propensity to Walk

Probabilistic Route Choice

- Base deterministic utility:
  - a×Time + b×Cost

- Random utility:
  - a×Time + b×Cost + **ε**

- Random coefficient:
  - (a+**α**)×Time + b×Cost
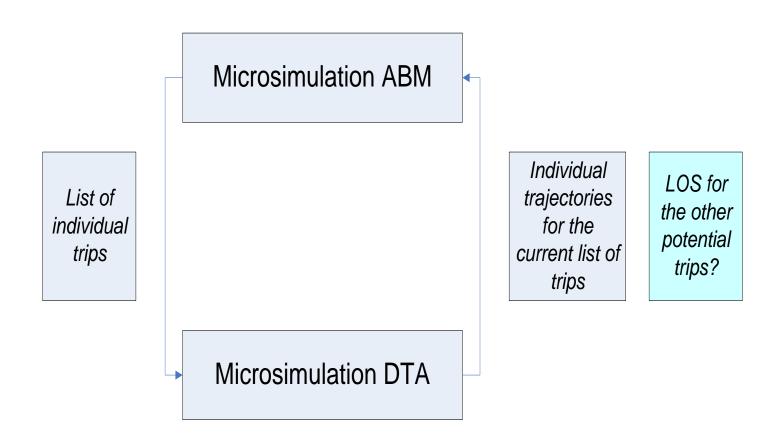
3. Integration Methodology

3 Levels of ABM-DTA Integration

- **Daily (regional long-term planning where equilibration is essential):**
  - **Methodology has been developed**
  - **Does not require significant modifications of ABM or DTA, rather interface**
  - **Does not ensure realistic demand at first iterations and may result in a gridlock**
- Trip (special events, evacuation, short-term planning):
  - Can be outlined
  - Will require significant software modifications
  - Better chance to ensure realistic demand and prevent from a gridlock
- Real-time:
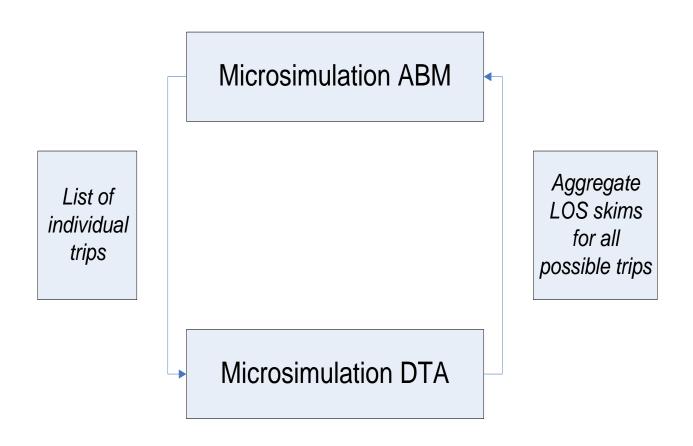 - Will be explored and formulated in the course of this project
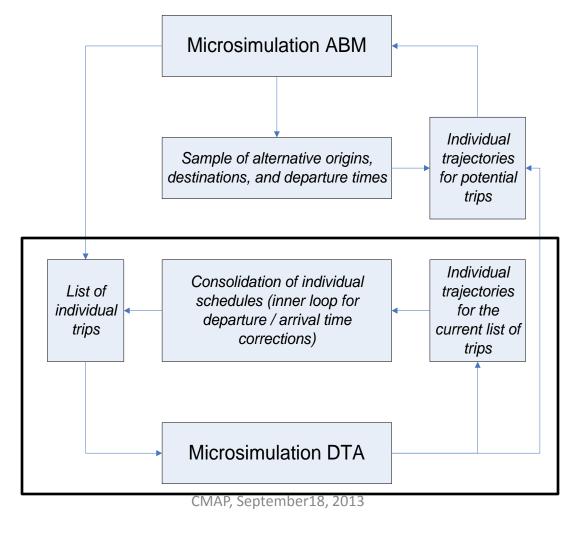
Conventional Integration Schema

4-step demand model

Trip tables

LOS skims for all possible trips

Static assignment

Integration Issue DTA→ABM

Possible Surrogate (SHRP C10)

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                    ┌──────────────────────────┐
                    │   Microsimulation ABM    │◄──┐
                    └──────────────────────────┘   │
┌──────────────┐    │                              │   ┌──────────────────┐
│   List of    │    │                              │   │    Aggregate     │
│  individual  │    │                              │   │   LOS skims      │
│    trips     │    │                              │   │    for all       │
└──────────────┘    │                              │   │ possible trips   │
                    │   ┌──────────────────────┐   │   └──────────────────┘
                    └──►│  Microsimulation DTA │───┘
                        └──────────────────────┘
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- Microsimulation ABM
- *List of individual trips*
- *Aggregate LOS skims for all possible trips*
- Microsimulation DTA

What's wrong with feeding back aggregate OD LOS skims?

- Aggregate OD LOS skims is only a surrogate for consistent individual path LOS:
  - Back to 4-step level of resolution and aggregation biases
- Infeasible to support individual segmentation pertinent to ABM:
  - VOT categories (8-10 at least)
  - Occupancy categories (3 at least)
  - Departure time 15-min bins (80)
- Behaviorally non-appealing:
  - No relation to individual experience, learning, adaptation

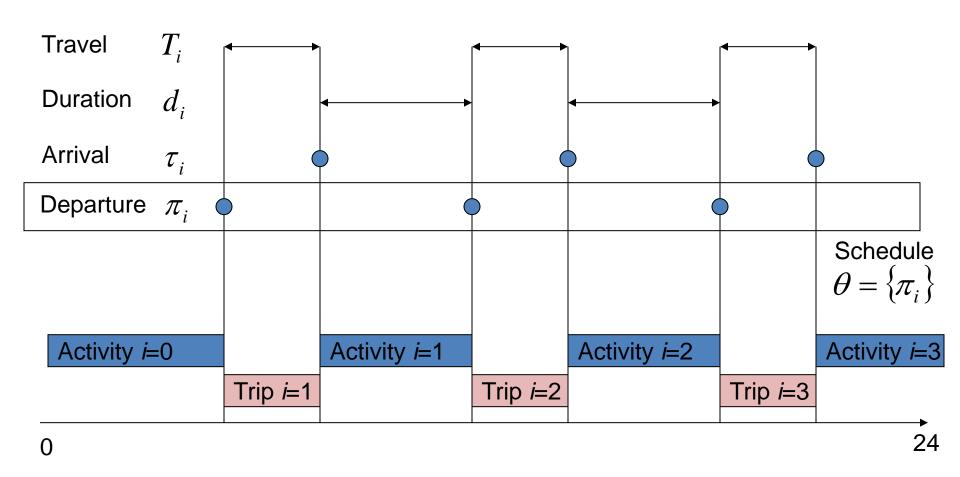# Suggested Approach for Day-Level Integration

Microsimulation ABM

Sample of alternative origins, destinations, and departure times

Individual trajectories for potential trips

List of individual trips

Consolidation of individual schedules (inner loop for departure / arrival time corrections)

Individual trajectories for the current list of trips

Microsimulation DTA

Temporal equilibrium to achieve individual schedule consistency

Key Innovations

- Temporal equilibration for inner loop:
  - Taking advantage of individual trajectories
  - Individual schedule consistency (cross-impacts of travel times and activity durations)
- Dynamically updated sampling of destinations for each individual:
  - Taking advantage of accumulated individual trajectories
  - Learning and adaptation process
- Individual travel "stress" measures based on travel budgets:
  - "Stressed" households processed in outer loop
  - "Non-stressed" households processed in inner loop

4. Individual Schedule Consistency & Adjustments
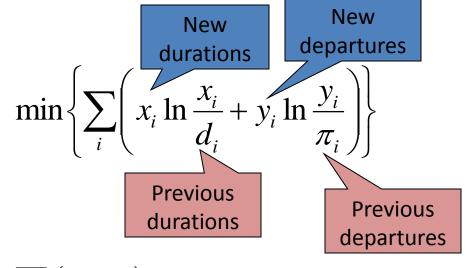
Individual Schedule Consistency

Travel T_i

Duration d_i

Arrival τ_i

Departure π_i

Schedule
$$\theta = \{\pi_i\}$$

Activity $i=0$　　Activity $i=1$　　Activity $i=2$　　Activity $i=3$

Trip $i=1$　　Trip $i=2$　　Trip $i=3$

0

24

Individual Schedule Consistency

- Analogous to network assignment models but considers entire day activity-trip chain:
  - Activities and trips represent big "links"
  - Flow preservation:
    - Every person has to be tracked through activities and trips w/o time gaps or overlaps
  - Consistent cost calculation for the entire daily schedule
    - No one link can be dropped

Schedule Adjustment: Maximum Entropy Approach

Find new schedule close to previous durations and departures

New durations

New departures

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

Previous durations

Previous departures

Daily consistency

$$\sum_i\left(x_i+t_i\right)=24$$

Departure time

$$y_i=\sum_{j\leq i}\left(x_j+t_j\right)$$

Changed travel times

Solution

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

Activity-Specific Weights for Schedule Adjustment

Activity type	Duration	Trip departure (to activity)	Trip arrival (at activity location)
Work (low income)	5	1	20
Work (high income)	5	1	5
School	20	1	20
Last trip to activity at home	1	1	3
Trip before work to NHB activity	1	5	1
Trip after work to NHB activity	1	10	1
NHB activity on at-work sub-tour	1	5	5
Medical	5	1	20
Escorting	1	1	20
Joint discretionary, visiting, eating out	5	5	10
Joint shopping	3	3	5
Any first activity of the day	1	5	1
Other activities	1	1	1

Schedule Adjustment Application

- Day-level:
  - All activities and trips are rescheduled

- Trip-level:
  - Only activities and trips after the given trip simulation are rescheduled (can be applied dynamically with a rolling horizon)

Schedule Adjustment Mechanisms: State of the Art & Practice

- No consensus on theory or prevailing practice
- Two different time scales:
  - Day-level equilibration for long-term planning (learning & adaptation)
  - Real-time non-equilibrium responses from certain time point on (end of particular trip)
- Two seemingly inconsistent behavioral foundations:
  - TOD choice model of ABM that can be re-run with constrained set of alternatives
  - Schedule delay approach for each trip

Time-of-Day Choice

- Integrated in CT-RAMP with many other day-level, tour-level, and trip-level choices
- Difficult to single out w/o violation of other choices
- Suggested approach:
  - Each person & HH is evaluated w.r.t to time pressure (proportion between travel time, out-of-home activity time, and in-home activity time)
  - Stressed HHs (at least one person is stressed) are re-simulated completely by CT-RAMP
  - Other HHs and persons are subject to individual schedule adjustments

TOD choice and Schedule Delay

- Seemingly unrelated approaches
- Should be brought to a common denominator to ensure consistency between modeling "stressed" and "unstressed" HHs
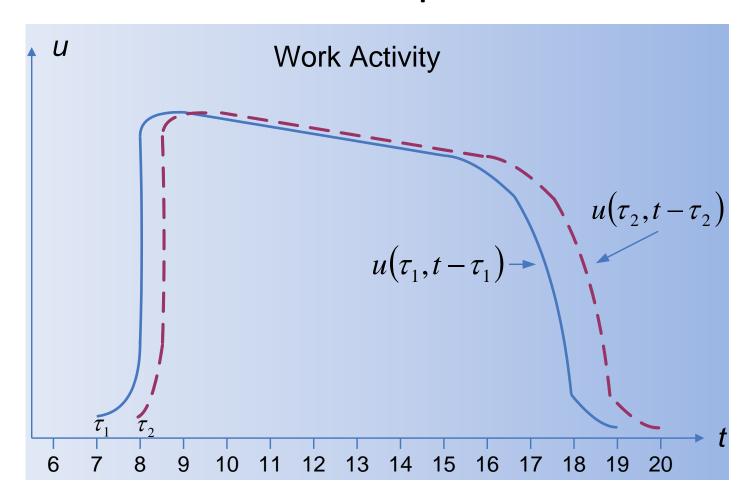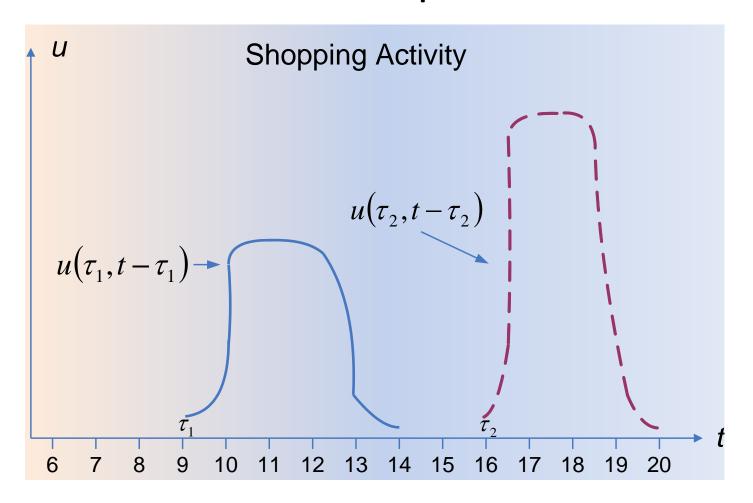
Schedule Delay Cost

Cost, $

Linear w/fixed   **Linear**

Non-linear

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)*
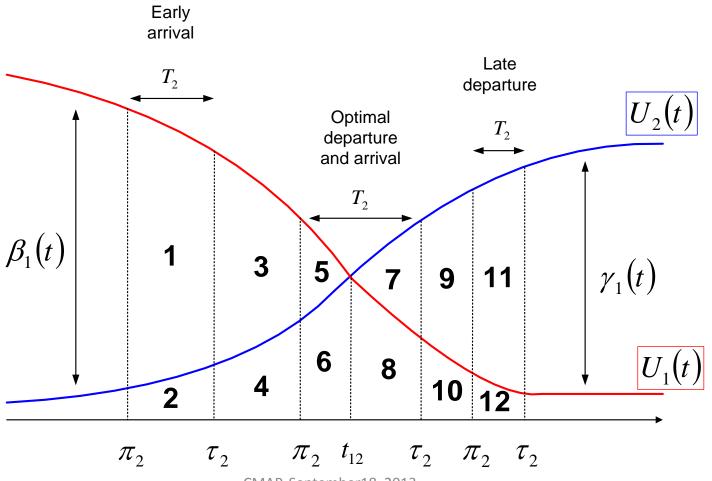- Considerable body of literature:
  - SP estimates: $\gamma \geq \alpha$

Temporal Utility Profile for Activity Participation

Temporal Utility Profile for Activity Participation

Shopping Activity

$u(\tau_1, t - \tau_1)$

$u(\tau_2, t - \tau_2)$

τ_1

τ_2

u

t

6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Utility Profile and Schedule Delay

Equivalence of Methods

Complexity & comprehensiveness (↓)

Perceived time

Mean-variance

Schedule delay

Temporal profile

↑ Piece-wise VDRF and fixed reliability ratio

↑ Optimal departure time, Fosgerau, 2007

↑ Fixed order of activities and constrained delays,
Tseng & Verhoeff, 2008
Engelson, 2011

Incorporation of Schedule Delay in Individual Schedule Adjustment

- Previously implemented entropy-maximizing approach:
  - Objective function terms with importance weights:
    - **AdjActDur × ln(AdjActDur/PlanActDur)**
    - **AdjTripDep × ln(AdjTripDep/PlanTripDep)**
    - **AdjTripArr × ln(AdjTripArr/PlanTripArr)**
  - Solved by simple balancing with entire-day schedule consistency constraints
  - Not fully consistent with schedule delay or TOD choice:
    - Importance weights cannot be directly derived from estimated TOD choice models and schedule delay models

Incorporation of Schedule Delay in Individual Schedule Adjustment

- Modified approach:
  - Objective function terms with importance weights:
    - **α × Max(PlanActDur-AdjActDur,0)** // shorter
    - **β × Max(AdjActDur-PlanActDur,0)** // longer
    - **λ × Max(PlanTripDep-AdjTripDep,0)** // depart earlier
    - **γ × Max(PlanTripDep-AdjTripDep,0)** // depart later
    - **μ × Max(PlanTripDep-AdjTripDep,0)** // arrive earlier
    - **ν × Max(PlanTripDep-AdjTripDep,0)** // arrive later
  - Results in LP problem with the same entire-day schedule consistency constraints
  - Fully consistent with schedule delay but what about TOD choice?
    - Coefficients have to be related to the TOD utility functions

Objective Function Linearization

- Min ∑ (α×ShortActDur + β×LongActDur + …)
  - S.t:
    - ShortActDur≥PlanActDur-AdjActDur
    - ShortActDur≥0
    - LongActDur≥AdjActDur-PlanActDur
    - LongActDur≥0
    - All previous schedule consistency constraints

TOD Choice and Schedule Delay

Trip arrival time choice alternatives:
Individual utilities

3:00 Systematic	3:00 Random	Un-Chosen
3:05 Systematic	3:05 Random	Un-Chosen
3:10 Systematic	3:10 Random	Chosen
3:15 Systematic	3:15 Random	Un-Chosen
3:20 Systematic	3:20 Random	Un-Chosen

μ

ν

CT-RAMP Software Modifications for Day-Level & Trip-Level Integration

- Schedule adjustment feedback interface:
  - Does not affect the core CT-RAMP and easy to implement
  - Can only reschedule trips but cannot cancel or add trips or change destinations
- Forward-looking activity adjustment:
  - Substantial modification of CT-RAMP
  - Continue daily pattern from some point on given the implemented activities and individual location

5. Destination Choice Set

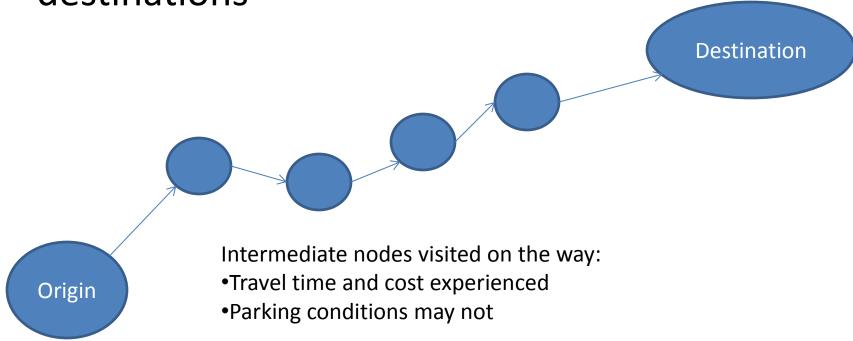# Pre-Sampling of Trip Destinations to Avoid Full Skim Proliferation

- 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 300×30,000 and 30×300 to ensure uniform unbiased samples
- Efficient accumulation of individual trajectories in microsimulation process

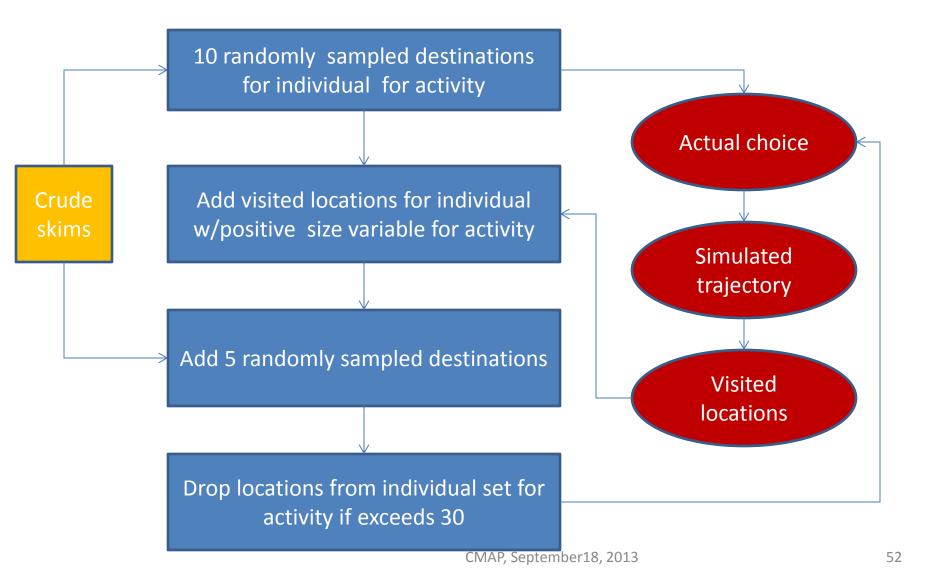# Sampling of Destination as Learning & Adaptation Process

- Current ABM implementation:
  - Sampling randomly & independently for each individual at each global iteration
  - No memory, no learning, no adaptation
- Pre-sampling destinations:
  - Helpful for accumulation of individual trajectories
  - No memory, no learning, no adaptation
- Dynamic formation of destination choice sets:
  - Helpful for accumulation of individual trajectories
  - Introduces memory, learning, adaptation
  - Does not violate the ABM structure

Learning about Space from Individual Trajectories (Dynamic Choice Set)

- One implemented trip provides individual learning experience w.r.t. multiple destinations

Destination

Origin

Intermediate nodes visited on the way:
- Travel time and cost experienced
- Parking conditions may not

Dynamic Destination Choice Set

LOS for Dynamically Updated Dest. Choice Set for Each Person & Activity

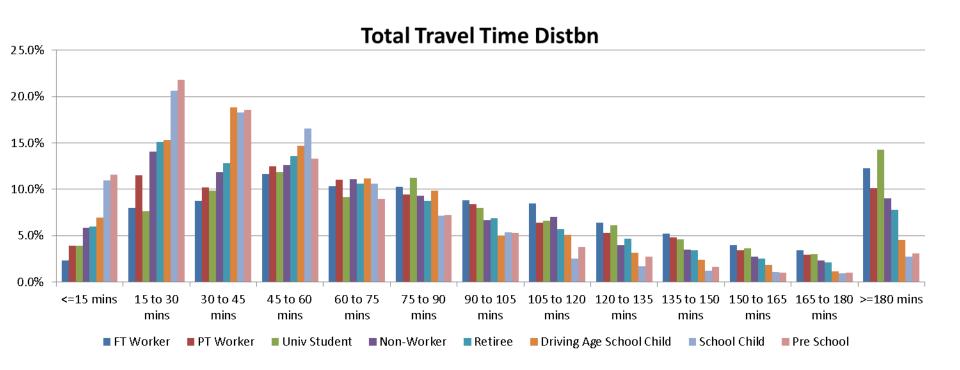| Orig	Dest	Departure time 6:00-6:15				Departure time 6:15-6:30
		Experienced trajectory time	Experienced trajectory cost	Estimated skim time	Estimated skim cost	…
Home	1001	10 min	0 cents			…
Home	2050	15 min	0 cents			…
Home	0005	20 min	0 cents			…
Home	8900	22 min	50 cents			…
Home	1111	30 min	120 cents			…
Home	3344			35 min	100 cents	…
…	…	…	…	…	…	…

LOS Variables for Outer Loop

- (I) Individual trajectories by departure time period for the same driver (personal learning experience), if not:

  - (II) Individual trajectories for the same OD pair by departure time period across similar individuals (what driver can hear from other people through social networks), if not:

    - (III) Aggregate OD skims by departure time period (advice from navigation device)
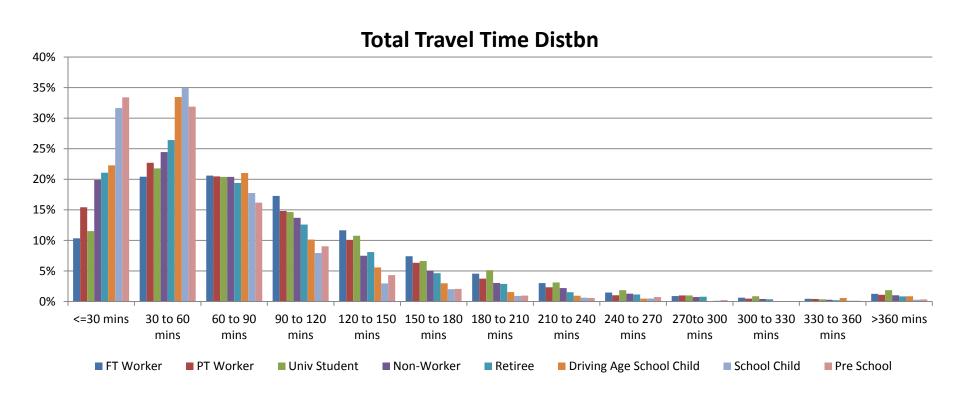
6. Travel "Stress" Evaluation

Travel "Stress"

- Behavioral meaning:
  - Experienced travel times unreasonable
  - Individual will seek other travel choices
- Formal meaning for ABM-DTA equilibration:
  - Generated individual activity-travel pattern does not belong to stationary solution
  - Entire daily pattern has to be re-generated
- Practical daily measure of travel "stress":
  - Total daily travel time
  - Travel overhead (travel time / out-of-home activity time)
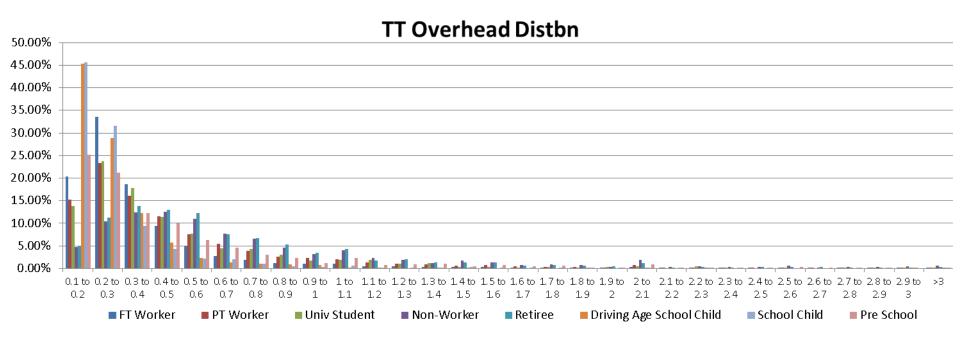 - More elaborate measures explored

Total Travel Time by Person Type (Chicago HTS, 2007)

Total Travel Time Distbn

Legend: FT Worker, PT Worker, Univ Student, Non-Worker, Retiree, Driving Age School Child, School Child, Pre School

Total Travel Time by Person Type (Chicago HTS, 2007)

Total Travel Time Distbn

Legend: FT Worker, PT Worker, Univ Student, Non-Worker, Retiree, Driving Age School Child, School Child, Pre School
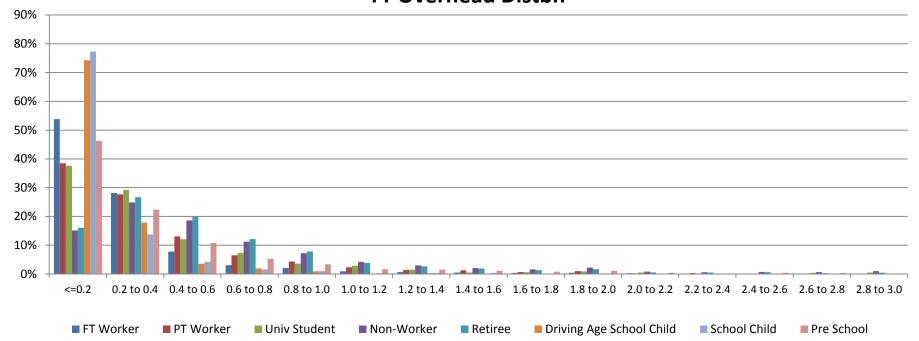
Travel Time Overhead by Person Type (Chicago HTS, 2007)

TT Overhead Distbn

Travel Time Overhead by Person Type (Chicago HTS, 2007)

TT Overhead Distbn

Travel "Stress" Thresholds

Person type	Max total travel time, min	Travel time overhead	Min total activity time for overhead, min
1=Full-time worker	240	0.5	180
2=Part-time worker	180	0.8	120
3=University student	240	0.8	120
4=Non worker U65	180	1.5	60
5=Retiree	150	1.5	60
6=Driving-age school child	150	0.4	120
7=Pre-driving-age school child	120	0.4	120
8=Preschool child	120	0.8	120

- Person is "stressed" if either the max time is reached or max overhead is reached in combination with min activity time
- HH is "stressed" if at least one person is "stressed"

Data Exchange ABM→DTA

- List of individual auto trips:
  - Origin
  - Destination
  - Departure time
  - Planned / Preferred Arrival Time (PAT)
  - Occupancy (SOV, HOV2, HOV3,…)
  - Continuous VOT/VOR: function of
    - Driver age, income, gender, education
    - Party size, composition
    - Situational time pressure
  - Driving style: function of
    - Driver age, income, gender, education

Data Exchange DTA→ABM

- (I) List of simulated auto trips (individual trajectories and sub-trajectories):
  - Origin, destination, departure time, occupancy, VOT/VOR, driving style
  - Arrival time (schedule delay vs. PAT)
  - Individual cost (toll, fuel)

- (II) Accumulated and averaged individual trajectories by OD pairs and 15-min bins (time, toll, fuel cost)
- (III) Aggregate LOS skim matrices (time, toll, fuel cost) by 15 min departure time bins and occupancy

Preliminary Conclusions

- ABM-DTA Integration is the main avenue for improvements of travel models
- Original thinking required:
  - Bring ABM and DTA to a common denominator
  - Make them talk to each other w/o aggregation biases
  - Make ABM-DTA integrated model efficient for a large region
- CMAP Project next steps:
  - Complete CT-RAMP modifications and schedule adjustment interface
  - Complete DynaSmart modifications on transit side
  - Implement and test day-level integration schema for a small sub-area
  - Apply integrated model for the entire CMAP region