Travel Model of Future

Demonstration of Integrated Dynamic Policy Sensitive Model of Travel Demand for the Mega-Region of New York

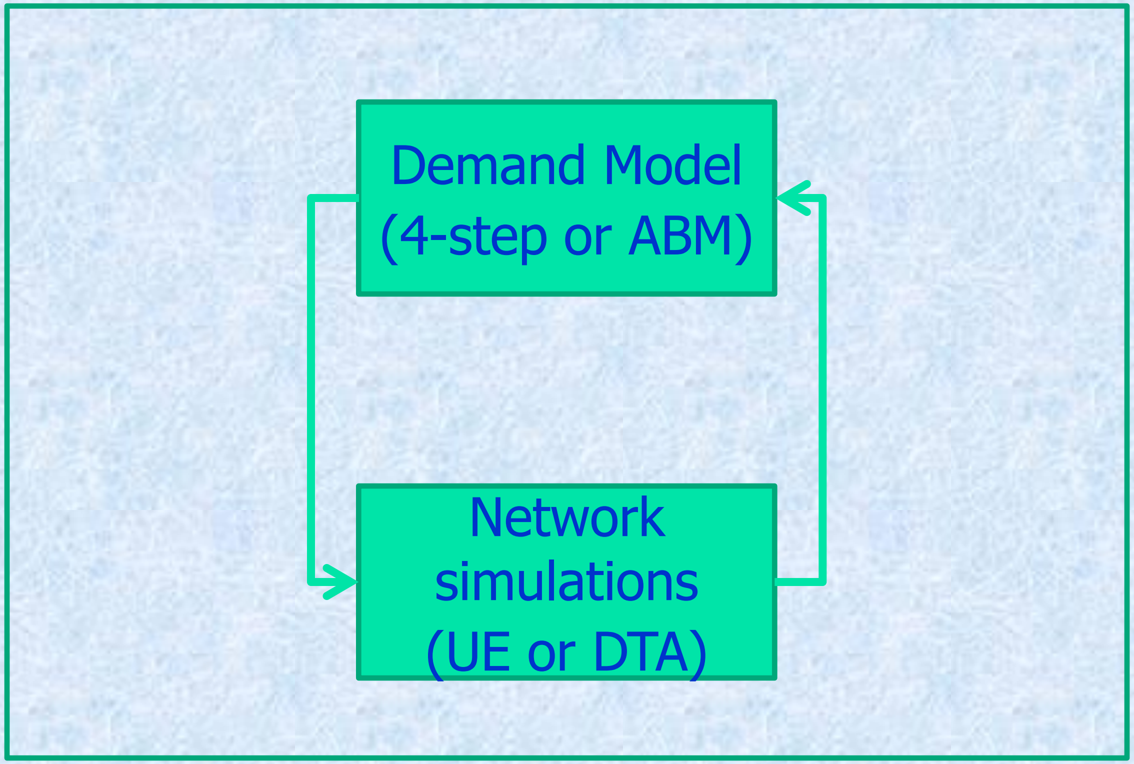
Zürich meets New York

A Festival of Swiss Ingenuity May 16-23, 2014

Workshop Outline

- Dr. Peter Vovsha PARSONS BRINCKERHOFF
  - Integration of advanced models of travel demand and network simulations as the main avenue in our profession
- Prof. Kay Ahxausen ETH zürich
  - MatSim platform and applications in Europe
- Dr. Michael Balmer senozon understanding mobility
  - New York ABM – MatSim integration demonstration

Integrated Regional Travel Model



From Stephen Hawking's "Grand Design"

"Putting a box around it, I'm afraid, does *not* make it a unified theory."

Two Generations of Travel Demand Models

- 1st generation: aggregate, trip-based, so-called 4-step models:
  - In practice since 1970th
  - Still widely applied in the US, especially by smaller MPOs and transit agencies
- 2nd generation: disaggregate, tour-based, so-called Activity-Based Models (ABMs):
  - In practice since early 2000th
  - Prevailing practice for major MPOs in US

Two Generations of Regional Network Simulation Models

- 1st generation: aggregate user equilibrium static assignments of traffic flows:
  - Based in pioneering work of Wardrop, 1952 and Beckman, 1956
  - In practice since 1970th as part of 4-step
  - Still widely applied in the US
- 2nd generation: Dynamic Traffic Assignment (DTA) with individual-vehicle microsimulation:
  - Equilibrium formulation based in intensive research since 1990th
  - In practice since early 2000th for corridor-level studies
  - Individual vehicle microsimulation techniques borrowed from traffic microsimulation models
  - Meso-level techniques emerged from 2000th

4 Major Options

Demand Model	UE	DTA
4-Step	1=Conventional well-explored	3=Usual for DTA in practice (demand is stretched)
ABM	2=Usual for ABM in practice (UE is stretched)	4=Most promising avenue (first attempts)

CONVENTIONAL INTEGRATION SCHEMA 4-STEP WITH UE

Fundamentals – Origins

UE – Beckmann, 1956

$$\min_{\{x_{ijr}\}} \left\{ \sum_a \int_0^{v_a} c_a(w)\,dw \right\}$$

Subject to:

$$\sum_r x_{ijr} = d_{ij}$$

$$v_a = \sum_{ijr} \delta_{ar} x_{ijr}$$

$$x_{ijr} \geq 0$$

Solution:

$$x_{ijr}\left(c_{ijr} - \min_r c_{ijr}\right) = 0$$

Entropy max – Wilson, 1967

$$\max_{\{y_{ij}\}} \left\{ -\sum_{ij} y_{ij} \ln y_{ij} \right\}$$

Subject to:

$$\sum_j y_{ij} = P_i \qquad \sum_i y_{ij} = A_j$$

$$\sum_{ij} c_{ij} y_{ij} = C$$

$$y_{ij} > 0$$

Solution:

$$y_{ij} = P_i \alpha_i A_j \beta_j \exp\left(-\theta c_{ij}\right)$$

a =links, *i*=origins, *j*=destinations, *r*=routes

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Combined UE & Trip Distribution, Evans, 1976

$$\min_{\{x_{ijr}\}} \left\{ \sum_a \int_0^{v_a} c_a(w)\,dw + \frac{1}{\theta} \sum_{ij} y_{ij} \ln y_{ij} \right\}$$

Subject to:

$$\sum_r x_{ijr} = y_{ij}$$

$$v_a = \sum_{ijr} \delta_{ar} x_{ijr}$$

$$x_{ijr} \geq 0$$

$$\sum_j y_{ij} = P_i$$

$$\sum_i y_{ij} = A_j$$

Solution:

$$x_{ijr}\left(c_{ijr} - \min_r c_{ijr}\right) = 0$$

$$y_{ij} = P_i \alpha_i A_j \beta_j \exp\left(-\theta \min_r c_{ijr}\right)$$

Combined UE & Mode Choice, Florian et al, 1977

$$\min_{\{x_{ijmr}\}} \left\{ \sum_{am} \int_0^{v_{am}} c_{am}(w)\,dw + \frac{1}{\theta} \sum_{ijm} y_{ijm} \left(\ln y_{ijm} - \gamma_m \right) \right\}$$

Subject to:

$$\sum_r x_{ijmr} = y_{ijm}$$

$$\sum_m y_{ijm} = d_{ij}$$

$$v_{am} = \sum_{ijr} \delta_{amr} x_{ijmr}$$

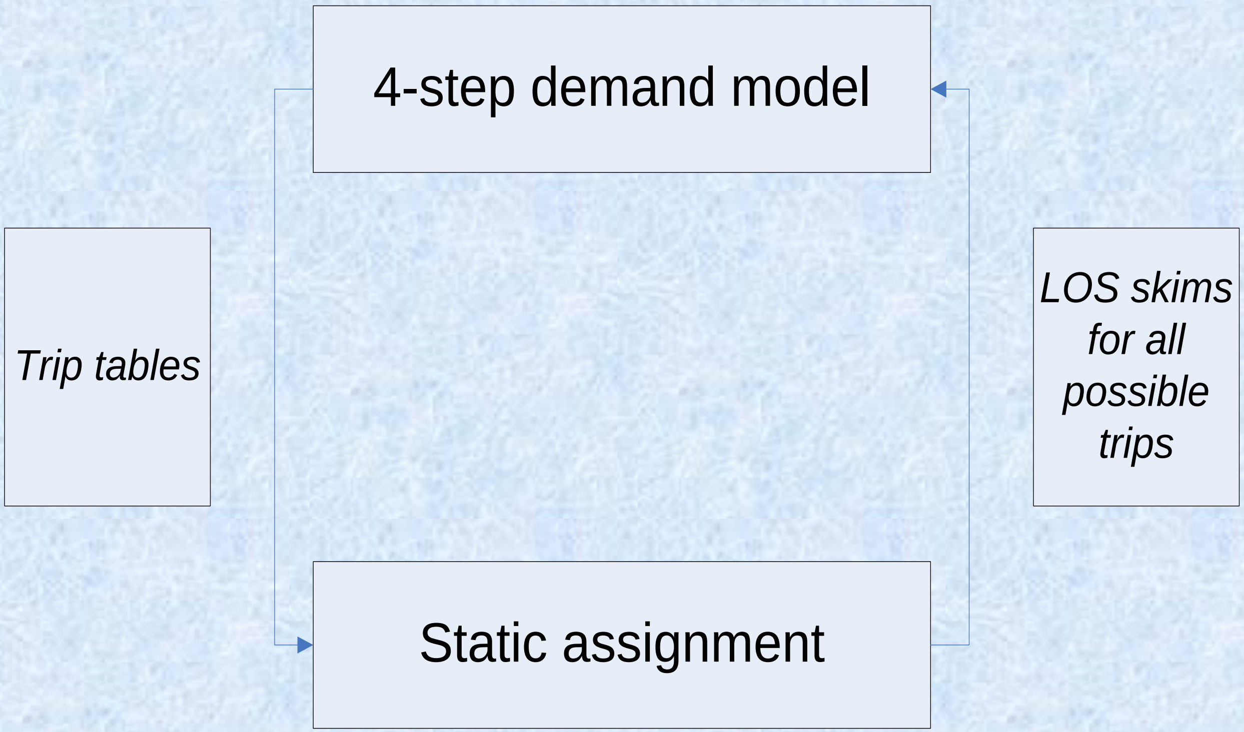
$$x_{ijmr} \geq 0$$

Solution:

$$x_{ijmr} \left(c_{ijmr} - \min_r c_{ijmr} \right) = 0$$

$$y_{ijm} = d_{ij} \frac{\exp\left(\gamma_m - \theta \min_r c_{ijmr} \right)}{\sum_n \exp\left(\gamma_n - \theta \min_r c_{ijnr} \right)}$$

Actual Implementation



Conclusions on Integration of 4-Step and UE

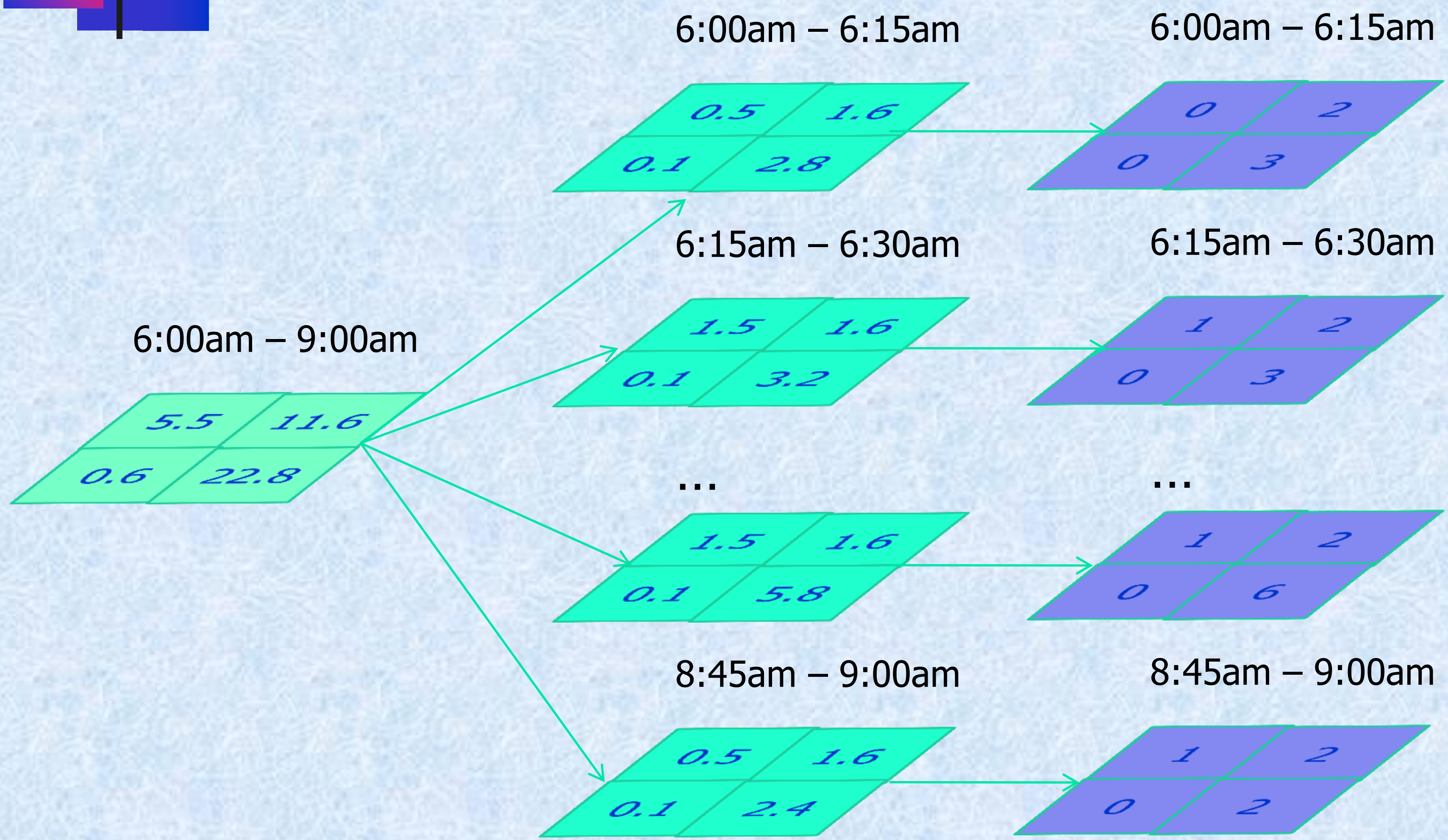
- What do modelers want?
  - Large regional networks w/high level of spatial resolution (4,000-5,000 zones and even more)
  - Numerous travel and population segments for better representation of behavior (purpose, income, gender, etc)
- Dead-end technology:
  - Both 4-step and UE are inherently limited
  - Integration is hampered by incompatible segmentation

4-STEP INTEGRATED WITH DTA

Incompatible Temporal Resolution

- 4-step operates with broad time-of-day periods and fractional trips
- DTA requires finer demand slices (15 min) and discrete trips
- Split factors are applied (developed from household survey or traffic counts) with subsequent rounding up the number of trips

Slicing & Integerizing Trip Tables



“Massaging” Trip Tables

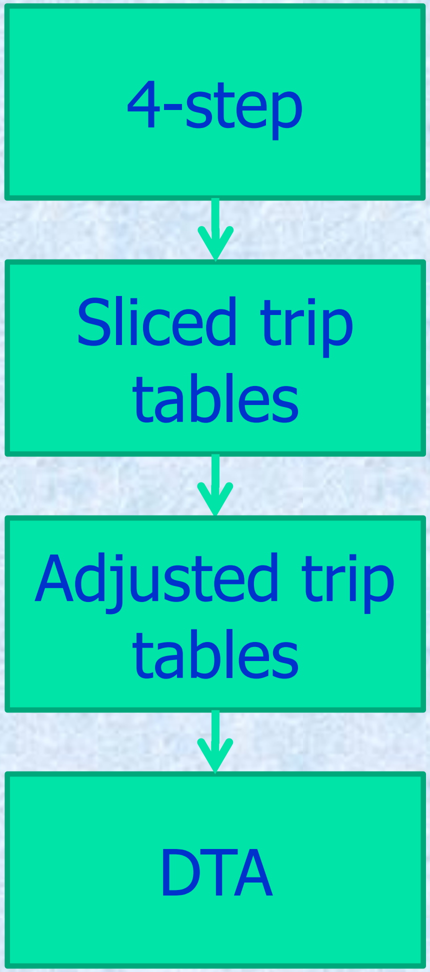
- Trip tables from 4-step model after slicing and integerizing do not replicate traffic counts with fine temporal resolution
- Matrix adjustment is common practice to match link & turn counts
- Static & dynamic matrix adjustment algorithms are improving

Matrix Adjustment Methods

- Start with seed matrix (daily, period-specific, hour-specific)
- Define targets to match and closeness function:
  - Link & turn counts (total or by vehicle class; daily, period-specific, hourly)
- Define structural preservation criteria:
  - Preserve trip distribution (daily, period, hour)
    - TAZ-to-TAZ
    - District-to-district
  - Preserve marginals (daily, period, hour)
  - Preserve TLD (daily, period, hour)
- Form optimization program and find a solution (or step towards optimum)
- Equilibrate optimization with assignment

Limited Value of Trip Table Adjustment

- This is a short term solution for certain projects (highway operations) when demand can be considered fixed
- Problematic for long-term planning studies:
  - How adjustments could be carried over into future?
  - Replace demand model with simple trip table factoring?
  - Feedback?



Equilibration is Essential for Long-Term Studies

- Future demand growth can exceed highway capacity:
  - UE allows for V/C>1
  - DTA with unrealistic demand would not work
- Equilibration can solve this problem:
  - Only if elastic trip generation and time-of-day choice models are applied (problematic with 4-step)
  - Trip distribution and mode choice may not be enough

Conclusions on Integration of 4-Step and DTA

- DTA is used as complementary tool for certain studies most frequently short-term
- 4-step is equilibrated with UE and then trip tables are additionally adjusted for DTA
- No promising avenue for 4-step & DTA integration and equilibration:
  - Inherent limitations of 4-step w.r.t. temporal resolution and time-of-day choice
  - Feedback from DTA to 4-step is not clear

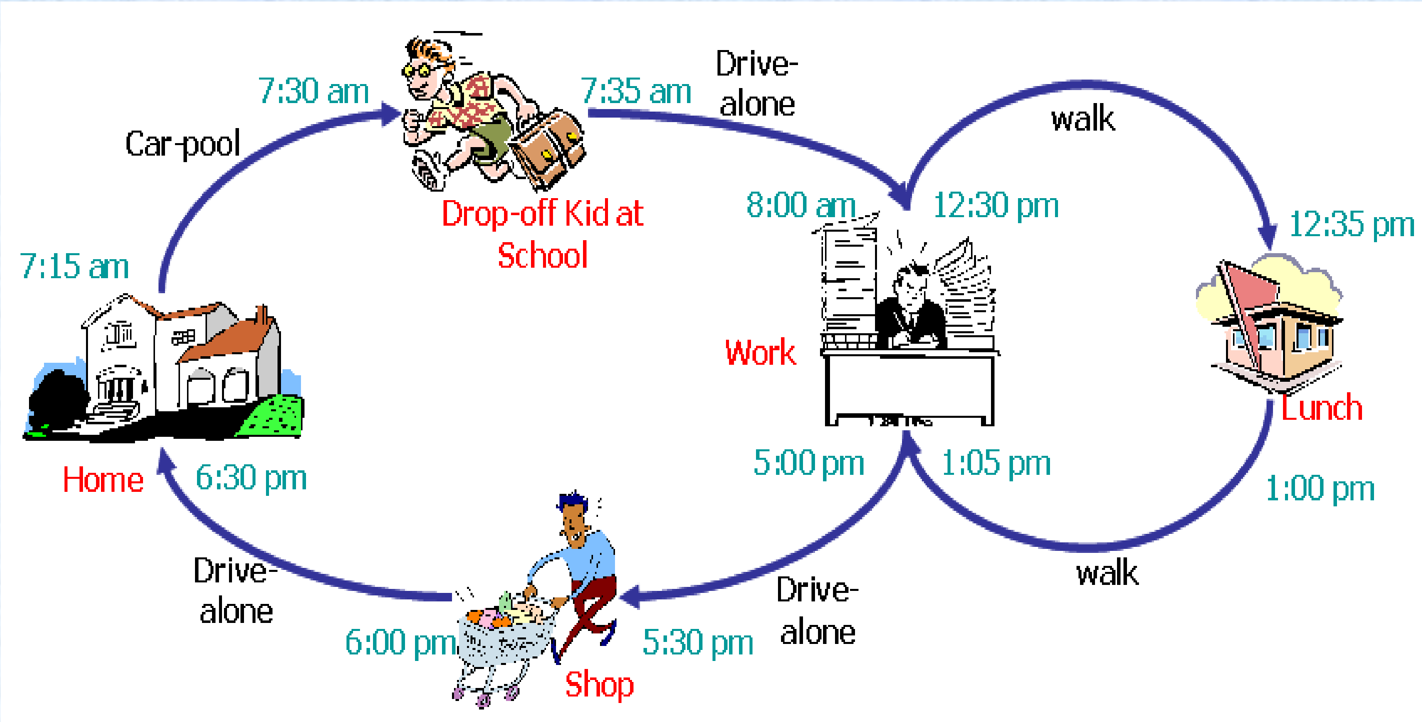
ACTIVITY-BASED MODELS OF TRAVEL DEMAND

Standard Features of ABMs in Practice in US, 2001-2014

Feature	ABM	4-Step
Main unit of travel	Tour (closed chain of trips)	Trip
Structural objects for modeling	Individual microsimulation of persons and households	Aggregate zone-to-zone flows (trip tables)
Travel generation mechanism	Derived from participation in activities	Attributed to population *a priori*

Activity-Based Tour-Based Modeling

- Daily activity patterns have related travel patterns, which are expressed as tours (account for entire daily activity chain)



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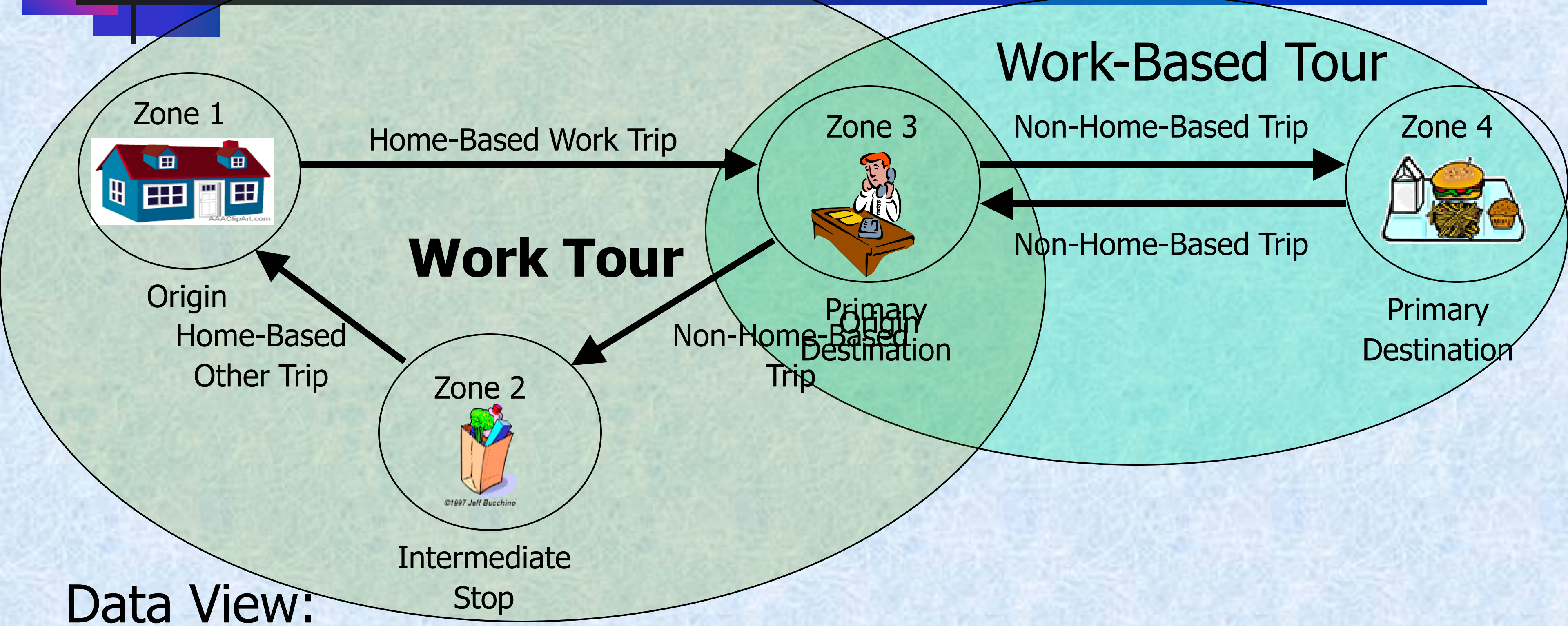
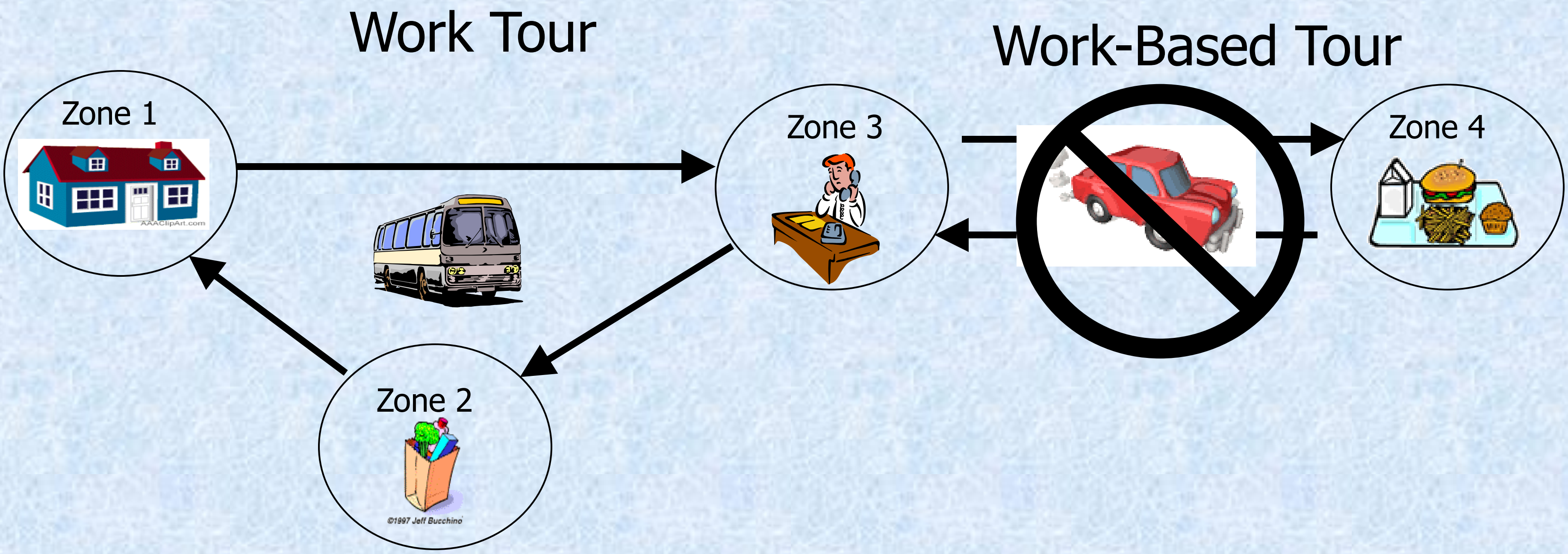
ABM: Tours and Trips



Data View:

HH #	Per #	Tour #	Purp	Origin TAZ	Destin. TAZ	Outbound Stop1 TAZ	Return Stop1 TAZ	Mode	Sub-tour	Sub-Tour Destin.
1023	1	1	Work	1	3	0	2	Transit	Yes	4

Tour Mode Consistency

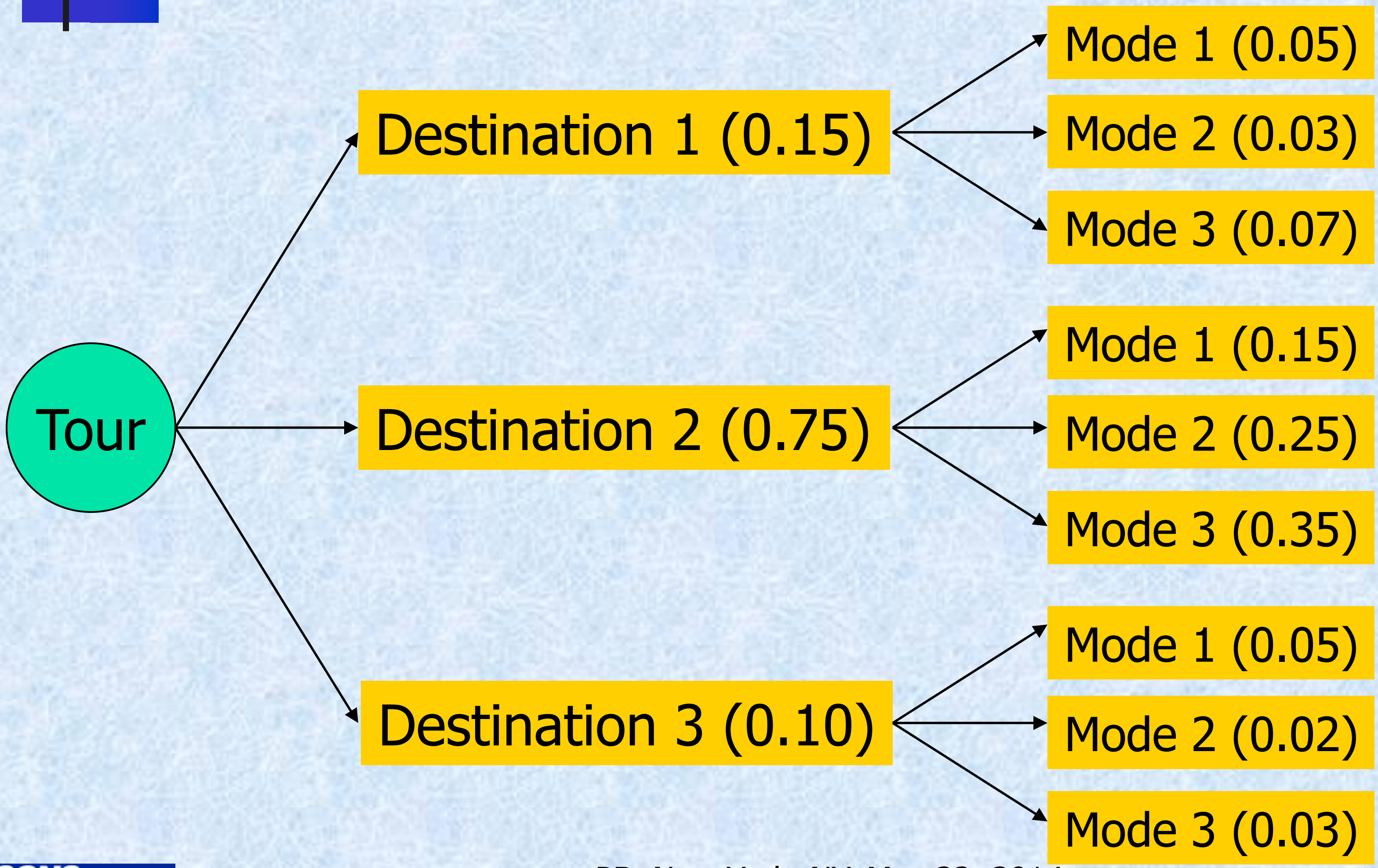


Bus to Work = Drive alone not available for lunch

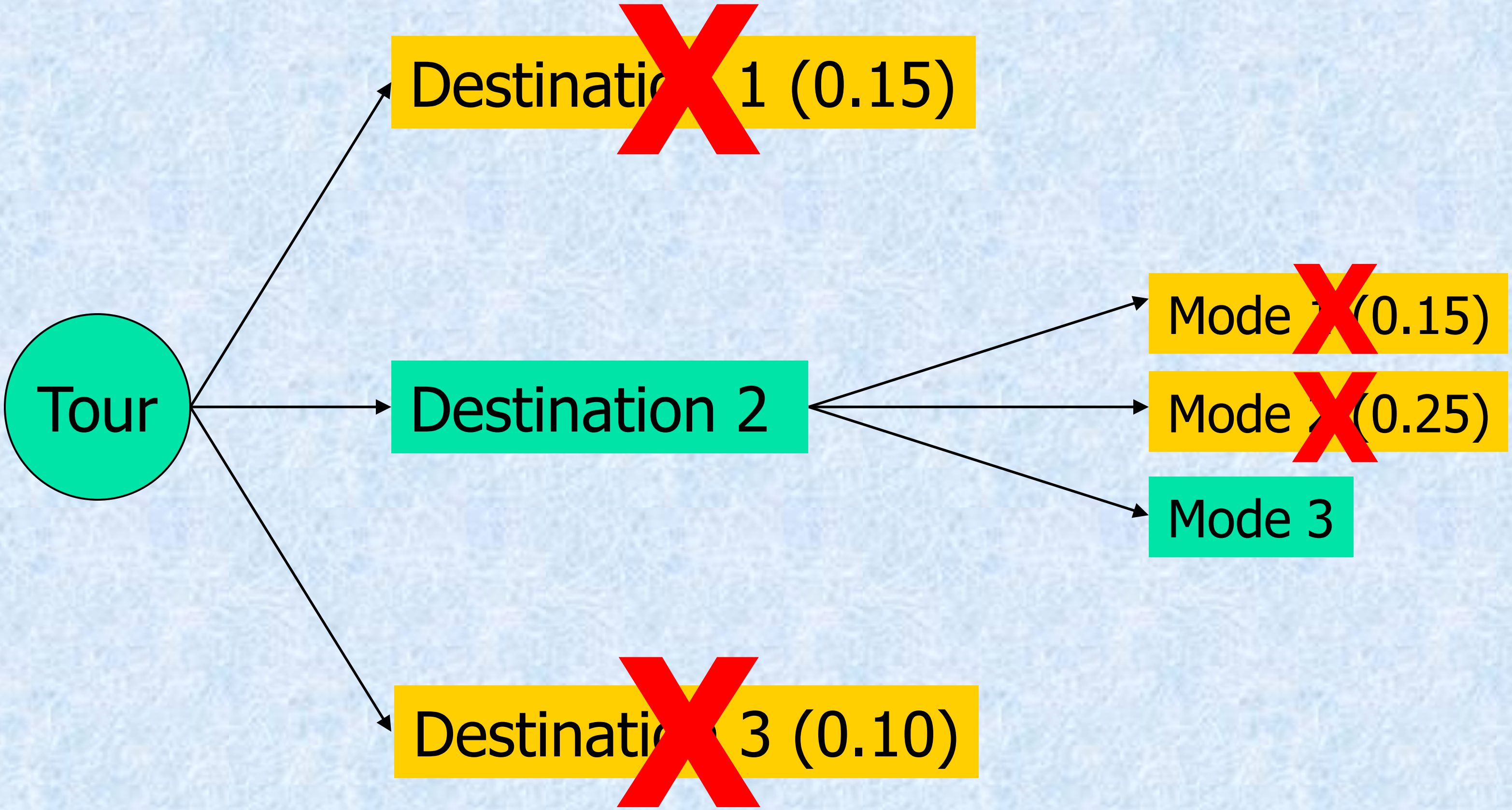
ABM Basics: Microsimulation

- Synthetic population is created that represents the actual population
- Travel is explicitly modeled for each person/household
- Monte Carlo simulation is used instead of fractional probability aggregation: discrete choices made for each traveler
- Model outcome looks like a large HH survey
- Results are aggregated and:
  - Assigned to transport networks
  - Compiled into reports

Fractional Probability



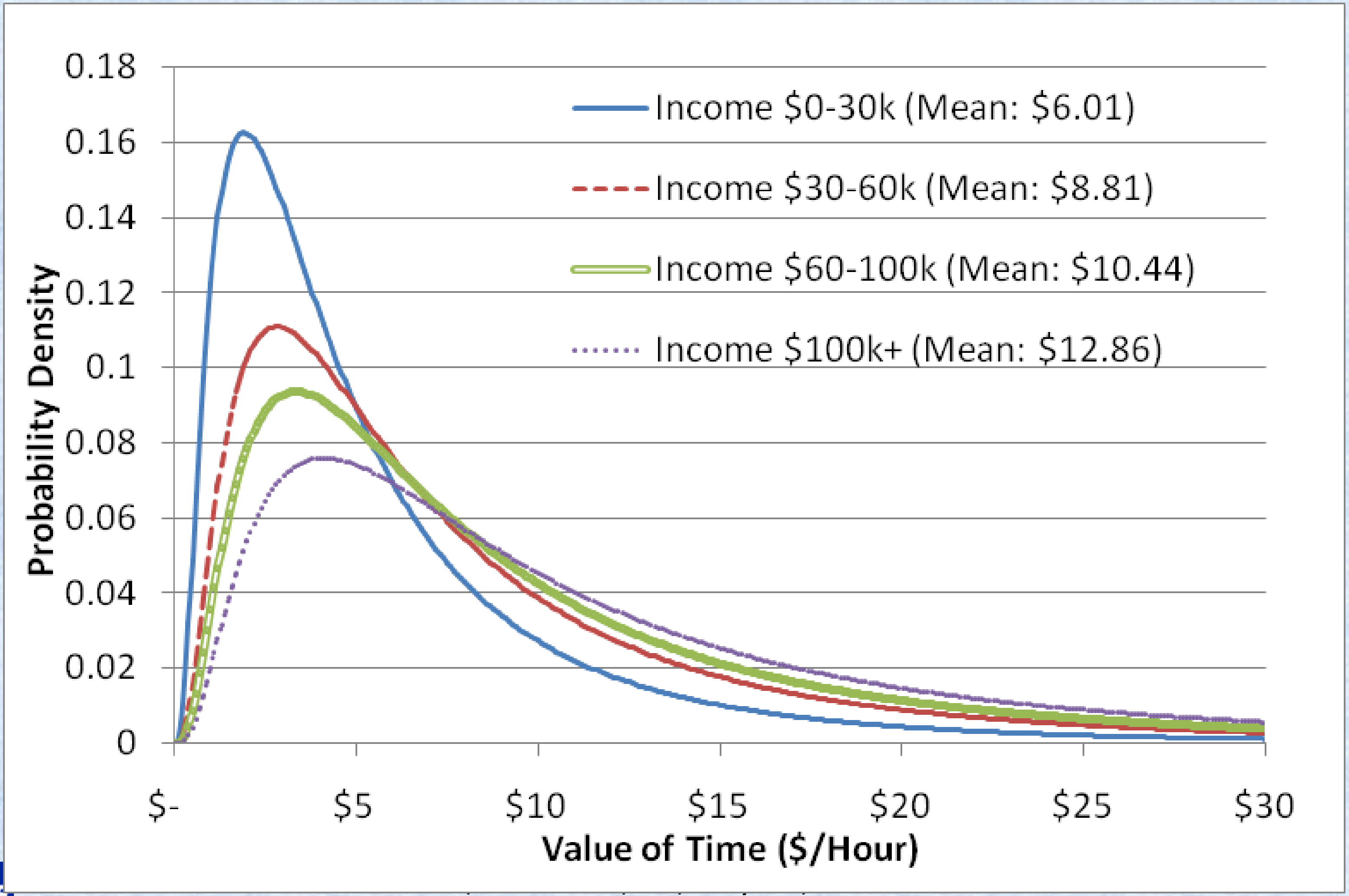
Microsimulation



Individual Parameter Variation

- IPV technique was successfully used for probabilistic VOT (SFCTA, CMAP), propensity to walk (CMAP), license plate rationing (NY)
- IPV can be used in a similar way for all types of payment media and individual discounts
- IPV requires a microsimulation framework; it should also be applied for network simulations

VOT Distribution (SFCTA ABM)



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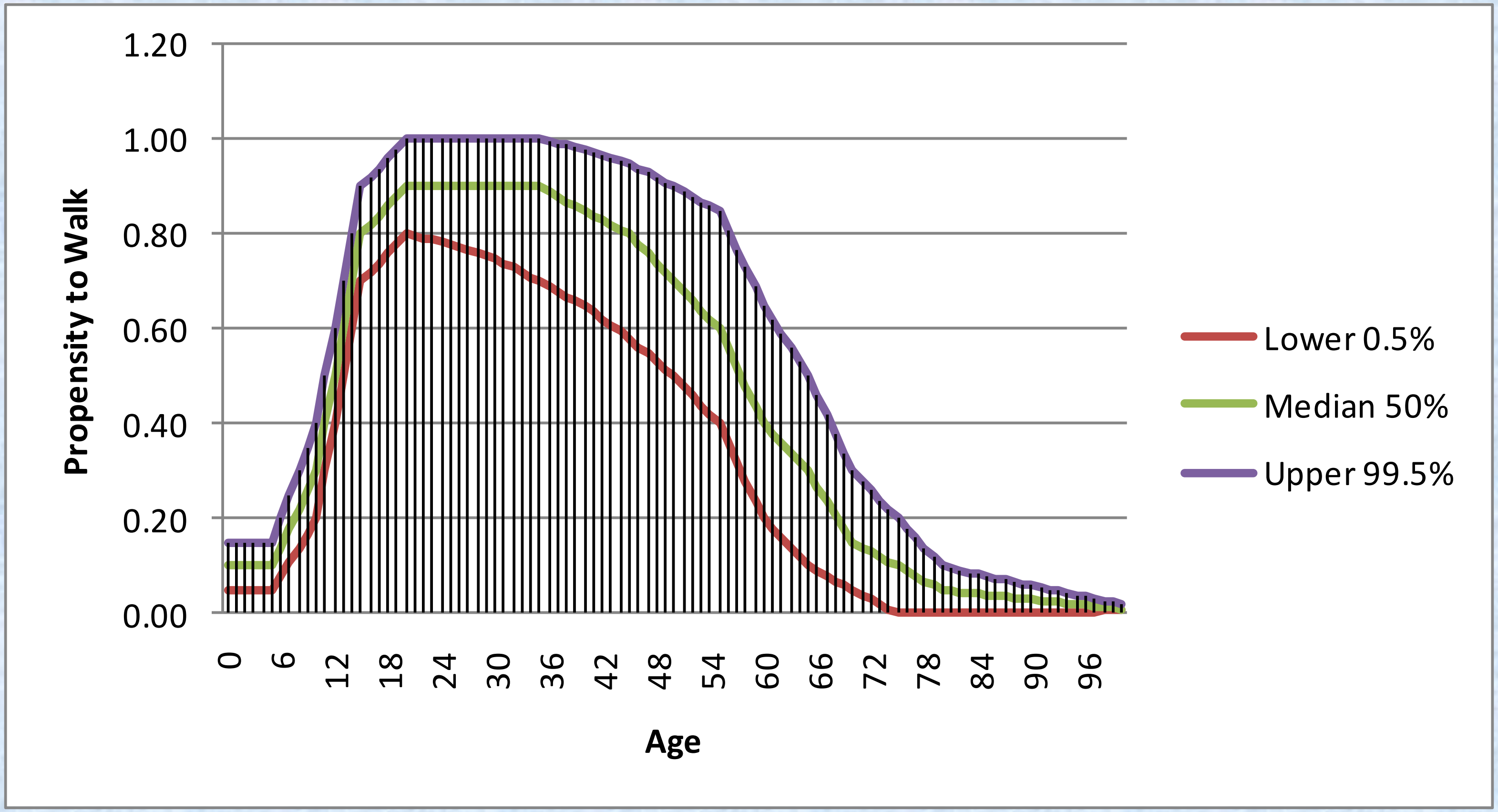
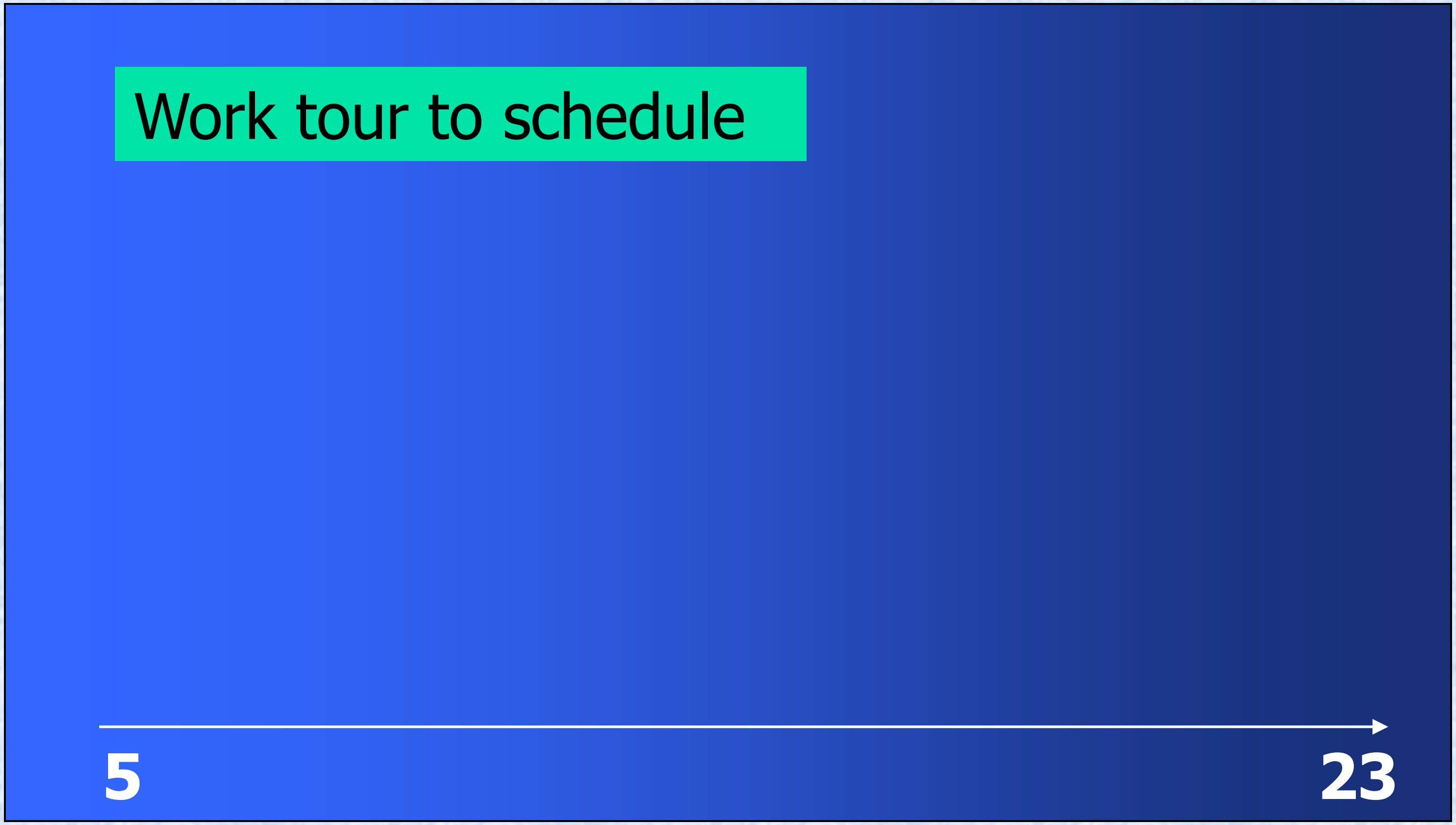
Distributed Propensity to Walk (CMAP ABM)



ABM Basics: Time Use

- Temporal resolution and time-use constitute clear advantages of ABM:
  - Activity participation requires time
  - Every person has 24 hours a day
- Temporal resolution is essential for:
  - Addressing policies like congestion pricing
  - Integration with advanced network simulation models
- Examples of ABM time-use follow:

Tour TOD choice



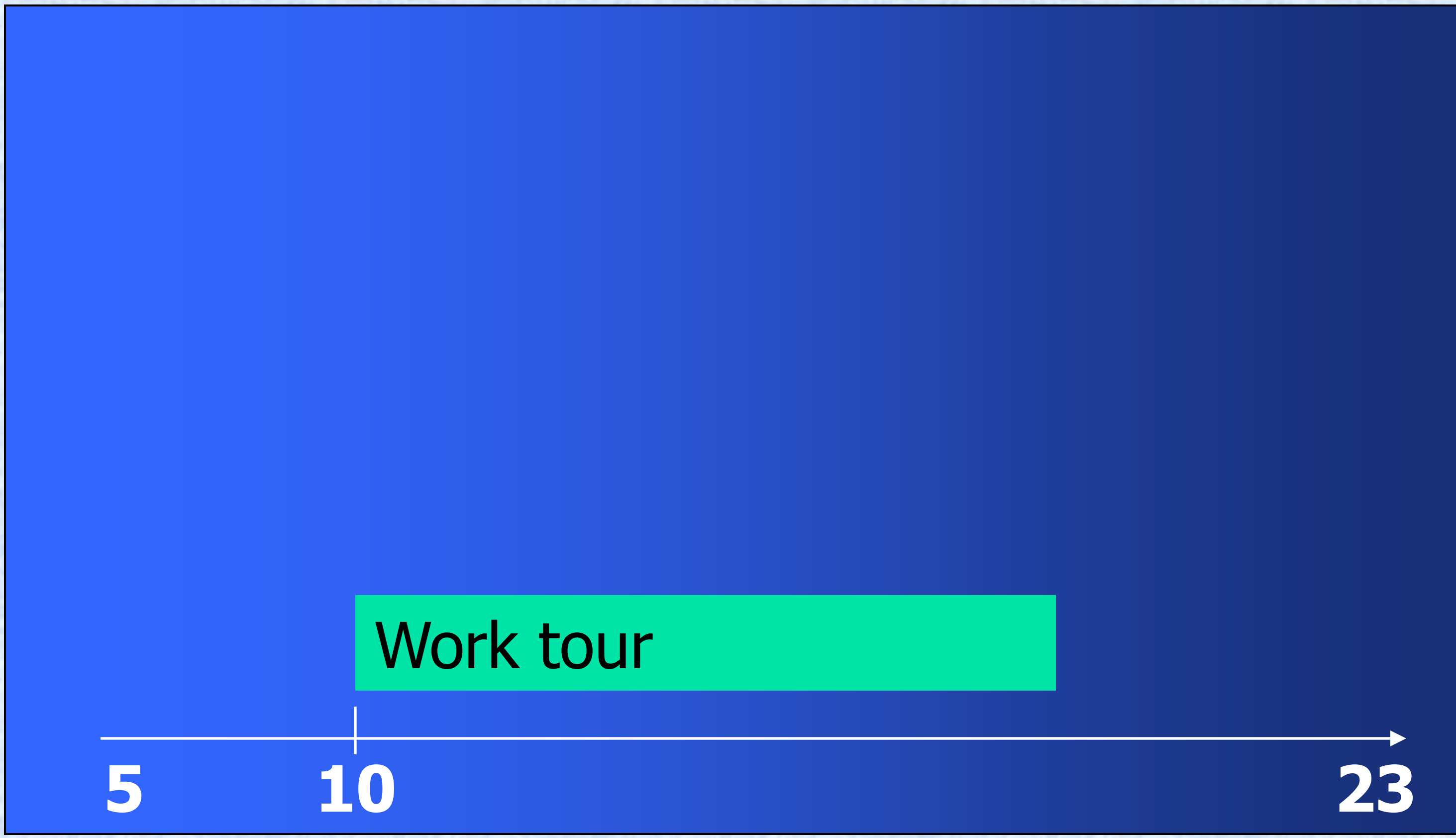
Tour TOD choice

Work tour to schedule

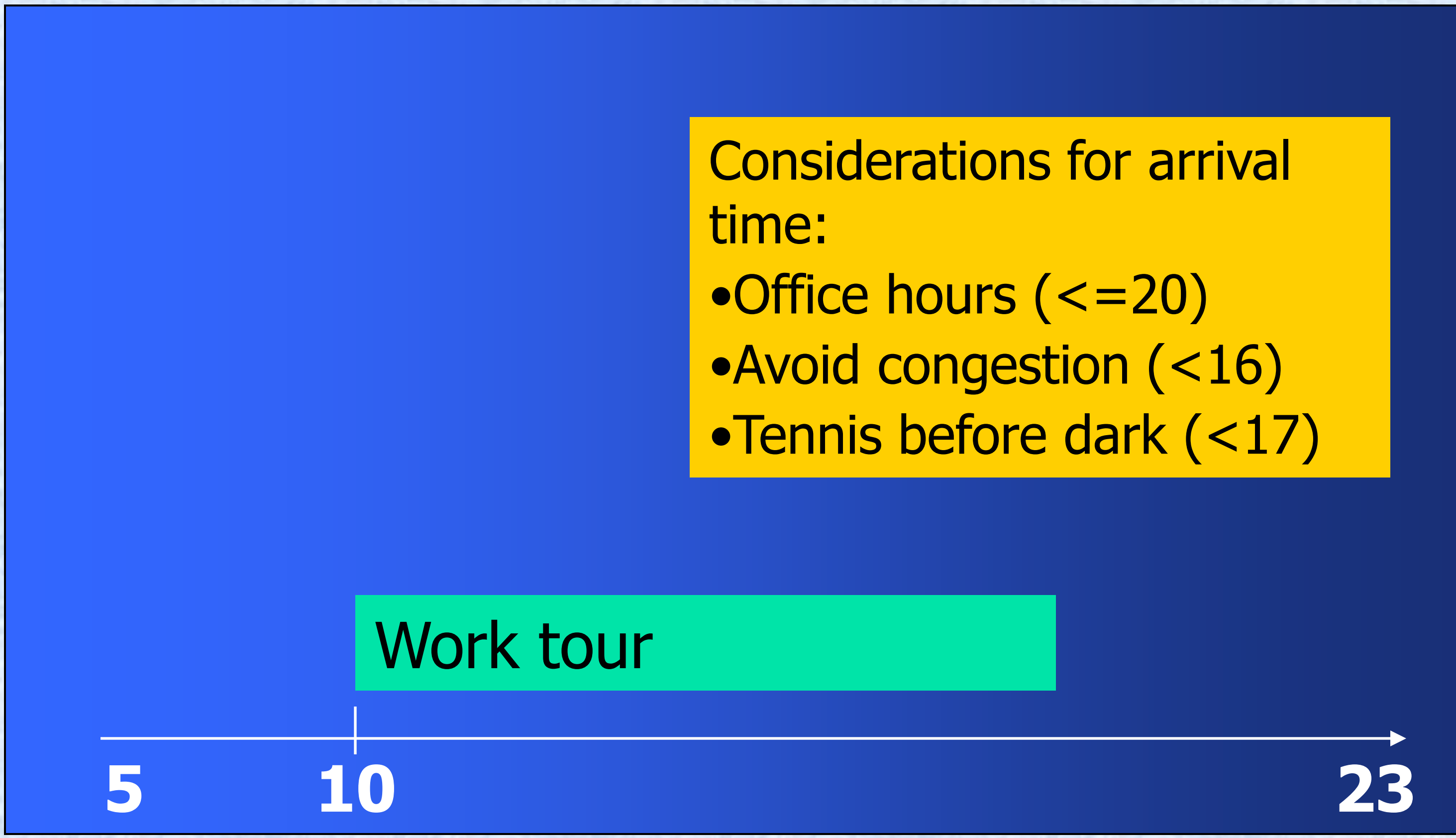
Considerations for departure time:
- Office hours (7-10)
- Avoid congestion (10+)
- Give ride to child (7)

5 → 23

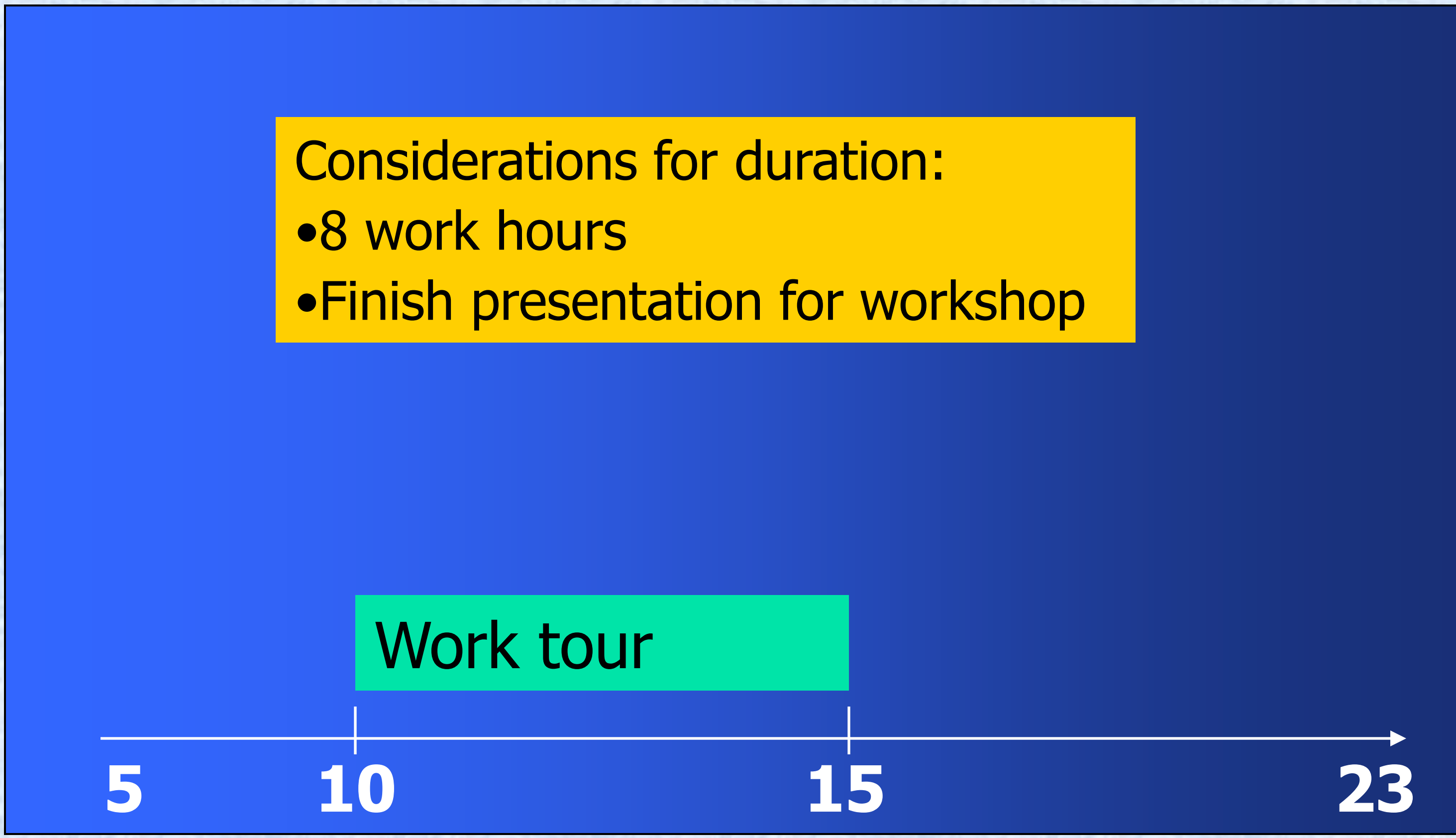
Tour TOD choice



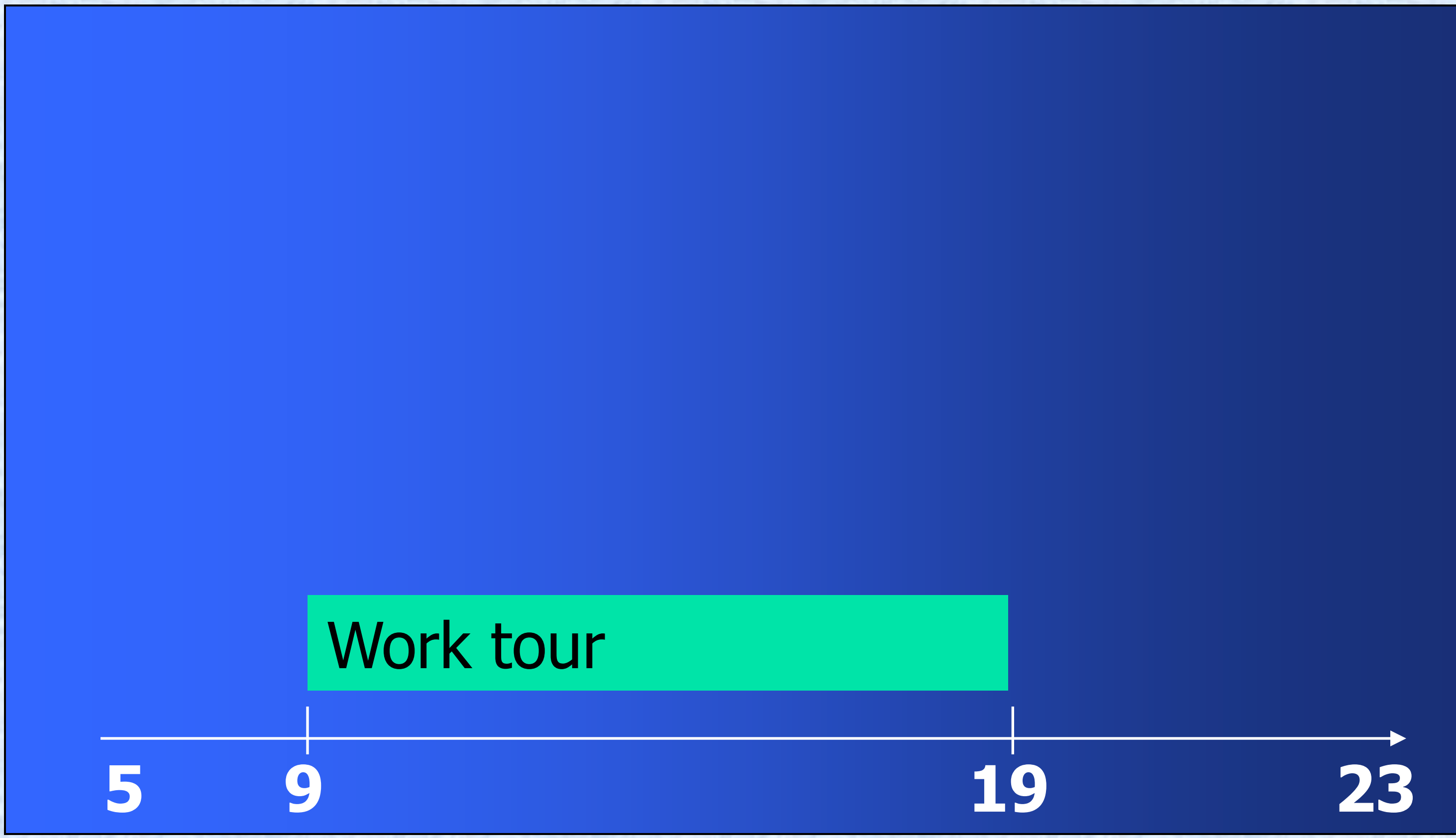
Tour TOD choice



Tour TOD choice



Tour TOD choice



Time-Use Concept: Sequential Processing of Tours

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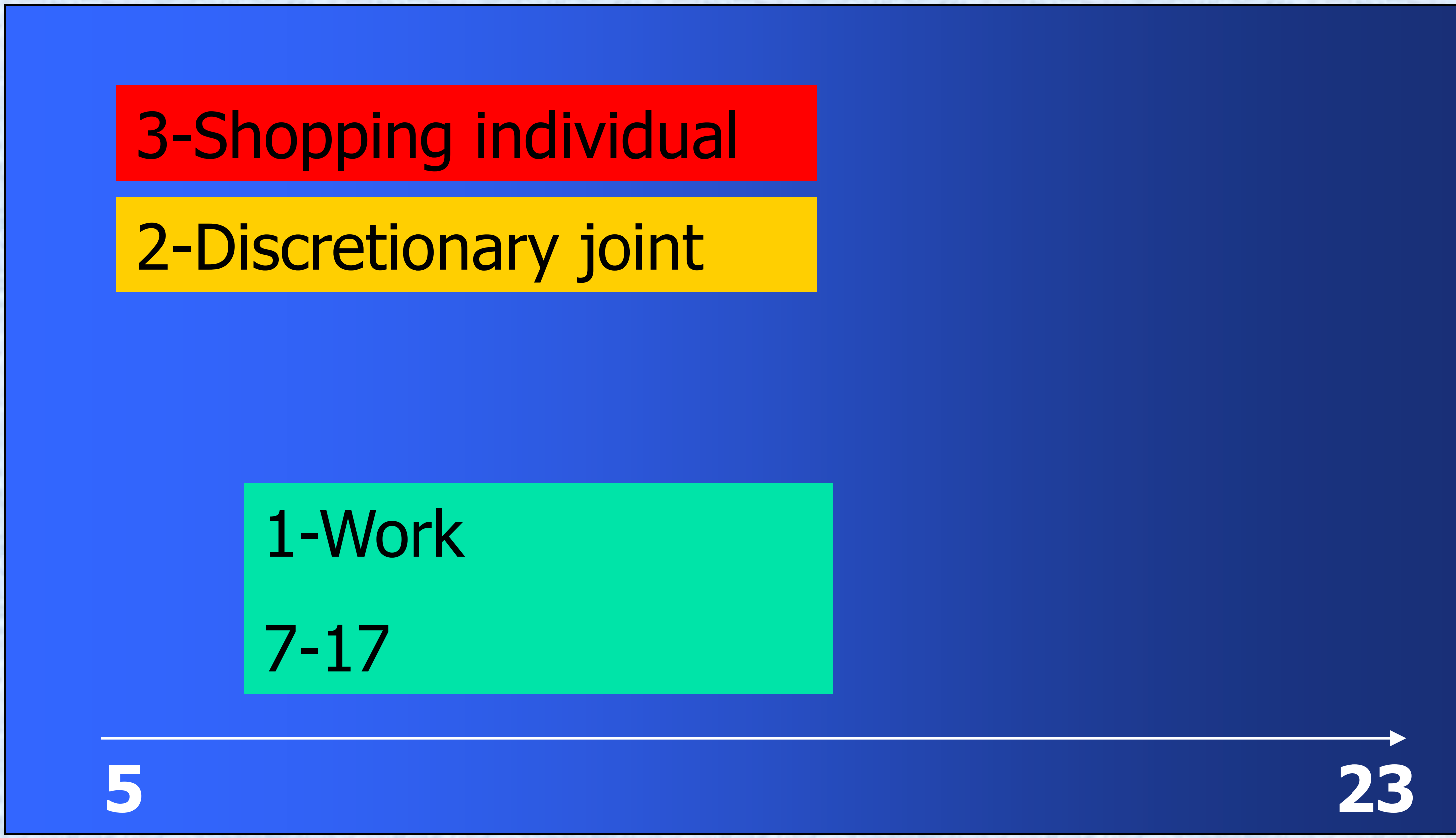

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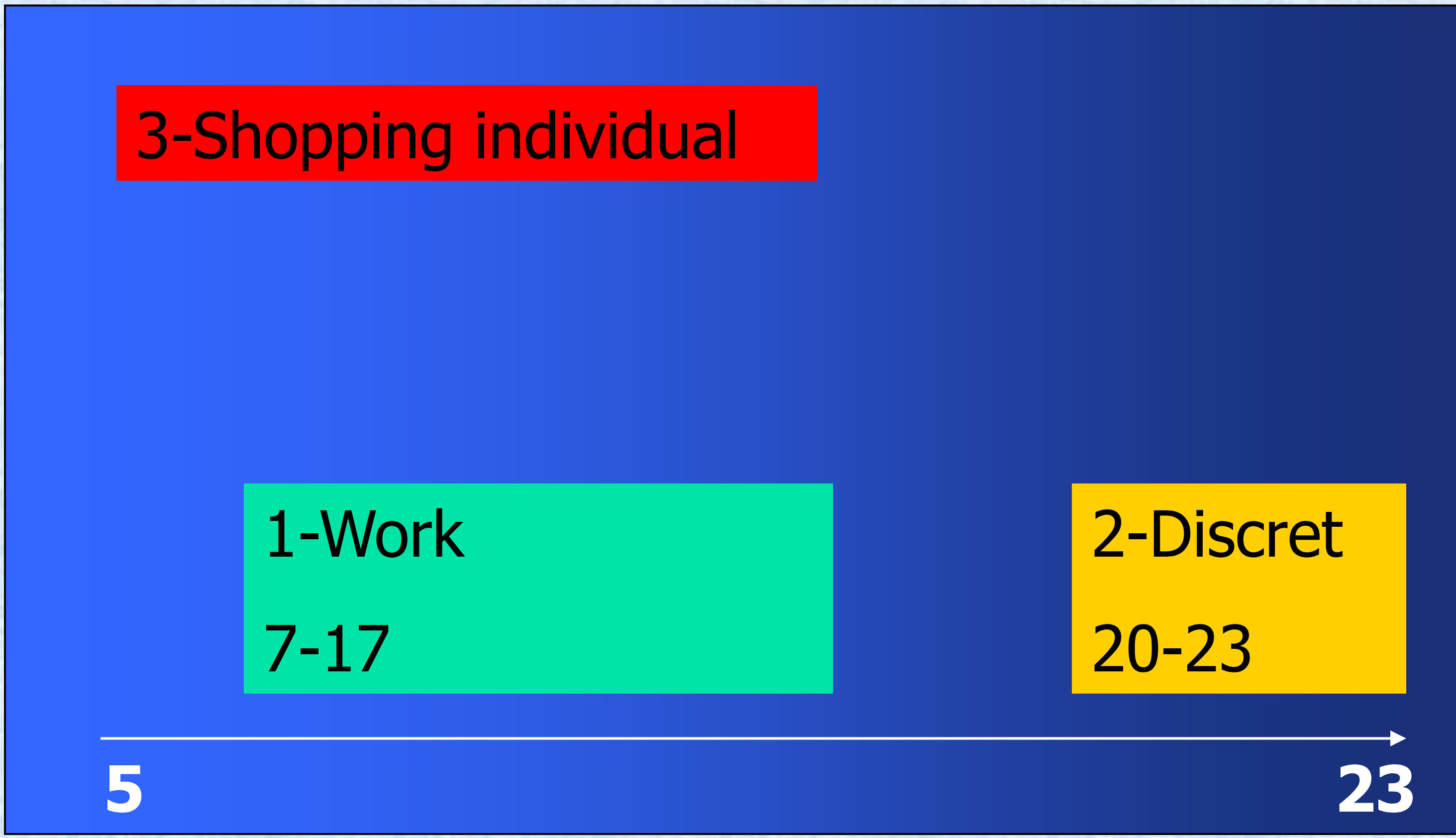

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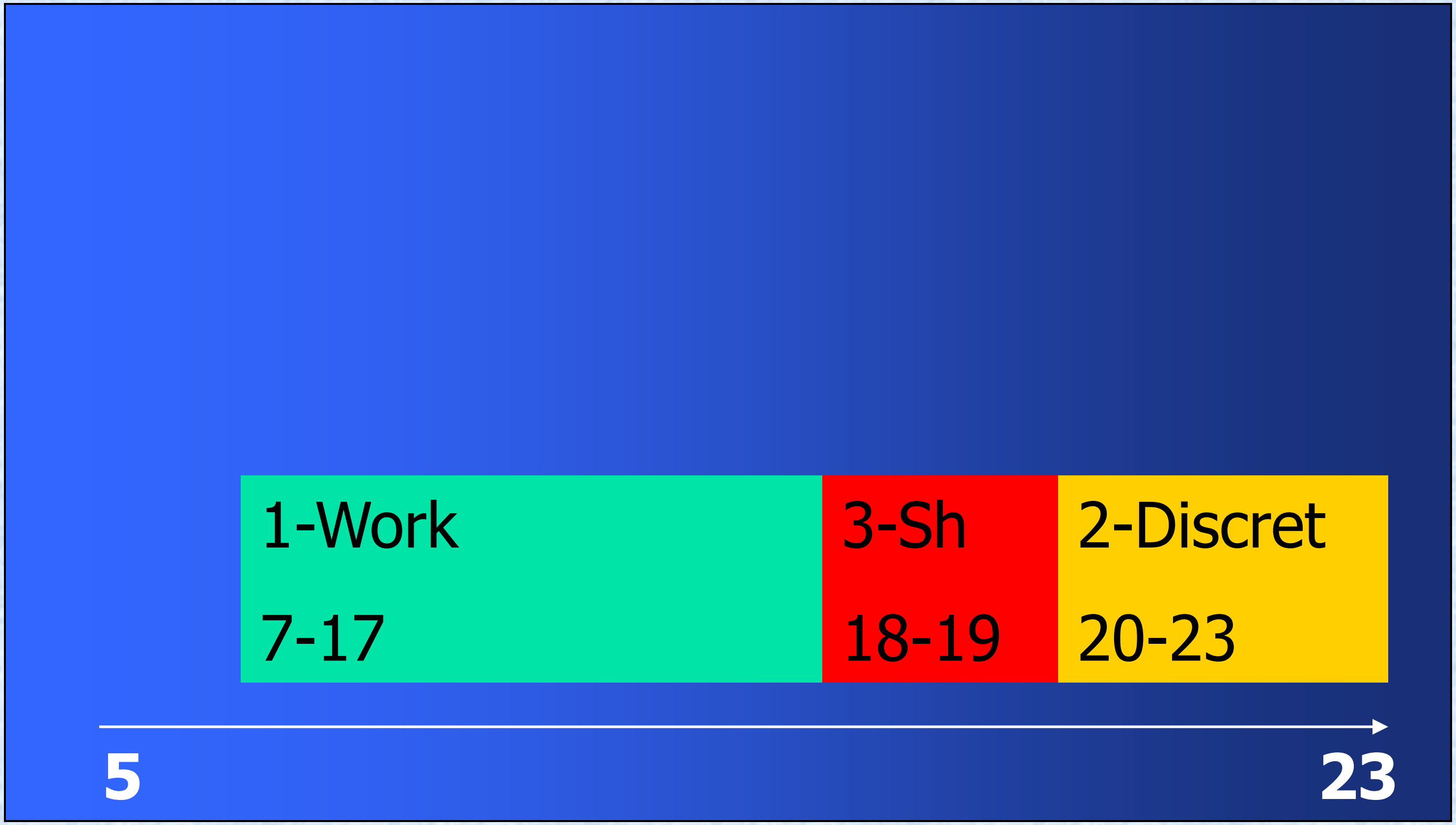
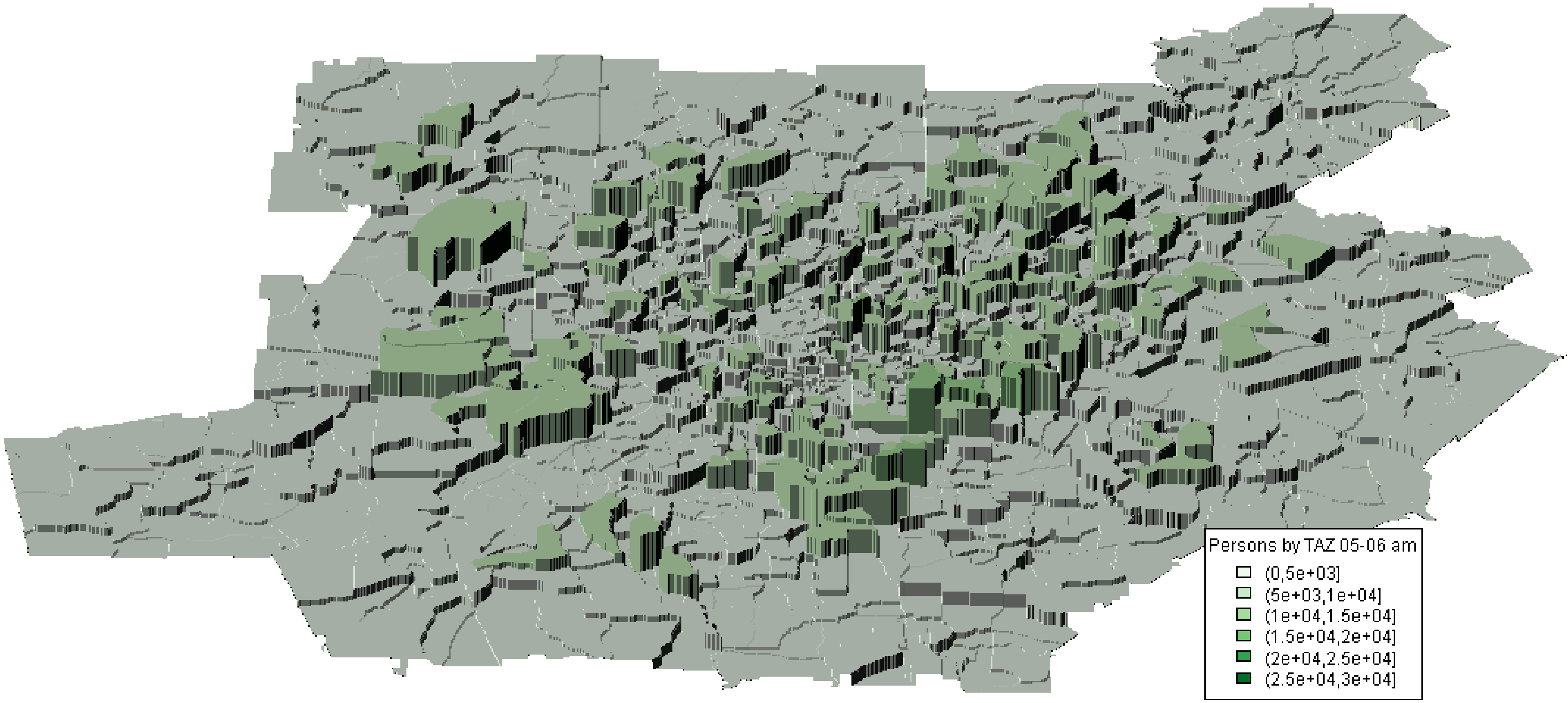
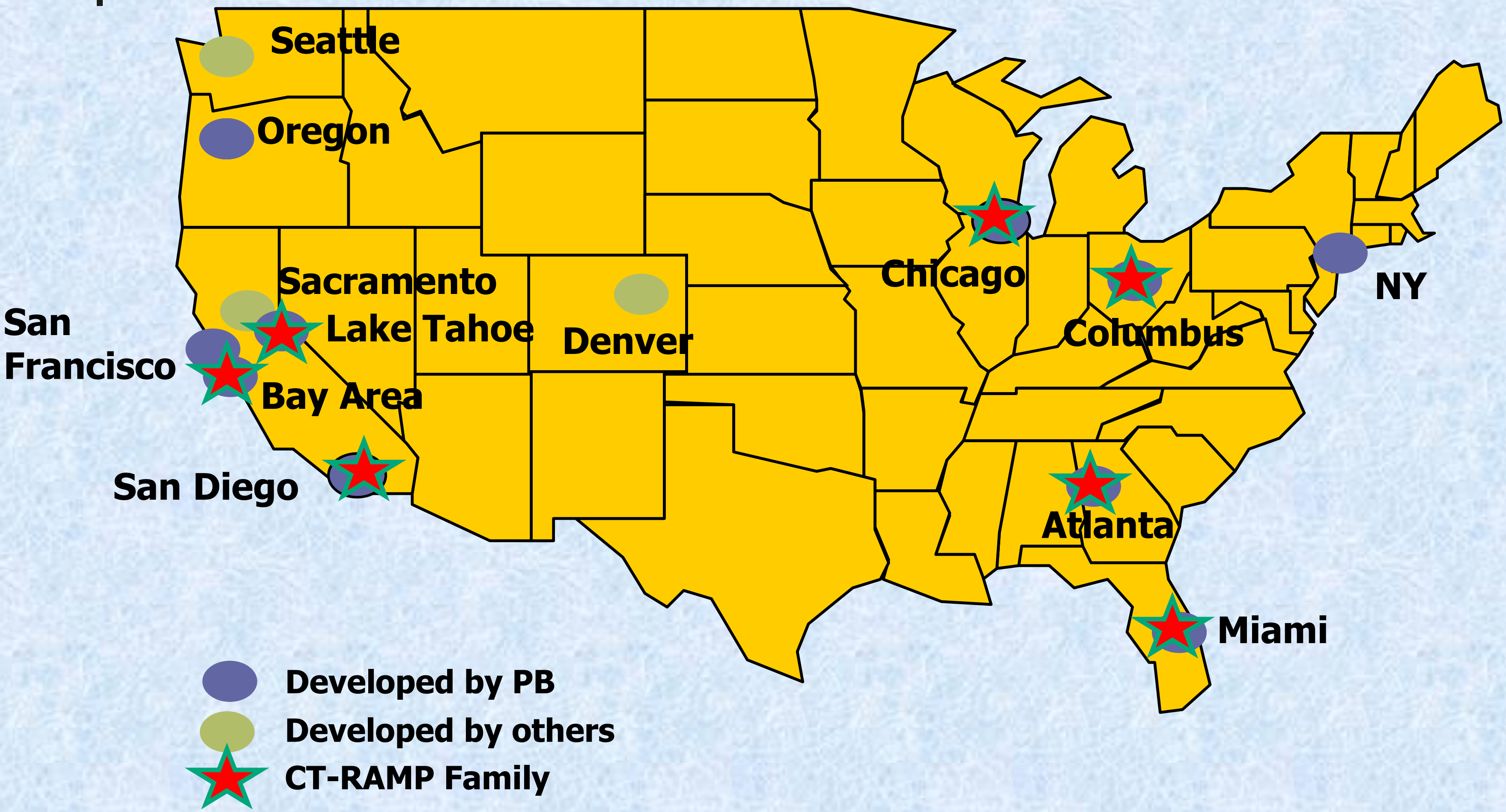


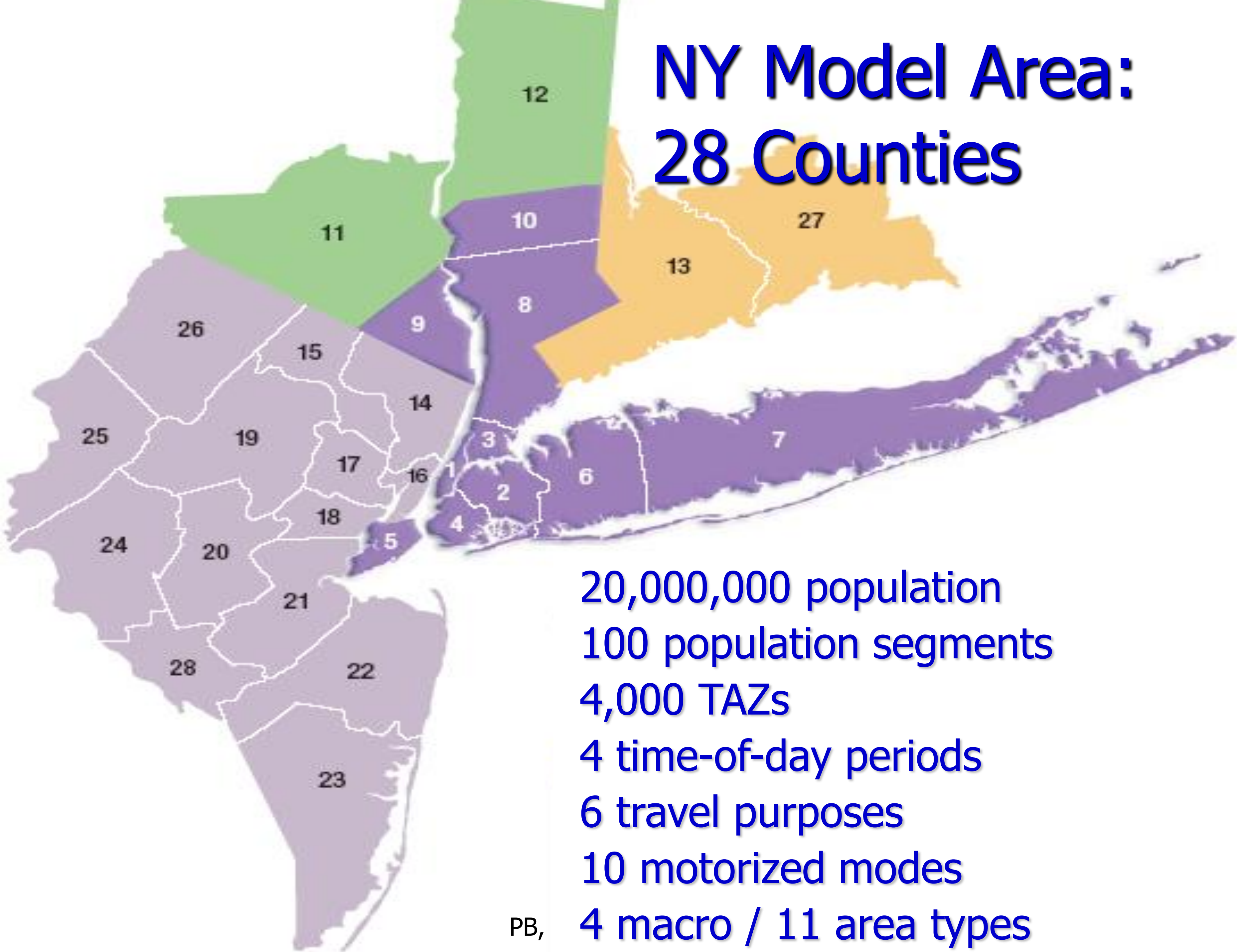
Persons By TAZ and Hour (Daytime Population, Atlanta, ARC ABM)



Completed ABMs in the United States in Practice



NY Model Area:
28 Counties

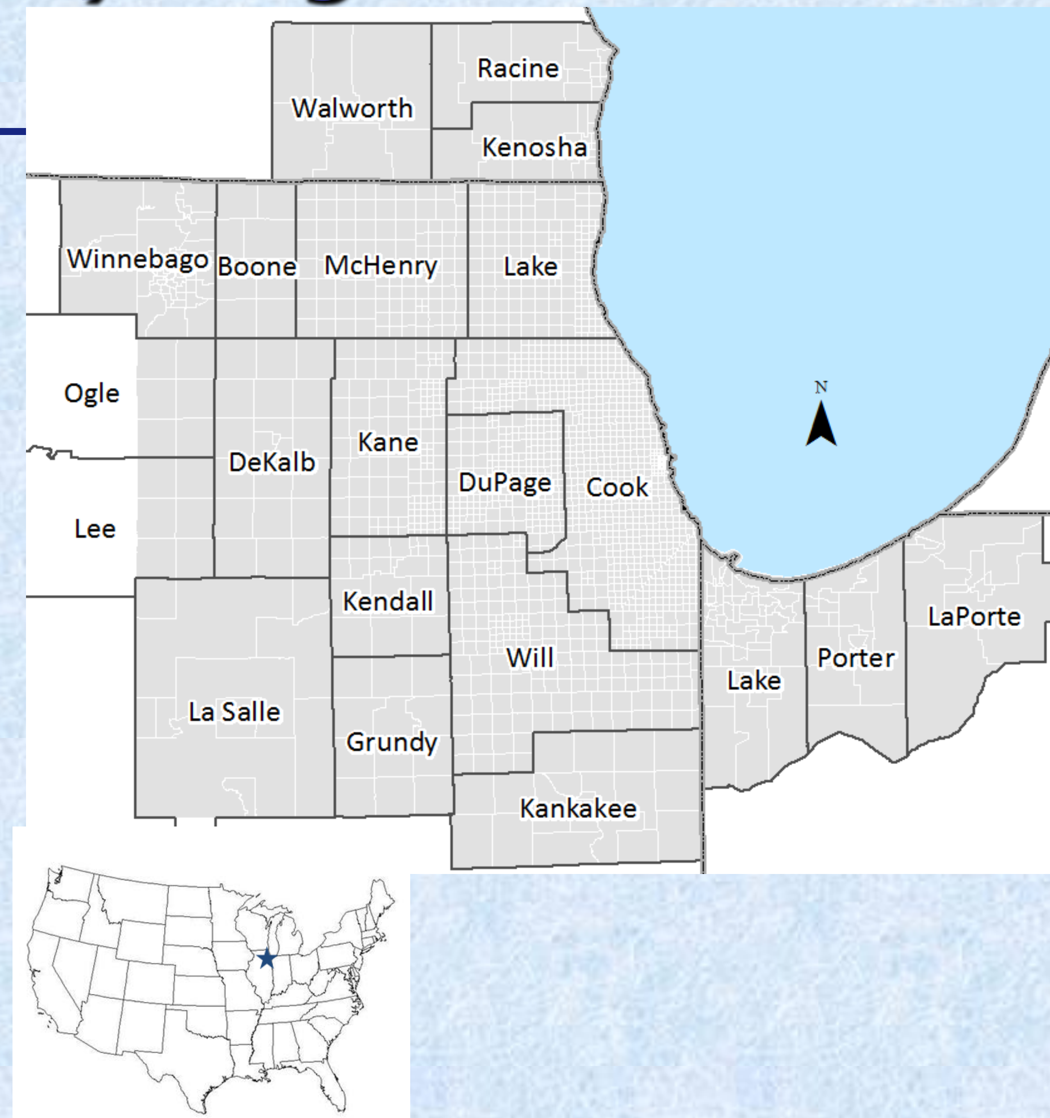


20,000,000 population
100 population segments
4,000 TAZs
4 time-of-day periods
6 travel purposes
10 motorized modes
4 macro / 11 area types

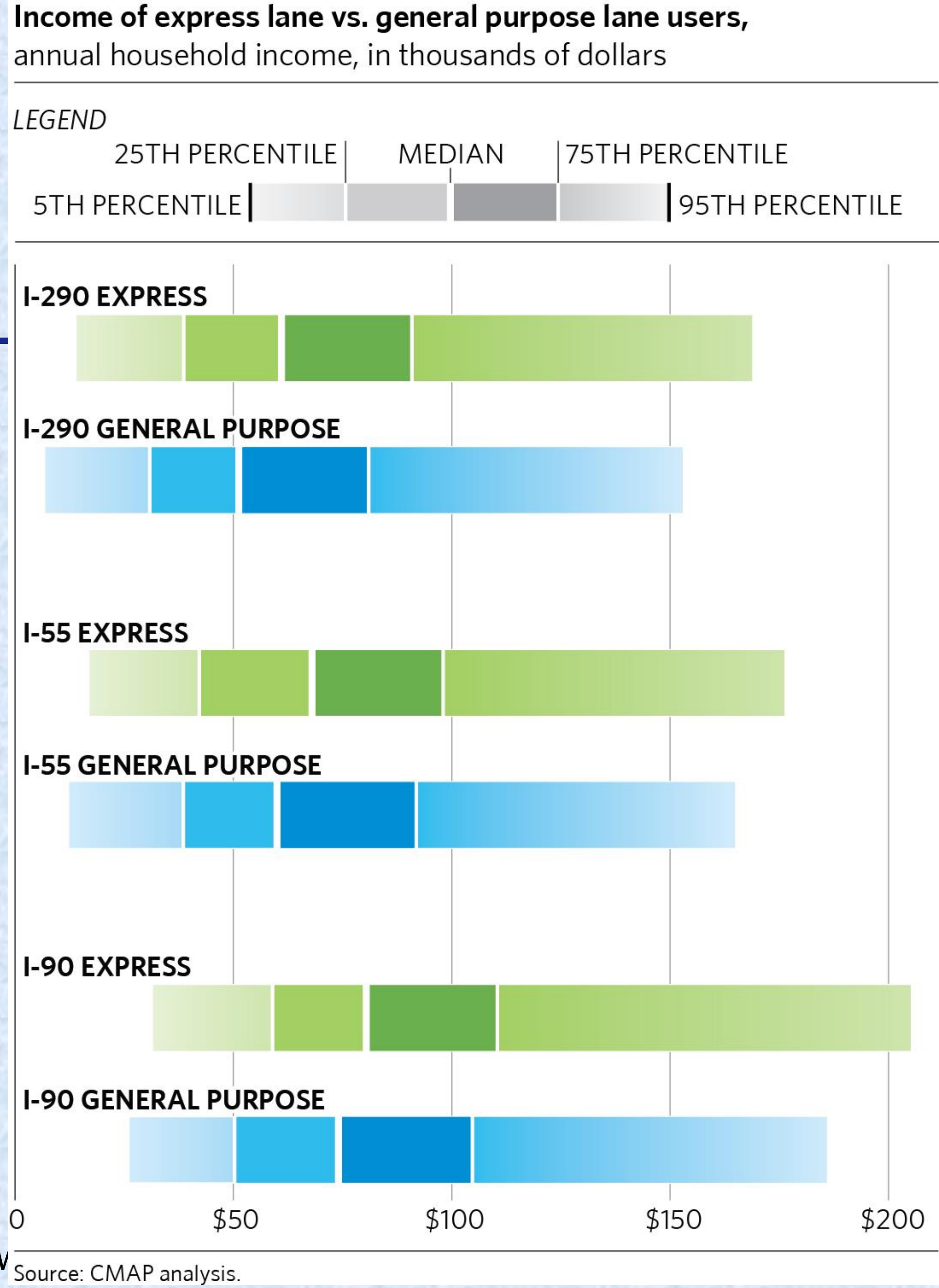
PB,

Chicago (CMAP) Region

- Population: 10.5 million
- Modeling Region
  - 21 counties in 3 states
    - Neighboring MPOs
      - SE Wisconsin
      - NW Indiana
  - 1,944 TAZs
  - Road Network
    - 15.0K nodes
    - 44.3K links
  - Rail Network
    - 6.6K nodes
    - 19.5K links



Income distribution of users of ML and GPL



CT-RAMP Family of ABMs Developed by PB SAG

- **C**oordinated **T**ravel **R**egional **A**ctivity-based **M**odeling **P**latform
- Main features:
  - Explicit intra-household interactions and Coordinated DAP (CDAP)
  - Continuous temporal dimension
  - Integration of activity generation, location, and TOD sub-models
  - Sensitive to a wide range of socio-economic variables, transportation costs/accessibilities, and land-use changes
  - JAVA-based package for ABM construction

Members of CT-RAMP Family

- 1st generation:
  - Columbus, OH (MORPC) – in practice since 2004
  - Lake Tahoe, NV (TMPO) – in practice since 2006
  - Atlanta, GA (ARC) – in practice since 2009
  - San-Francisco Bay Area, CA (MTC) – in practice since 2010
- 2nd generation:
  - Chicago, IL (CMAP) – in practice since 2011
  - San-Diego, CA (SANDAG) – in practice since 2012
  - Miami, Fl (SERPM) – in practice since 2012
- 3rd generation:
  - Phoenix/Tucson, AZ (MAG) – started in 2010
  - Jerusalem, Israel (JTMT) – started in 2011
  - Ohio 3C Project – started in 2013:
    - Columbus (MORPC)
    - Cleveland (NOACA)
    - Cincinnati (OKI)
  - LA, CA (SCAG) – started in 2013 (Hybrid of CT-RAMP and MDCEV)
  - Nashville, TN (NMPO) – started in 2013 (PopSyn)

ADVANCED ABM INTEGRATED WITH UE

What is Different with ABM?

- Complicated chains of choices with structural changes in the list of agents instead of predetermined matrix of choices pertinent to 4-step
- Entropy-maximizing formulation for demand terms is theoretically possible but impractical because of dimensionality
- Microsimulation of crisp choices instead of fractional probabilities

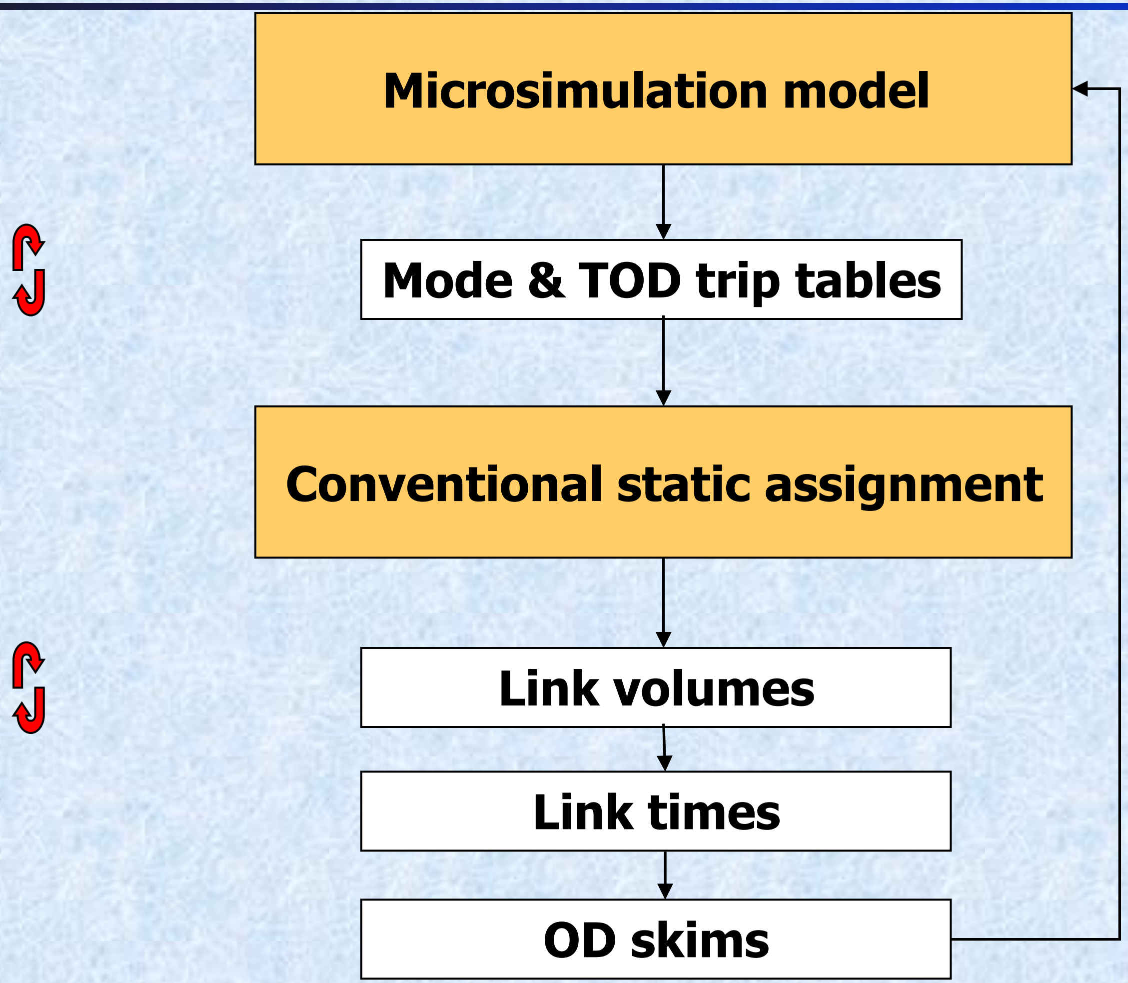
Practical Methods: Enforcement & Averaging

- Simple feeding back LOS variables does not ensure convergence
- 2 ways to ensure convergence by iterating:
  - Enforcement to ensure replication of "crisp" individual choices:
    - Theoretical foundation
    - Empirical strategies
  - Averaging:
    - Continuous LOS variables (skims)
    - Link volumes (before skimming)
    - Trip tables

Enforcement Methods

- Re-using same random numbers / seeds:
  - Each household / person has a fixed seed
  - Structural stability of decision chains by reserving choice placeholders
- Gradual freezing of travel choices:
  - Subsets of households
  - Travel dimensions
- Analytical discretizing of probability matrices:
  - Avoiding Monte-Carlo (no random numbers!)

Averaging Methods (NY BPM)



New Challenge – Continuously Distributed VOT: Chicago Pricing ABM

- Basic VOT estimated for each travel purpose and person type
- Situational variation of VOT applied for each person based on lognormal distribution – essential for pricing studies
- Car occupancy accounted by cost sharing:
  - VOT for HOV2 is 1.6 of highest participant VOT
  - VOT for HOV3+ is 2.3 of highest participant VOT
- For static assignments VOT has to be aggregated across individuals into discrete vehicle classes

Resulted Classes for Assignment

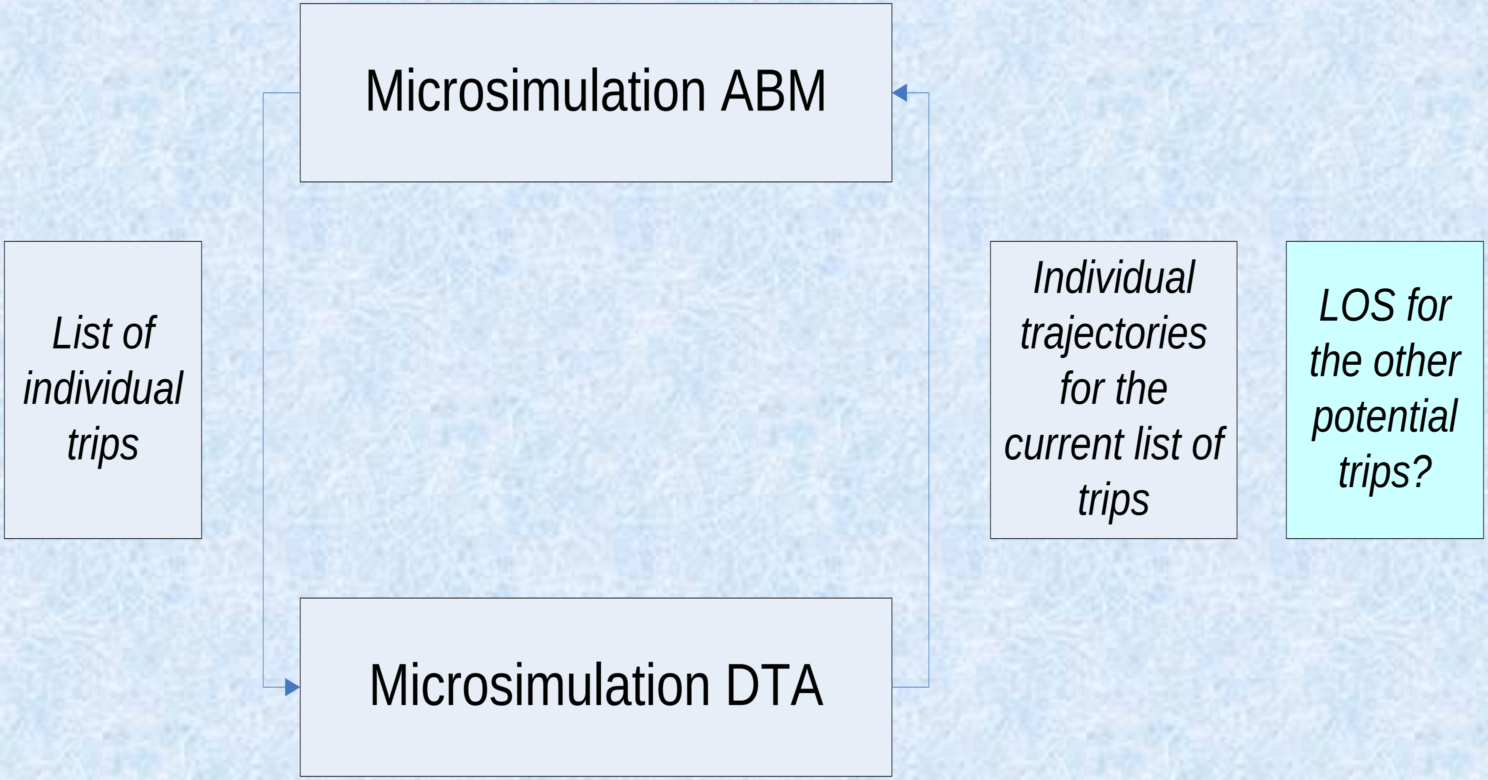
Vehicle type & VOT	Non-toll SOV	Non-toll HOV2	Non-toll HOV3+	Toll SOV	Toll HOV2	Toll HOV3+
Auto low	1	3	5	2	4	6
Auto high	7	9	11	8	10	12
Commercial	13			14		
Light truck	15			16		
Medium truck	17			18		
Heavy truck	19			20		
External low	21	23	25	22	24	26
External high	27	29	31	28	30	32
Airport low	33	35	37	34	36	38
Airport high	39	41	43	40	42	44

Conclusions on Integration of ABM and UE

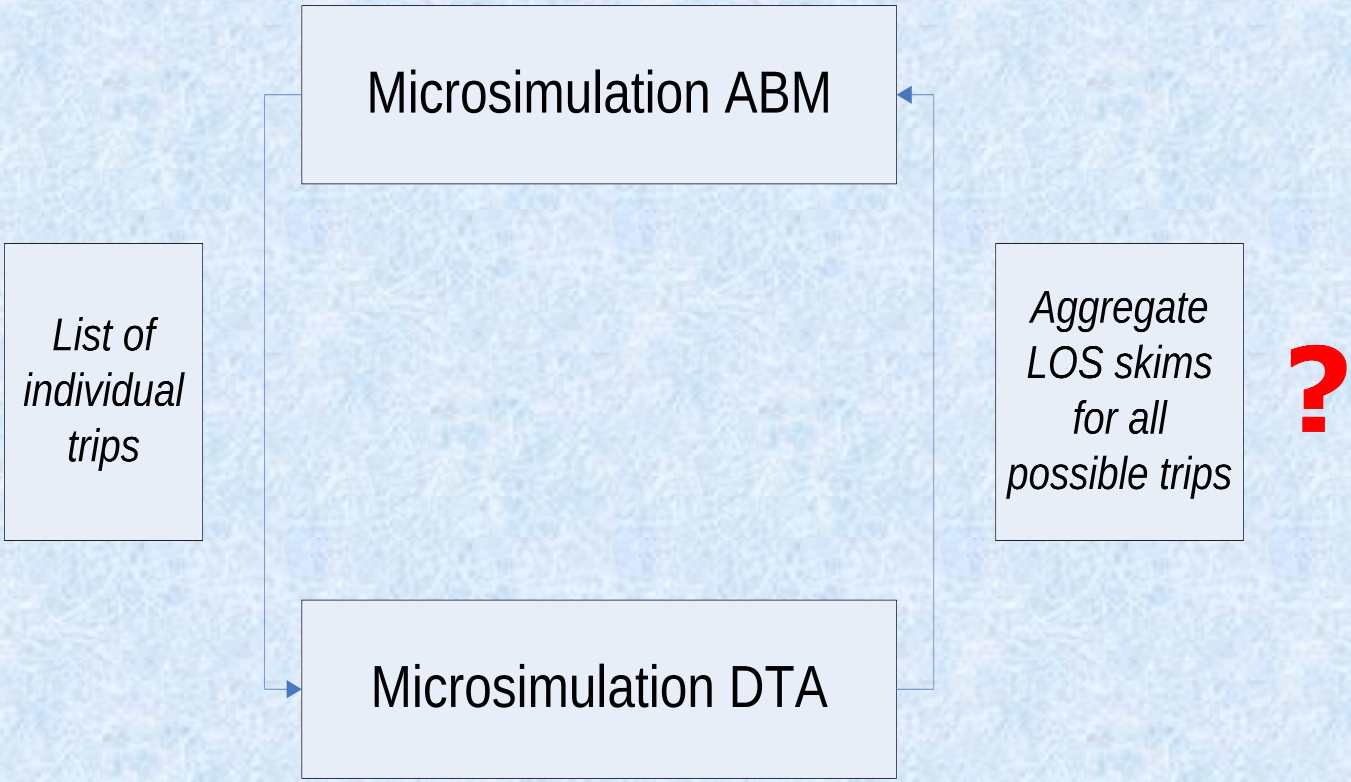
- Effective & efficient practical strategy:
  - MSA of link volumes and
  - MSA on trip tables
- Enforcement can be applied effectively
- Segmentation incompatibility is exacerbated due to continuous VOT and other individual variables of ABM:
  - Better network model is needed

ABM INTEGRATED WITH DTA

Integration Issue DTA-to-ABM



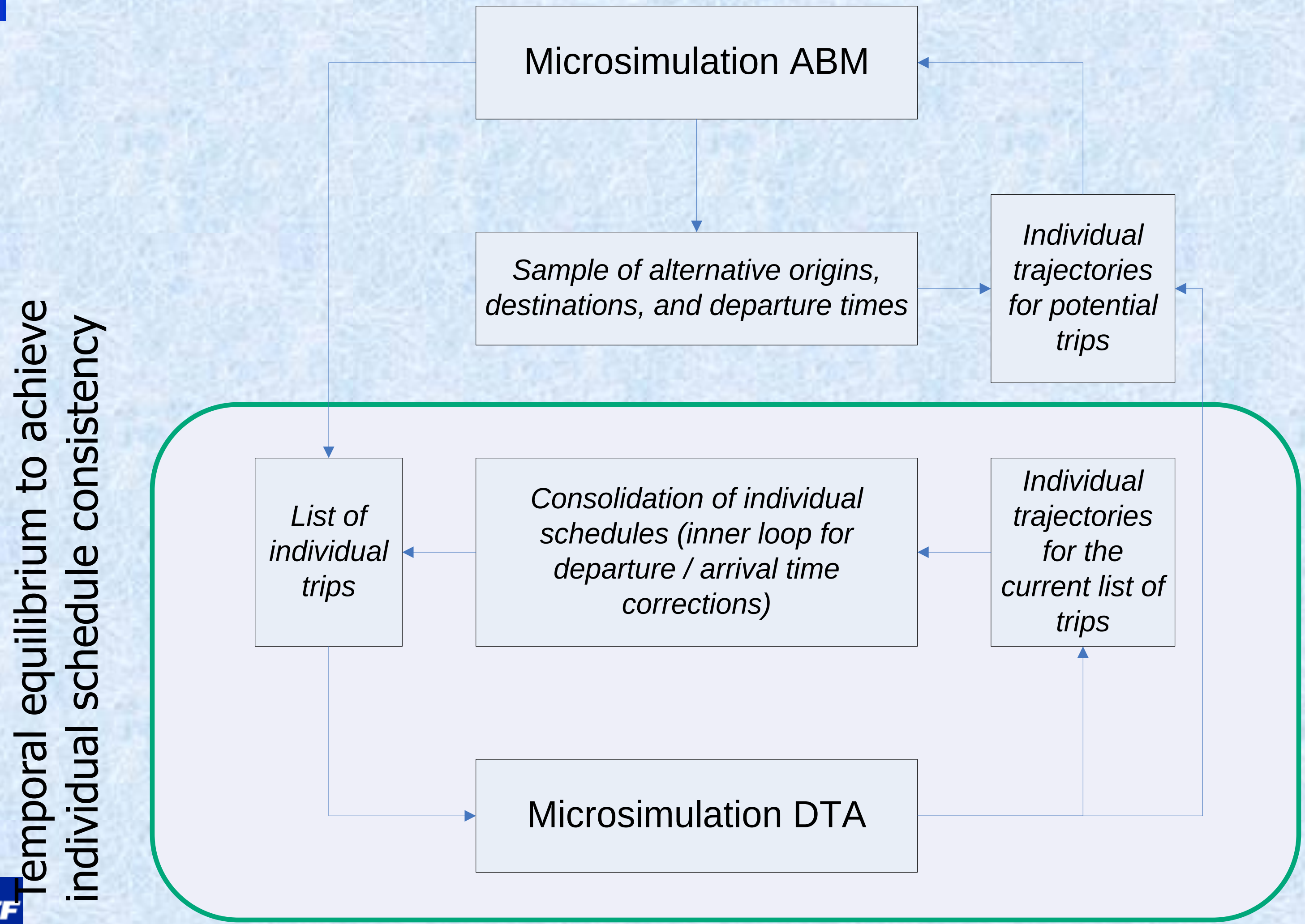
Possible Surrogate (SHRP 2 C10)



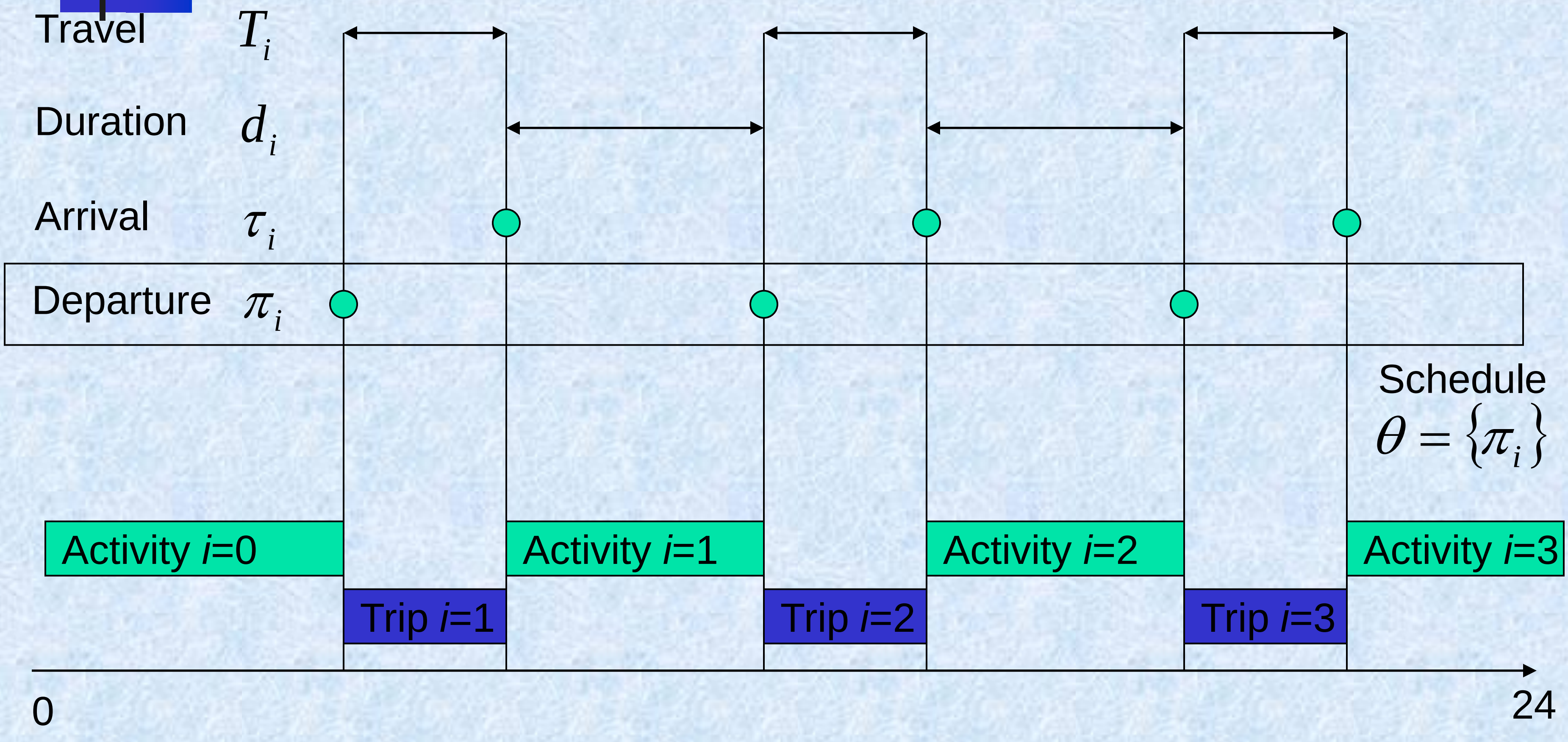
What’s wrong with feeding back aggregate LOS OD skims?

- Aggregate OD LOS skims is only a surrogate for consistent individual path LOS:
  - Back to 4-step resolution and aggregation biases
- Infeasible to support individual level of segmentation pertinent to ABM (“curse of dimensionality”):
  - VOT categories (7-8 at least)
  - Occupancy categories (3 at least)
  - Departure time bins (15 min at least)
- Behaviorally non-appealing:
  - No relation to actual individual experience, learning, or adaptation

2-Level Equilibration Schema Developed by PB SAG



Schedule Consistency



Schedule Adjustment

Find new schedule close to previous durations and departures

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

New durations

New departures

Previous durations

Previous departures

Daily consistency

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

Changed travel times

Departure time

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

Solution

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

Agent vs. Simulated Individual

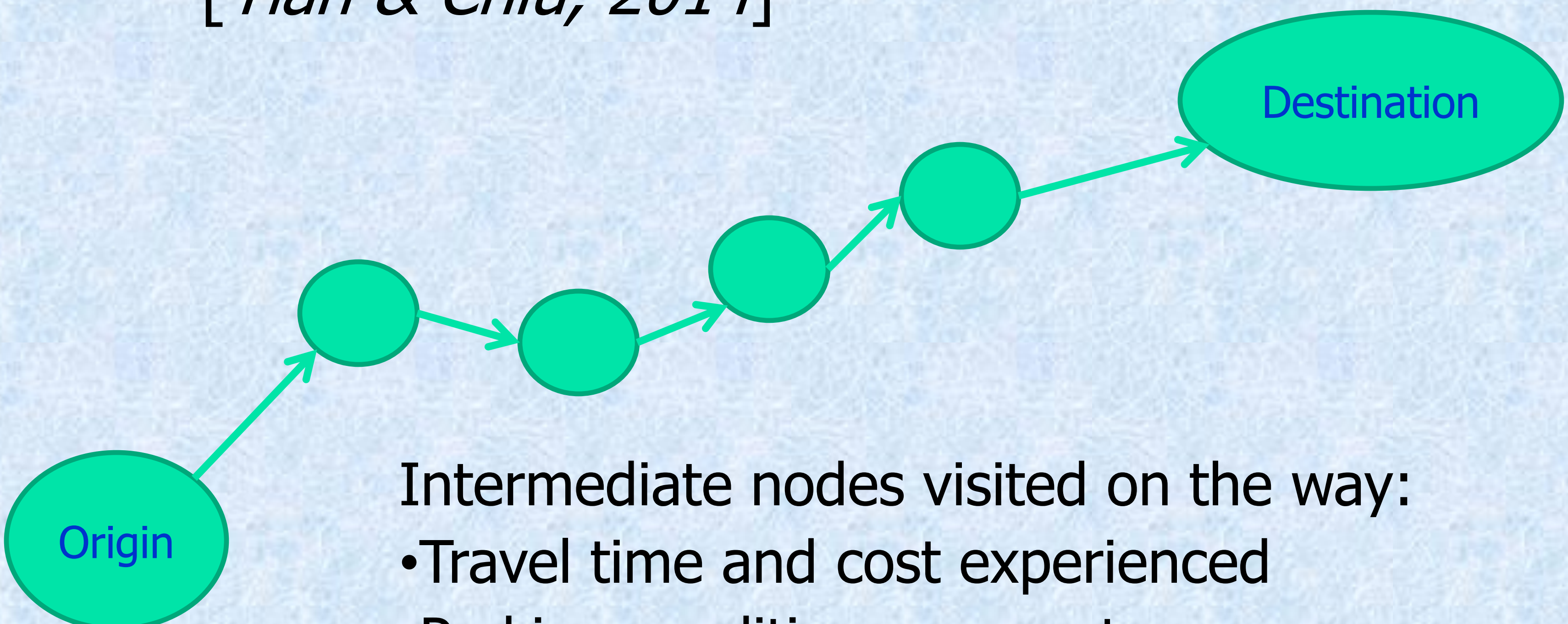
- Intelligence:
  - Active autonomous behavior and control
  - Knowledge-level interaction and behavior activation instead of method invocation
  - **Can change parameters and decision rules to achieve goals**
- Constrained & dynamically updated information:
  - **Learn about environment and each other, form choice sets**
  - Contagion, stigmergy, referencing, modality
- Interact with each other and not with environment only:
  - Emergent collective behavior (complex, non-linear, discontinuous)
  - Competition, bids, offers, negotiations instead of densities/logsums
  - **Cooperation, group decision-making, explicit intra-household and inter-household interactions**

Dynamic Choice Set

- In the focus of research on choices with large number of alternatives:
  - Location choices
  - Network route choice
- "Mental Maps" and gradual learning [*Arentze & Timmermans, 2000-2013*]:
  1. Start with limited choice set (can be a single alternative)
  2. Choose the best alternative
  3. Evaluate satisfaction level (not a standard RUM!)
  4. If not, add one more "probe" alternative to choice set, go to 2

Learning about Space from Individual Trajectories (Dynamic Choice Set)

- One implemented trip provides individual learning experience w.r.t. multiple destinations [*Tian & Chiu, 2014*]



Intermediate nodes visited on the way:

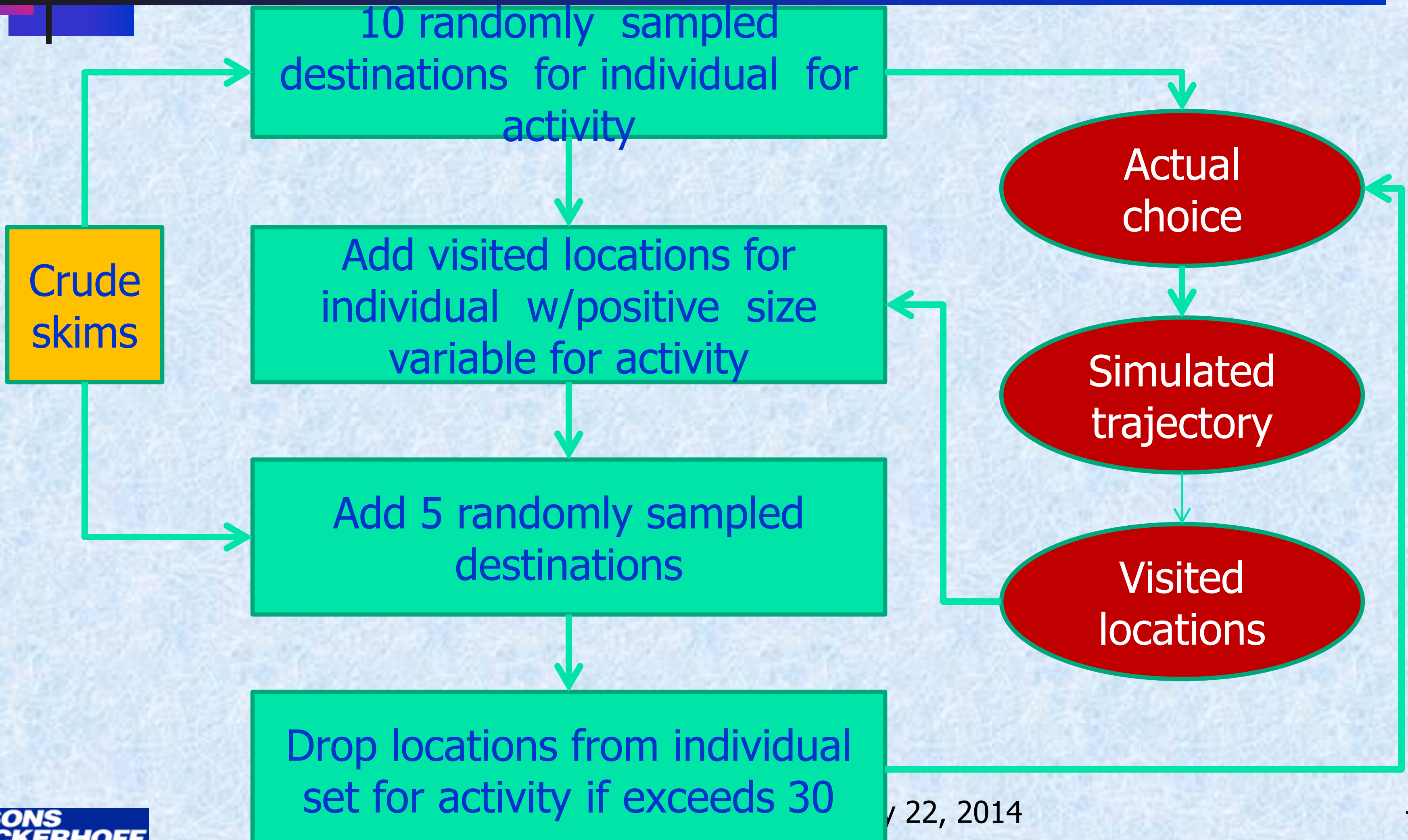
•Travel time and cost experienced

•Parking conditions may not

Sampling of Trip Destinations to Avoid Full Skim Proliferation

- (Standard) destinations are sampled in ABM for efficiency:
  - 30 out of 20,000 MAZ for each modeled tour & trip
  - Sampled randomly with importance (size variable and distance)
  - No memory, experience, or learning
- (Suggested) Intelligent dynamically updated choice set for each individual and activity:
  - Efficient accumulation of individual trajectories in microsimulation process
  - Behaviorally appealing

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)

Conclusions on Integration of ABM and DTA

- ABM-DTA integration is the most promising avenue:
- First ABM-DTA integration projects:
  - SHRP 2 C10:
    - Sacramento, Jacksonville, Tampa
  - MPO-sponsored (all PB):
    - CMAP, SANDAG, JTMT
- For small metropolitan areas under 1 million ABM-DTA integration is already realistic with many DTA platforms
- For large metropolitan areas DTA is still a challenge:
  - MatSim offers one of the first solutions

NY BPM – MatSim Integration Demonstration

- Promising real-size exercise for the mega-region of NY:
  - 20 million people handled by NY BPM to generate demand patterns
  - Full-size regional highway and transit networks handled by MatSim for entire-day simulation (24 hours)
- Next step:
  - Full integration of the NY ABM with MatSim utilizing innovative integration paradigm