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

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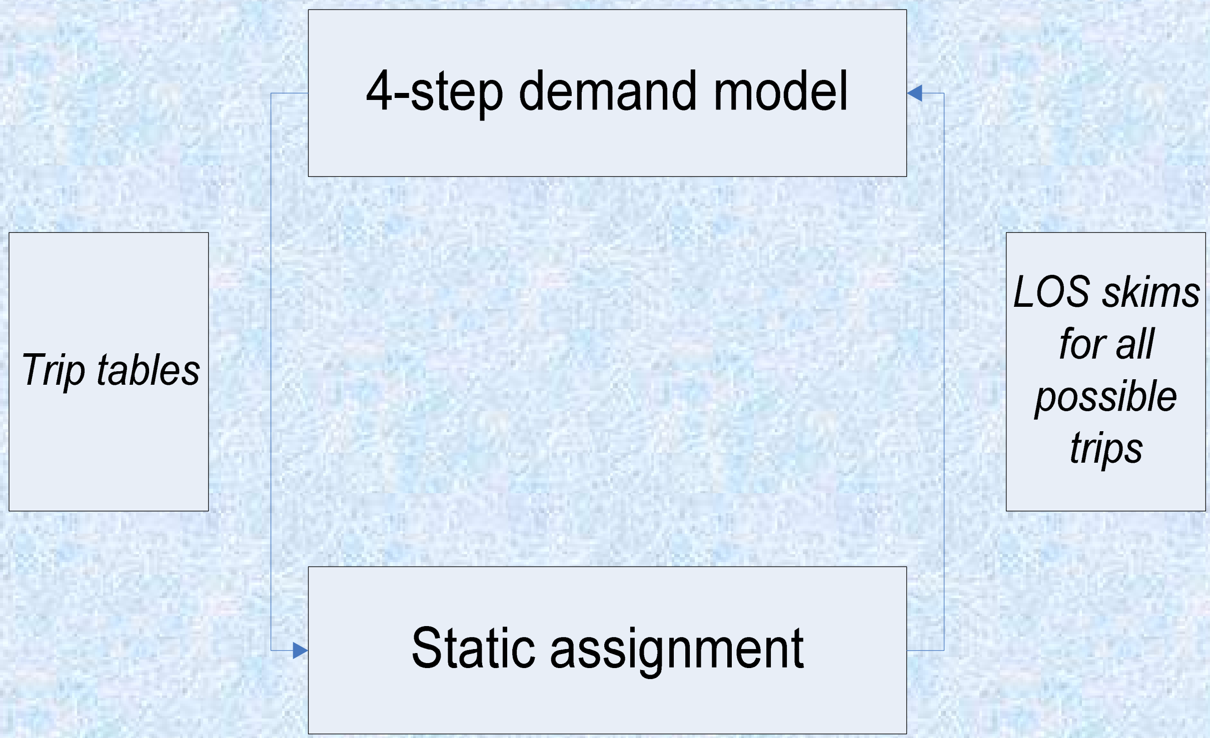
SHRP 2 Projects

- C04 “Improving Our Understanding How Highway Congestion and Pricing Affect Travel Demand”
- L04 “Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools”

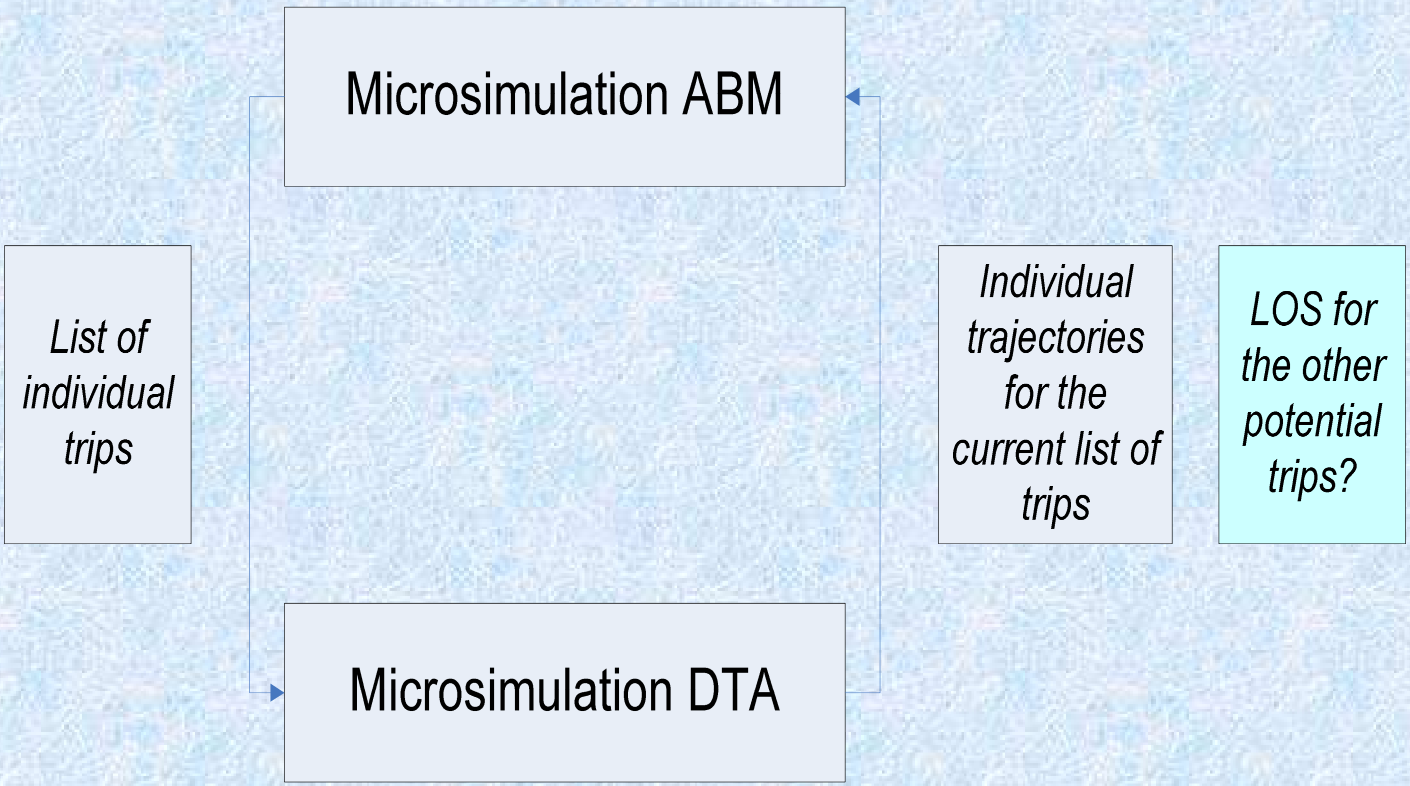
Topics to Discuss / Concepts

- 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

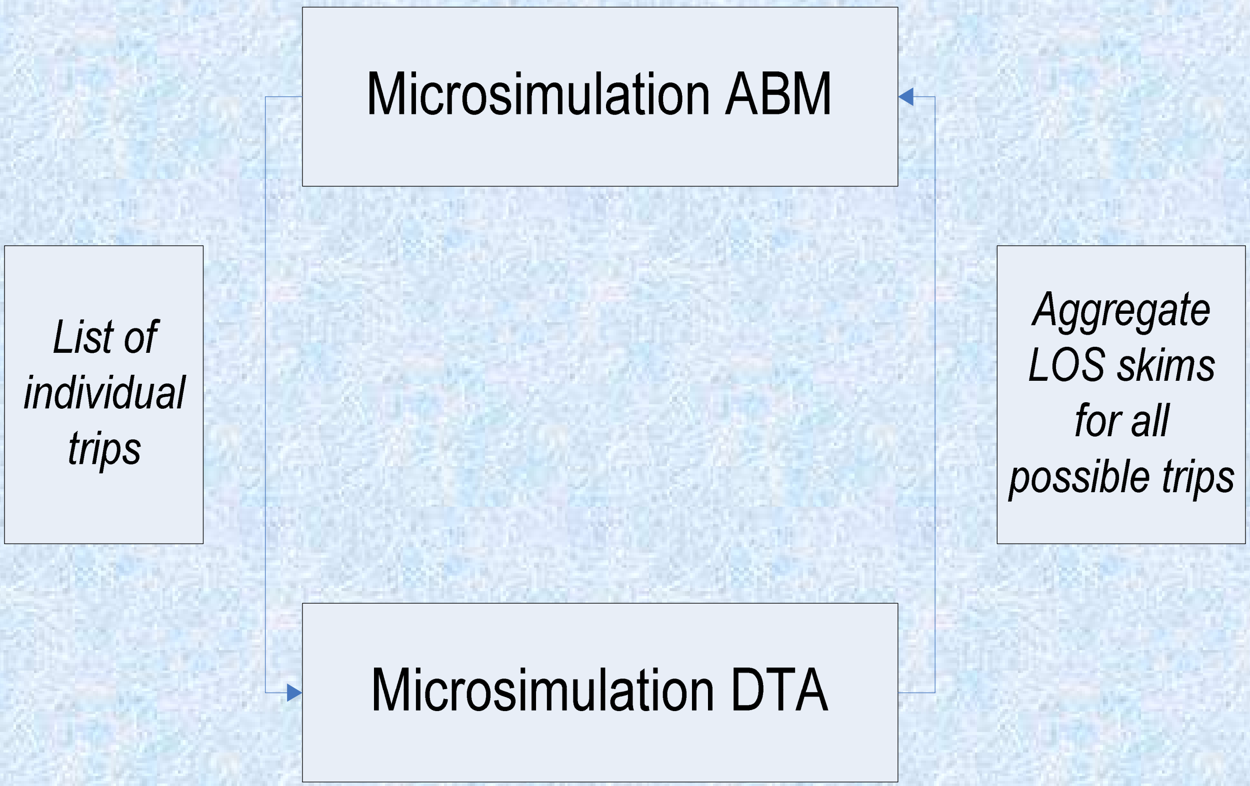
Conventional Integration Scheme



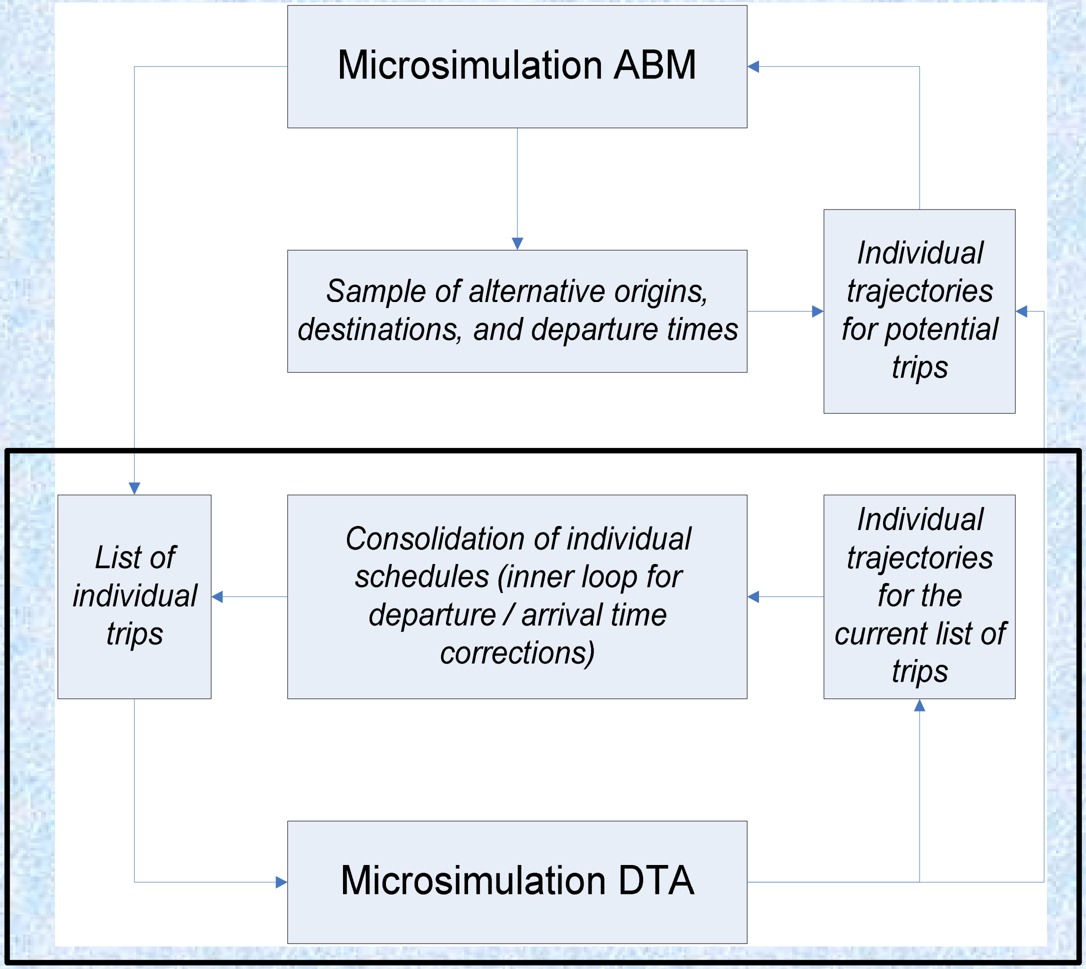
Integration Issue DTA-to-ABM



Possible Surrogate

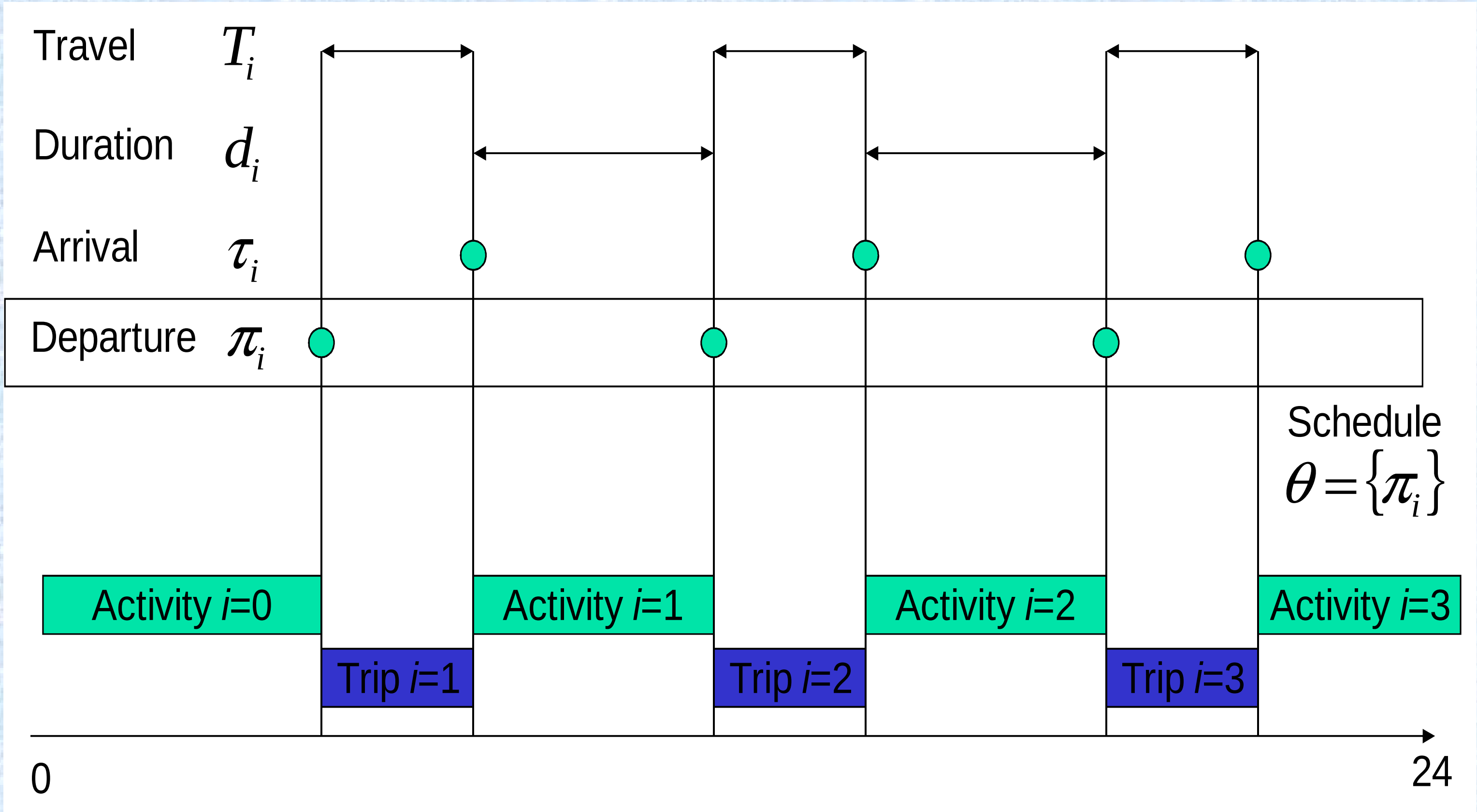


Suggested Approach



Temporal equilibrium to achieve individual schedule consistency

Individual Schedule Consistency



Schedule Adjustment Prototype

Find new schedule close to previous durations and departures

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

New durations

New departures

Previous durations

Previous departures

Daily consistency

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

Changed travel times

Departure time

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

Solution

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

Schedule Adjustment Extended

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

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

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

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

$$x_i = d_i \times \left\{\prod_{j>i}\left[\left(\frac{\pi_j}{y_j}\right)^{u_j} \times \left(\frac{\tau_j}{z_j}\right)^{v_j}\right]\right\}^{\frac{1}{w_i}}$$

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 after 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

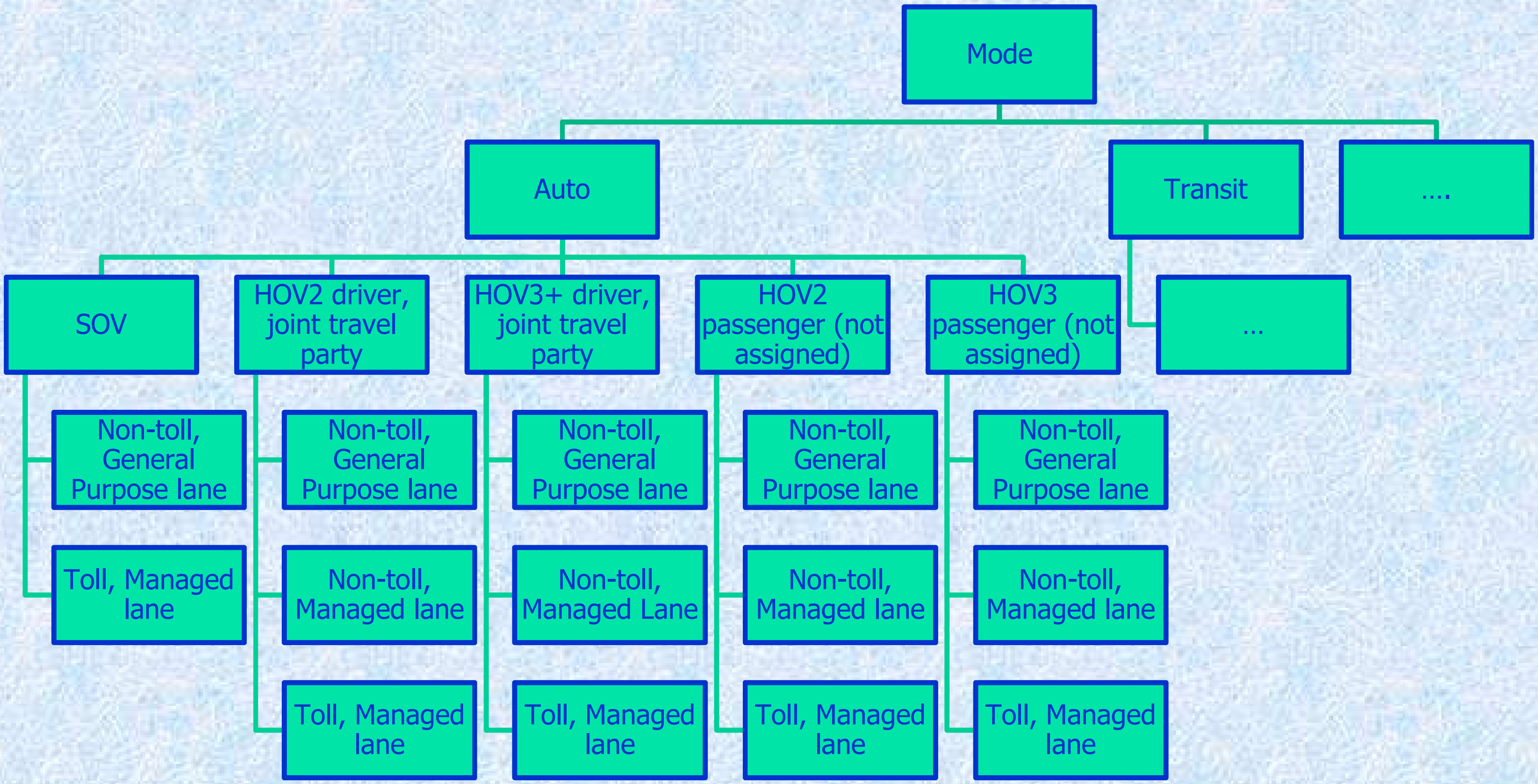
Pre-Sampling of Trip Destinations

- 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 300×30,000 and 30×300 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



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 80-90-95th and 50th percentile (asymmetric)
- (**Risk measure**) Probability of delay of certain length (asymmetric)
- (**Lateness measure**) Average delay (asymmetric)

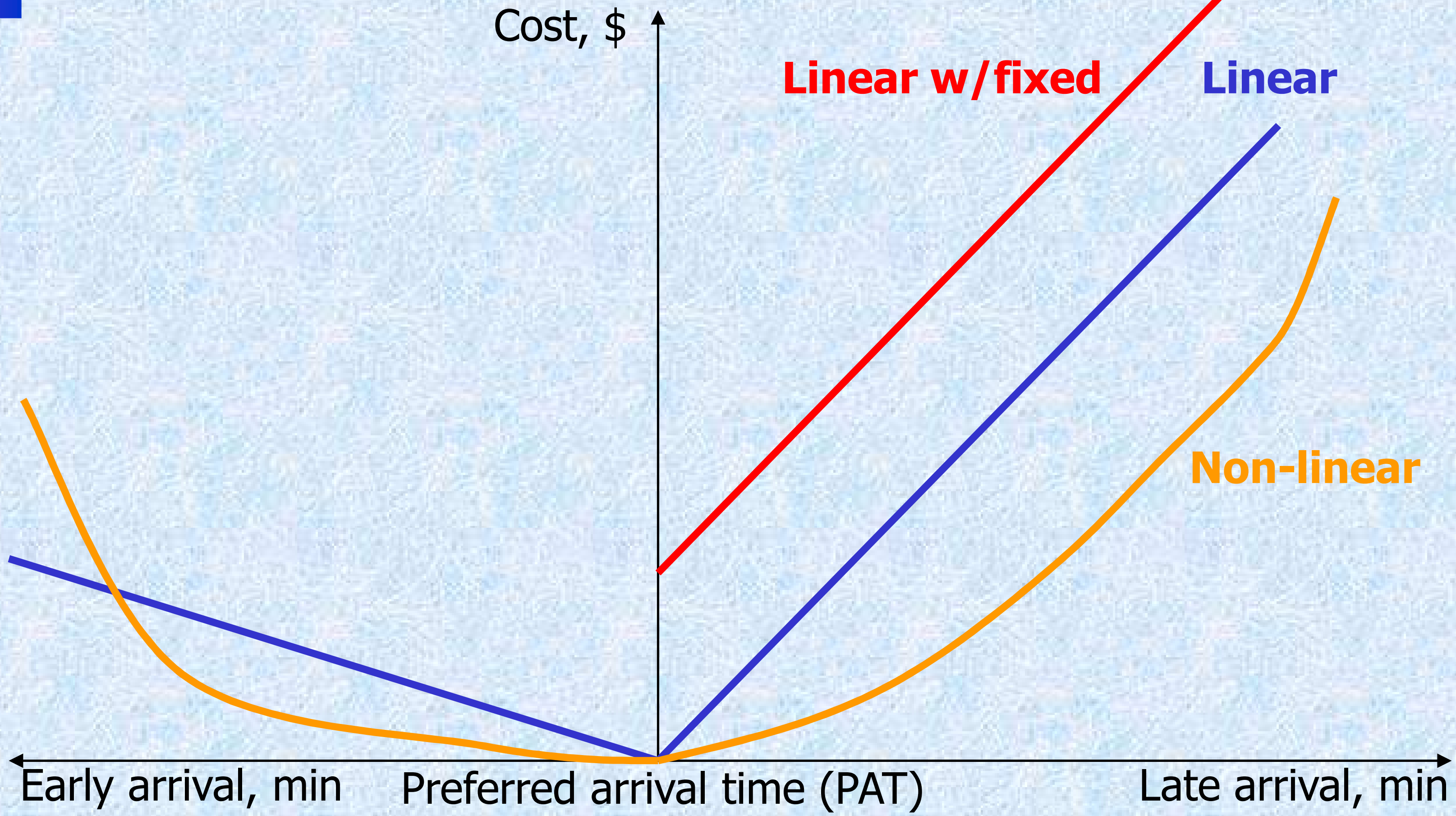
Reliability Ratio (ρ)

- **$U=\alpha\times Time+\beta\times Cost+\gamma\times Reliability$**
  - $VOT=\alpha/\beta$
  - $VOR=\gamma/\beta$
  - $\rho=\gamma/\alpha=VOR/VOT$
- It is more complicated with non-linear models:
  - VOT, VOR, and **ρ** becomes functions of time, cost, or distance
  - These variables must be fixed at certain values to calculate VOT, VOR, and **ρ**

Recommended Weights for Perceived Time

Travel time conditions	**Weight**	**LOS**	**V/C**
Free Flow	1.00	A, B	Under 0.5
Busy	1.05	C	0.5-0.7
Light Congestion	1.10	D	0.7-0.8
Heavy Congestion	1.20	E	0.8-1.0
Stop Start	1.40	F	1.0-1.2
Gridlock	1.80	F	1.2+

Schedule Delay Cost



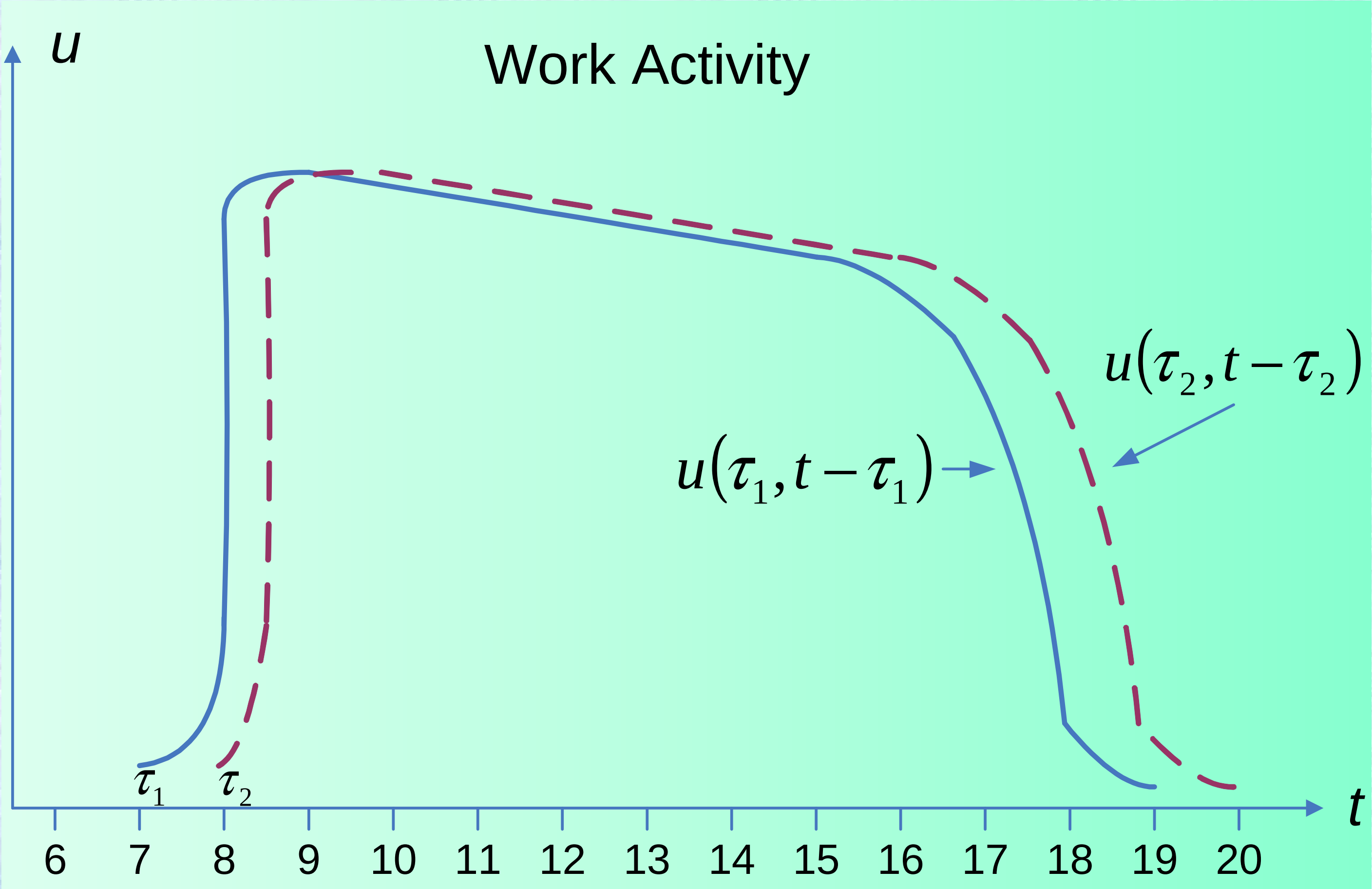
Schedule Delay Cost

- $\boldsymbol{U = \alpha \times T + \beta \times SDE + \gamma \times SDL + \delta \times L}$
- 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: $\gamma \geq \alpha$

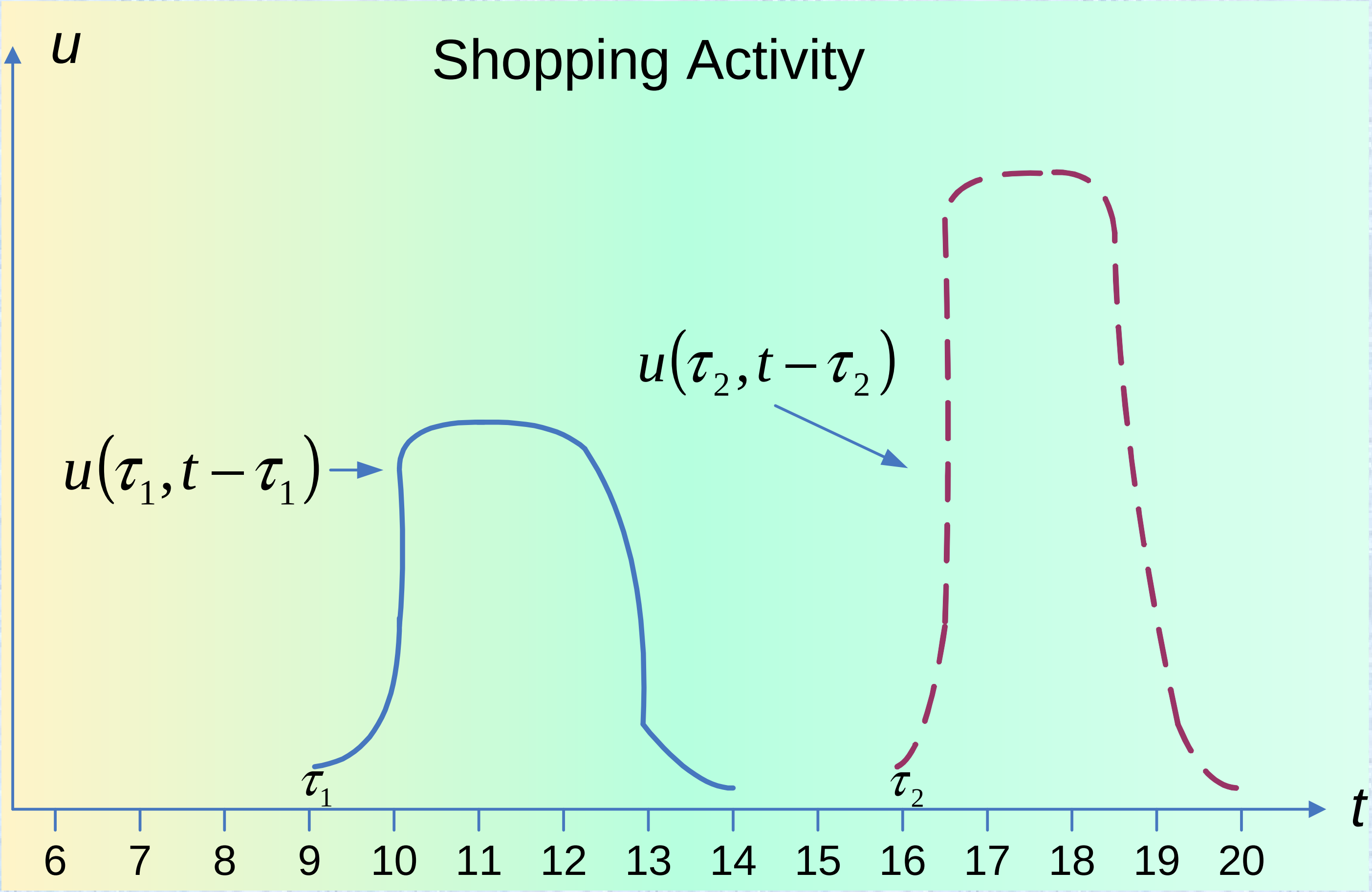
Summary of Defaults for ρ

Population segment	Travel segment	Perceived congested time vs. free-flow	STD vs. mean time	Buffer 90^{th}-50^{th} vs. median time	Lateness against PAT vs. mean time
High income (60K+)	To work	2.0	0.8	1.0	3.0
	From work	1.5	0.6	0.7	2.0
	Non-work	1.2	0.4	0.5	1.8
Low income (U60K)	To work	2.5	1.0	1.2	6.0
	From work	1.2	0.3	0.4	1.7
	Non-work	1.1	0.2	0.2	1.5

Temporal Utility Profile for Activity Participation



Temporal Utility Profile for Activity Participation



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

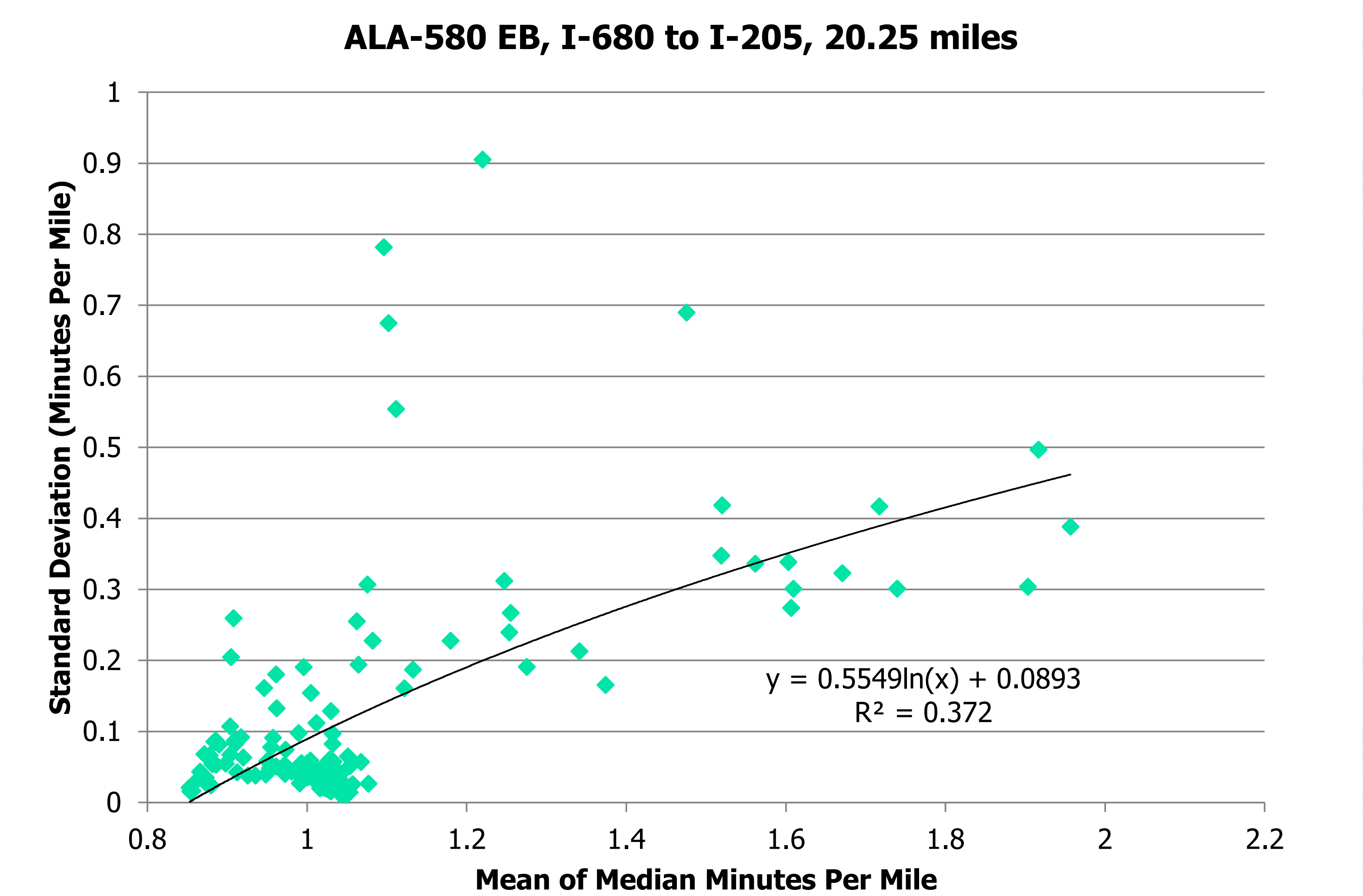
Reliability in Network Simulations

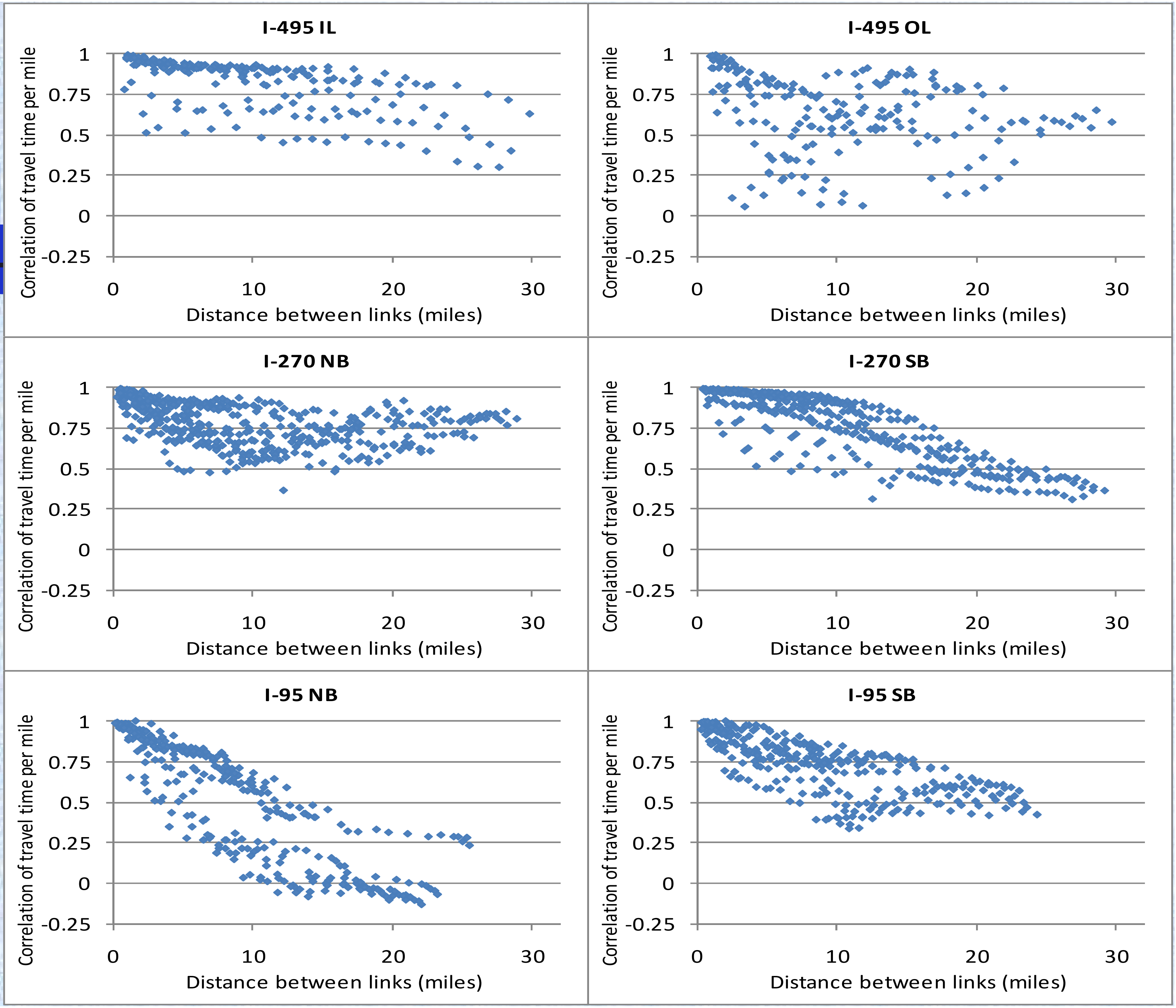
- Challenges:
  - Incorporate reliability in route choice
  - Generate OD reliability measures (skims)
- Methods:
  - Analytical (single run)
  - Simulation (multiple runs)

Traffic Physics at Link Level

- Volume-Delay-Reliability Function (VDRF):
  - Average time $\mathbf{t_a=f(v_a)}$
  - STD (or other Reliability measure): $\boldsymbol{\sigma_a=g(t_a)=g[f(v_a)]}$ or $\boldsymbol{\sigma_a=h(v_a)}$
- Growing number of VDRF estimated:
  - $\boldsymbol{\sigma_a=g(t_a)}$ – linear, slightly non-linear
  - $\boldsymbol{\sigma_a=h(v_a)}$ – highly non-linear (convex)

Link-Level Functions (L03)




I-495 IL
I-495 OL
I-270 NB
I-270 SB
I-95 NB
I-95 SB
Correlation of travel time per mile
Distance between links (miles)
1
0.75
0.5
0.25
0
-0.25
0
10
20
30

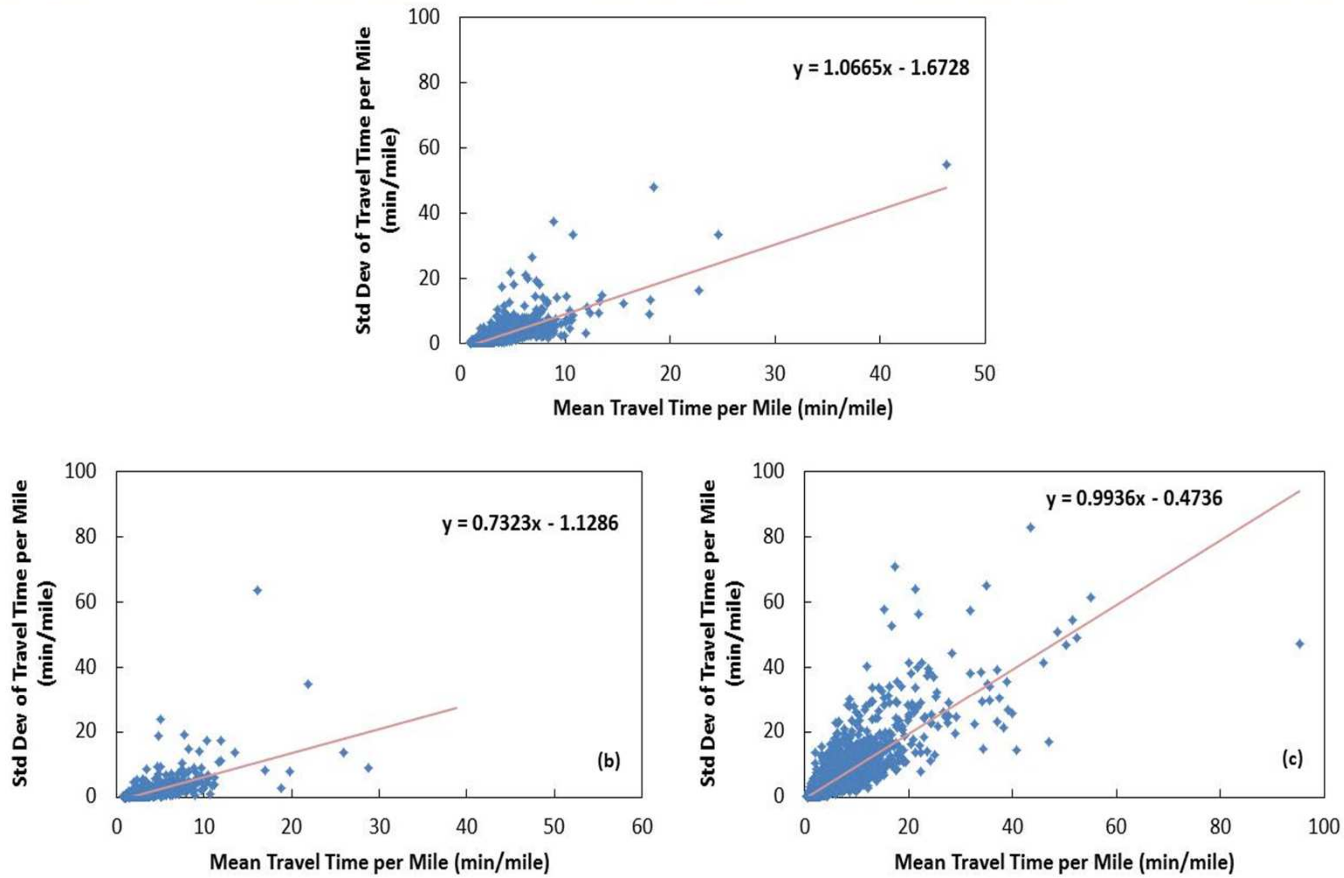
2 Implementation Frameworks for Mean-Variance Method

- 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)

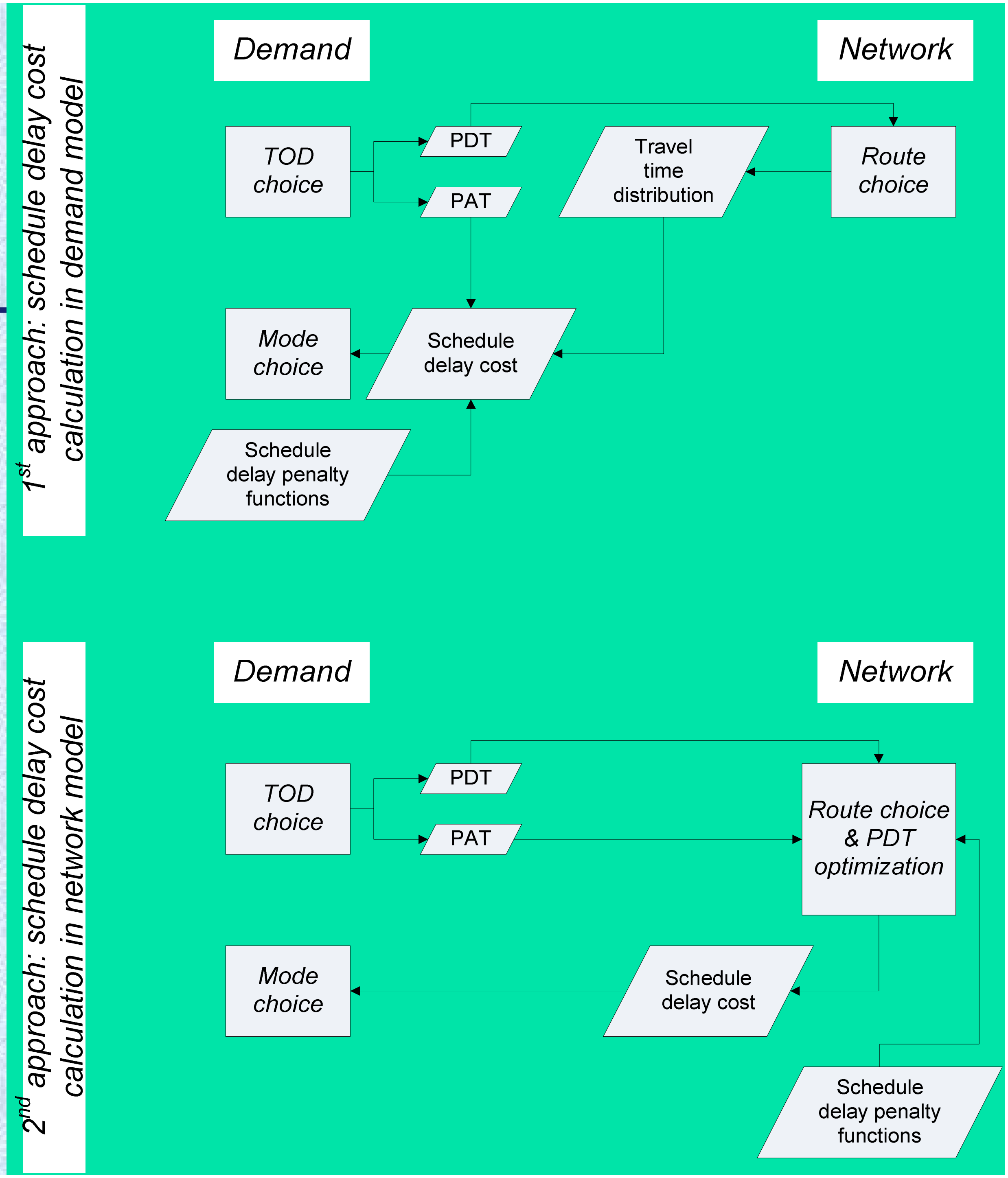
Example of Scaling Procedures to Construct Route STD

- 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) $-0.5 \le -\mu \le 0$ (perfect correlation)

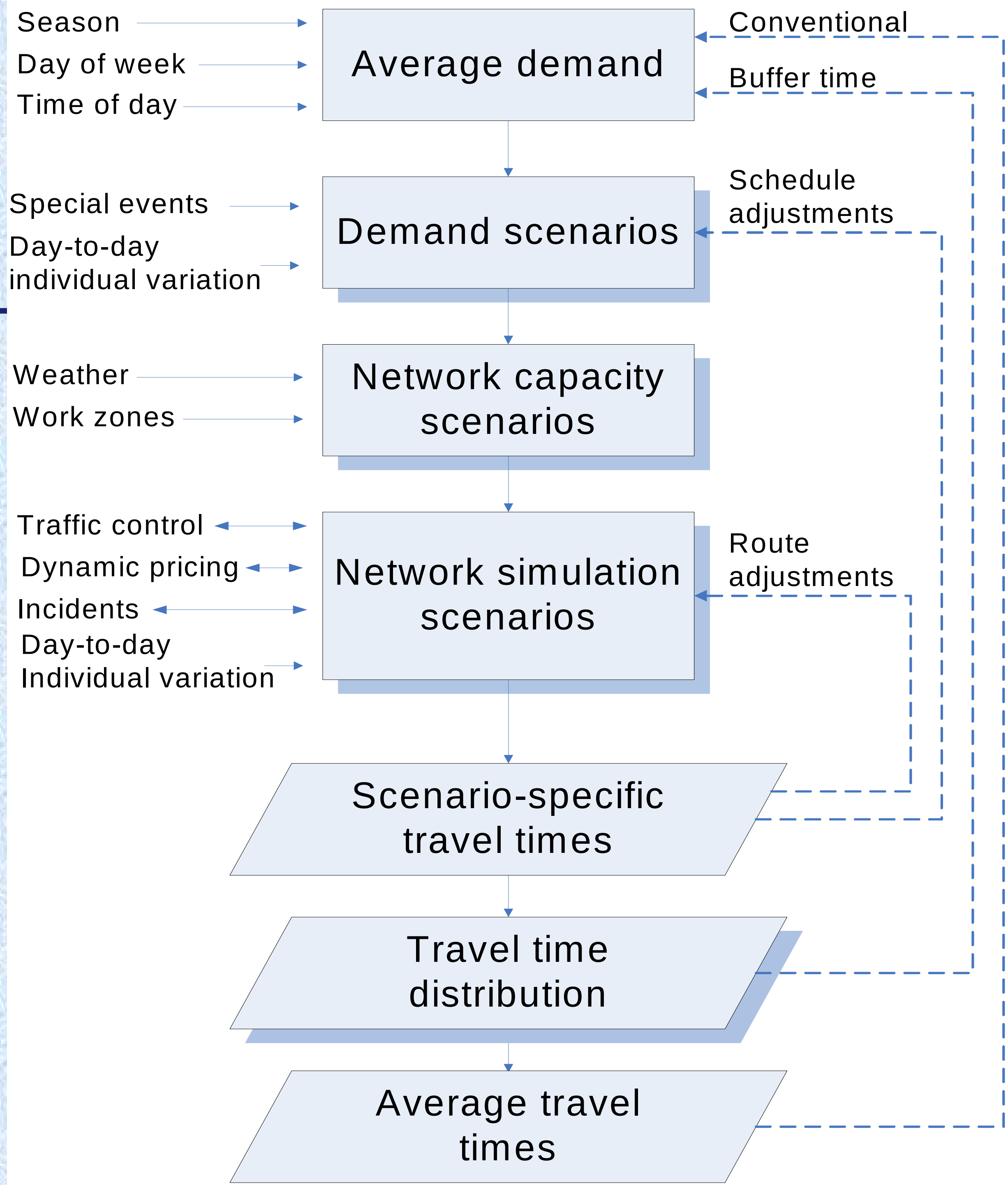
Self-Calibration of μ in Link-Based Assignment

- 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



Multiple-Run Framework



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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

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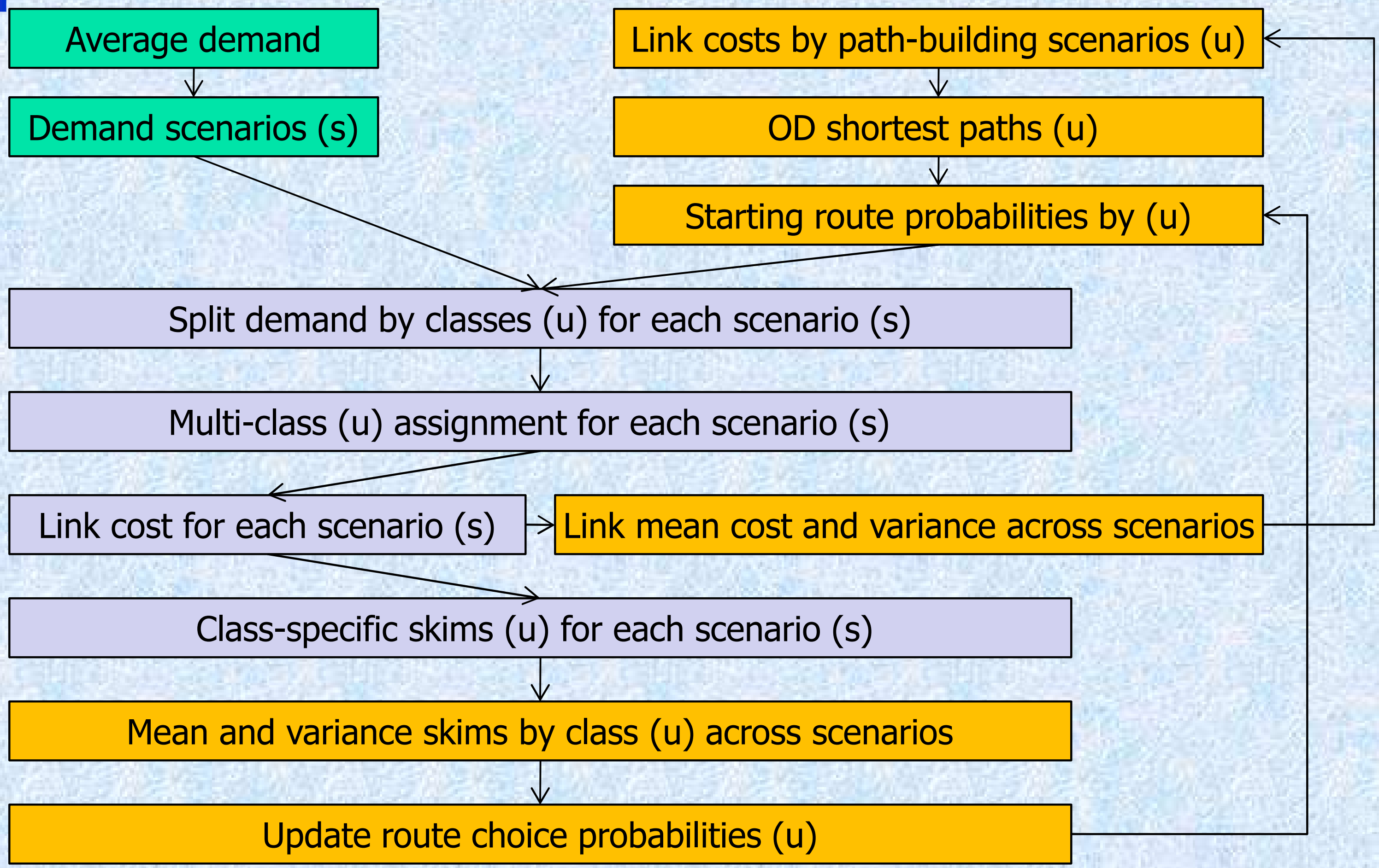
Equilibrium Assignment with Random Demand and Reliability



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)