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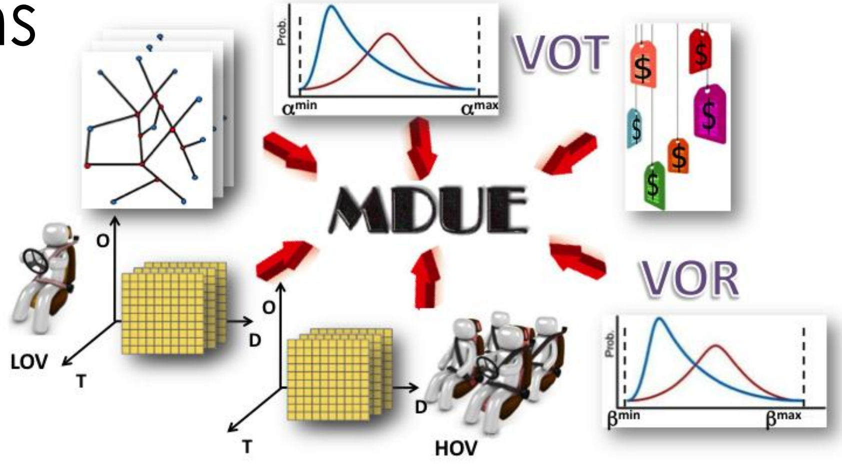
Integrating Dynamic Traffic Assignment and Activity-Based Demand Models for Large Scale Network Applications



Hani S. Mahmassani
Kuilin Zhang

Integrated Travel Models Workshop, ITM 2012

NORTHWESTERN UNIVERSITY

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In collaboration with

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SHRP2

STRATEGIC HIGHWAY RESEARCH PROGRAM

On projects funded by Strategic Research Highway Program SHRP 2
and FHWA, US DOT

NORTHWESTERN UNIVERSITY

OUTLINE

1. Motivation and Key Issues
2. Reliability, Pricing and User Heterogeneity in Dynamic Equilibrium Framework
   - Challenges
   - Formulation and Algorithms
   - Large-Scale Issues
3. Application to New York Regional Network
4. Concluding Remarks

MOTIVATION

- Why do we need integrated dynamic network models?
- Why capture behavior?
- Responses to congestion, interventions (pricing, information, management actions…) three key objectives:

  MOBILITY, RELIABILITY, SUSTAINABILITY

- Support strategic and operational planning decisions by agencies
- Next generation of interventions: information-based, personalized, dynamic, predictive, multimodal

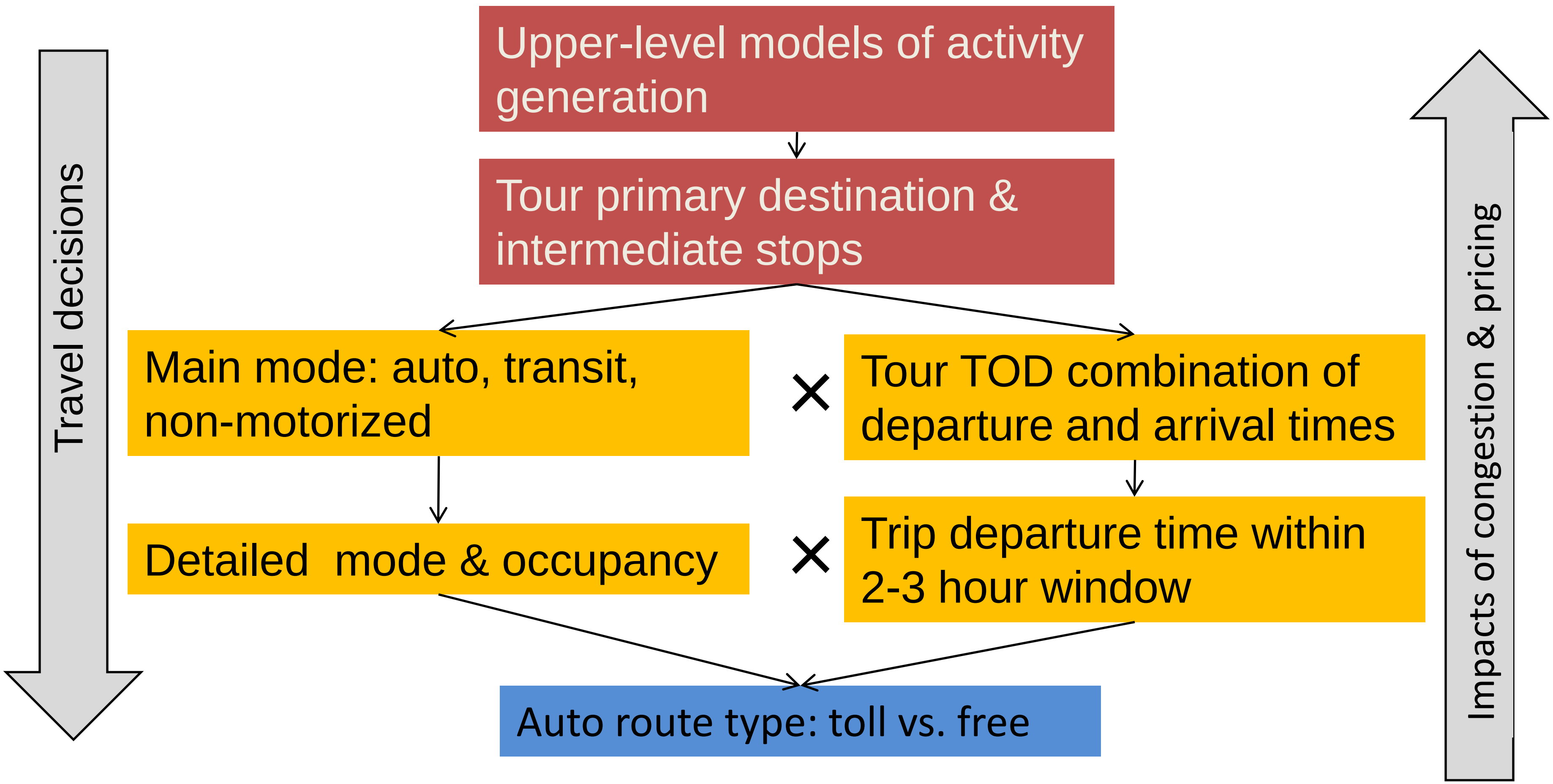
DELIVERING THE METHODS: SIX KEY CHALLENGES

- ADVANCED BEHAVIOR MODELS
- HETEROGENEOUS USERS
- INTEGRATION WITH NETWORK MODELS:

  THE PLATFORM– SIMULATION-BASED MICRO-ASSIGNMENT DTA
- GENERATE THE ATTRIBUTES: RELIABILITY IN NETWORK LEVEL OF SERVICE
- CONSISTENCY BETWEEN BEHAVIOR (DEMAND) AND PHYSICS (SUPPLY): EQUILIBRATION
- PRACTICAL LARGE NETWORK APPLICATION: INTELLIGENT IMPLEMENTATION

User Behavior and Heterogeneity

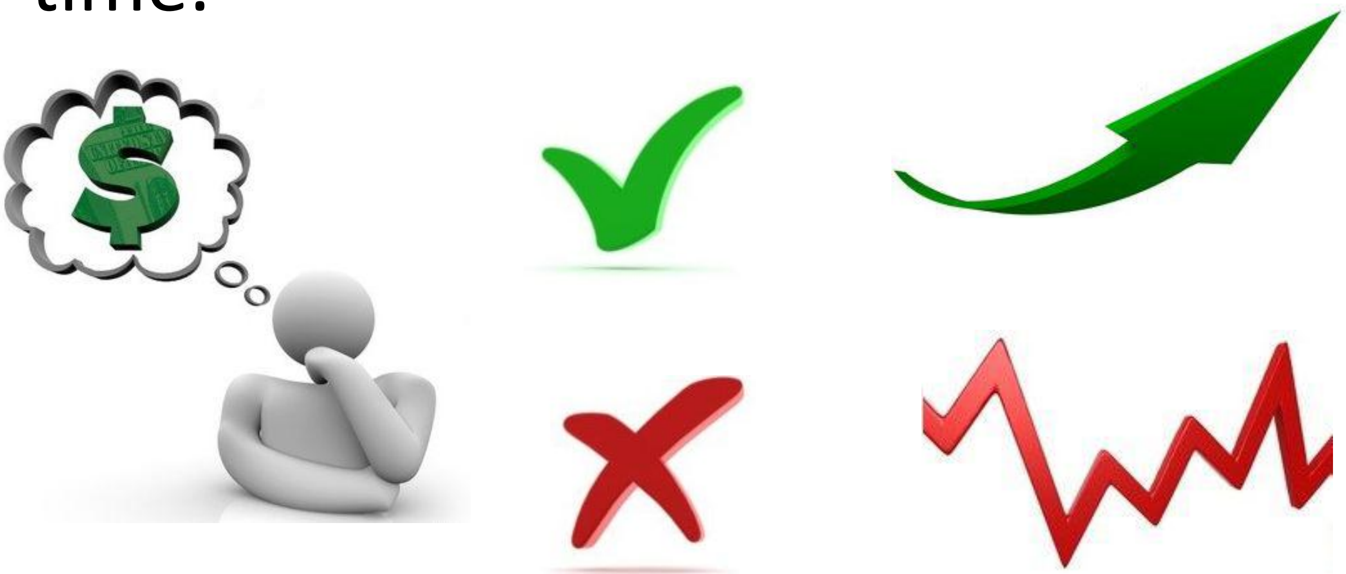
Choice Frameworks



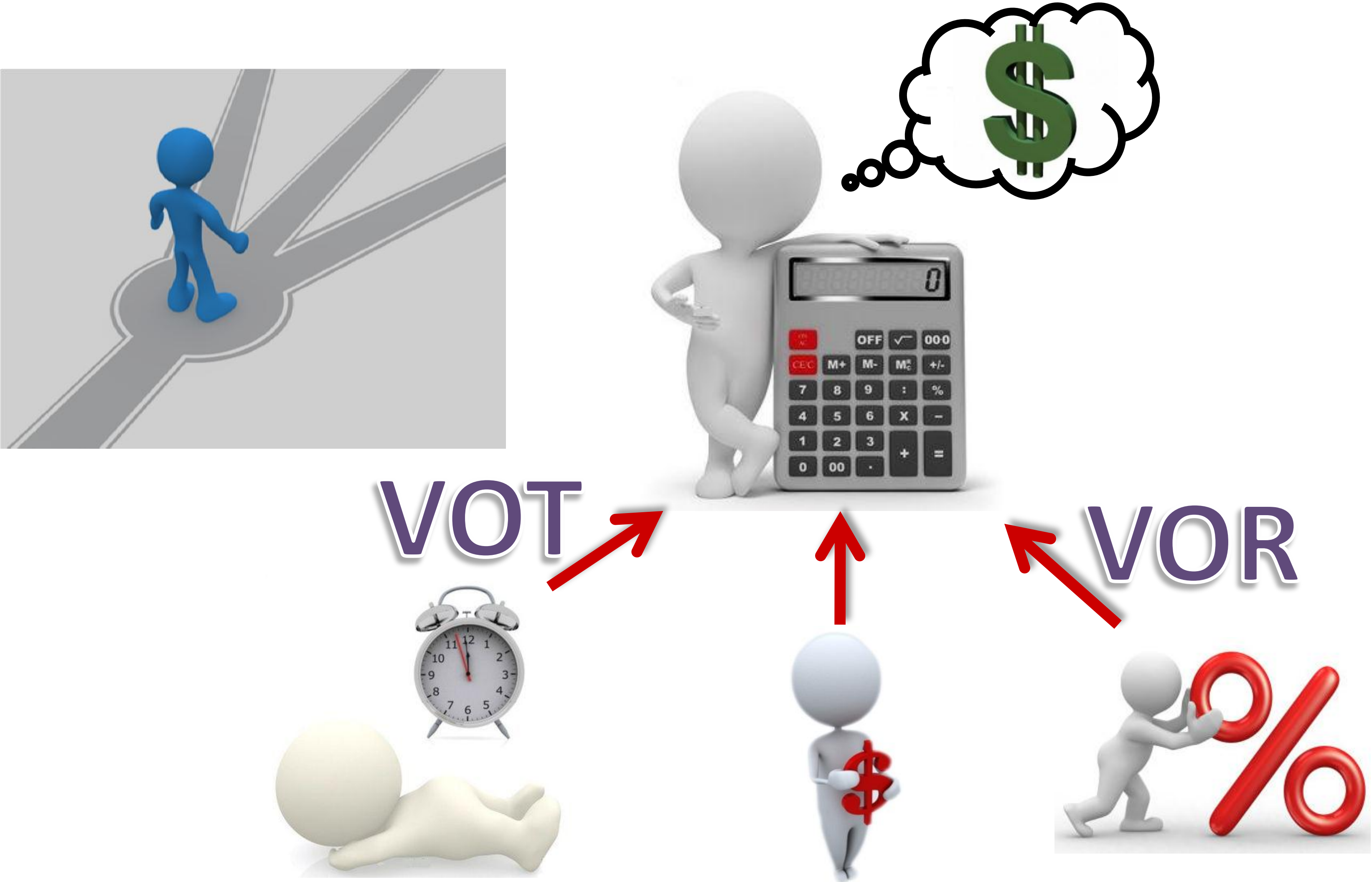
Source: Peter Vovsha (2010); SHRP2-C04

Travel Time Reliability

- Travel time reliability is manifested in that a trip maker may be willing to pay a premium (toll) to achieve greater reliability in travel time.



Individual's Path Choice Decision



User Heterogeneity

- Recognize user heterogeneity in the path choice model
  - Conventional traffic assignment models consider a homogeneous perception of tolls by assuming a constant VOT in the path choice model.
  - Empirical studies (e.g. Hensher, 2001; Brownstone and Small 2005; Cirillo et al. 2006) found that the VOT varies significantly across individuals.

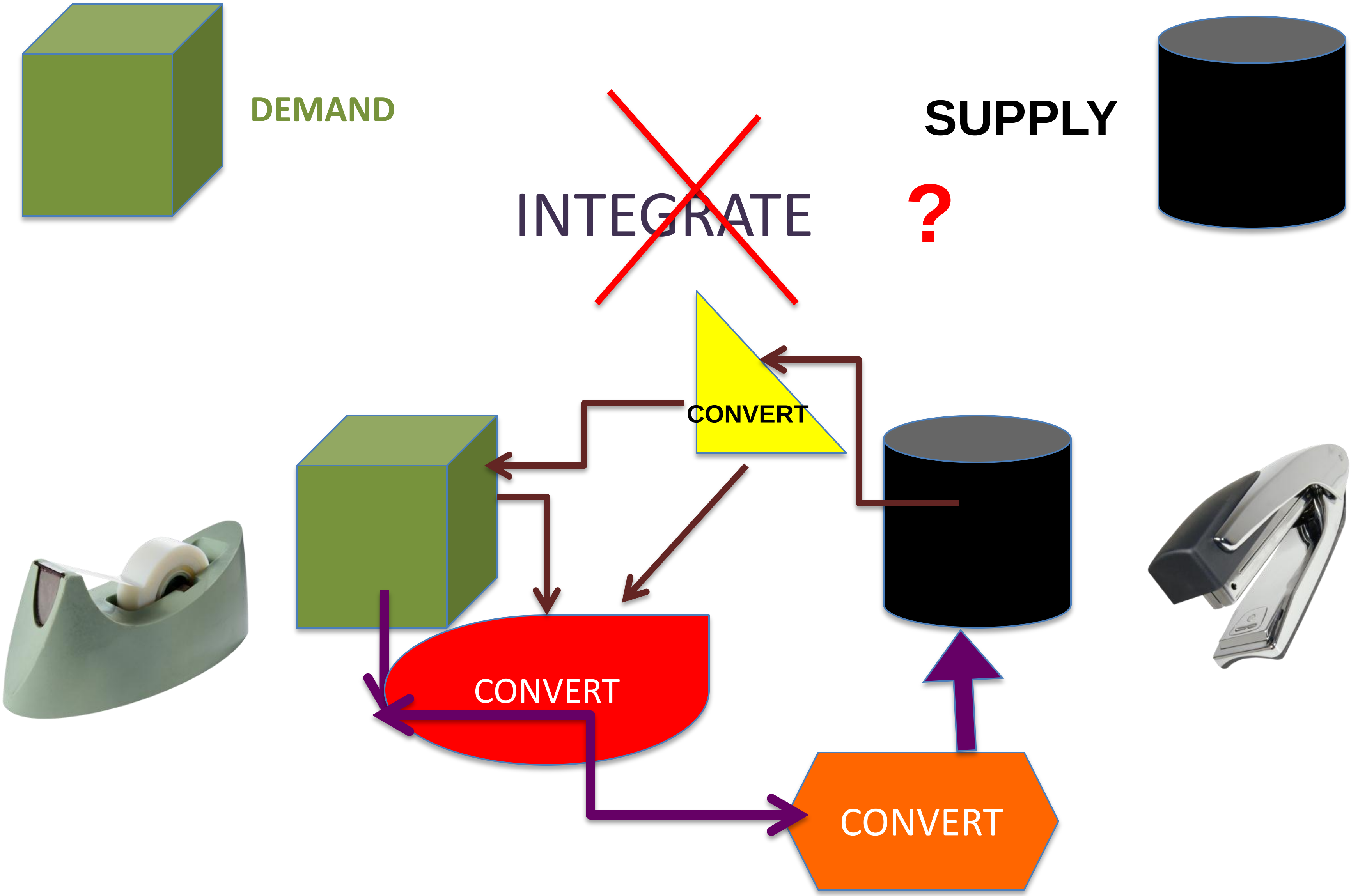
Beyond Value of Time…

User Heterogeneity

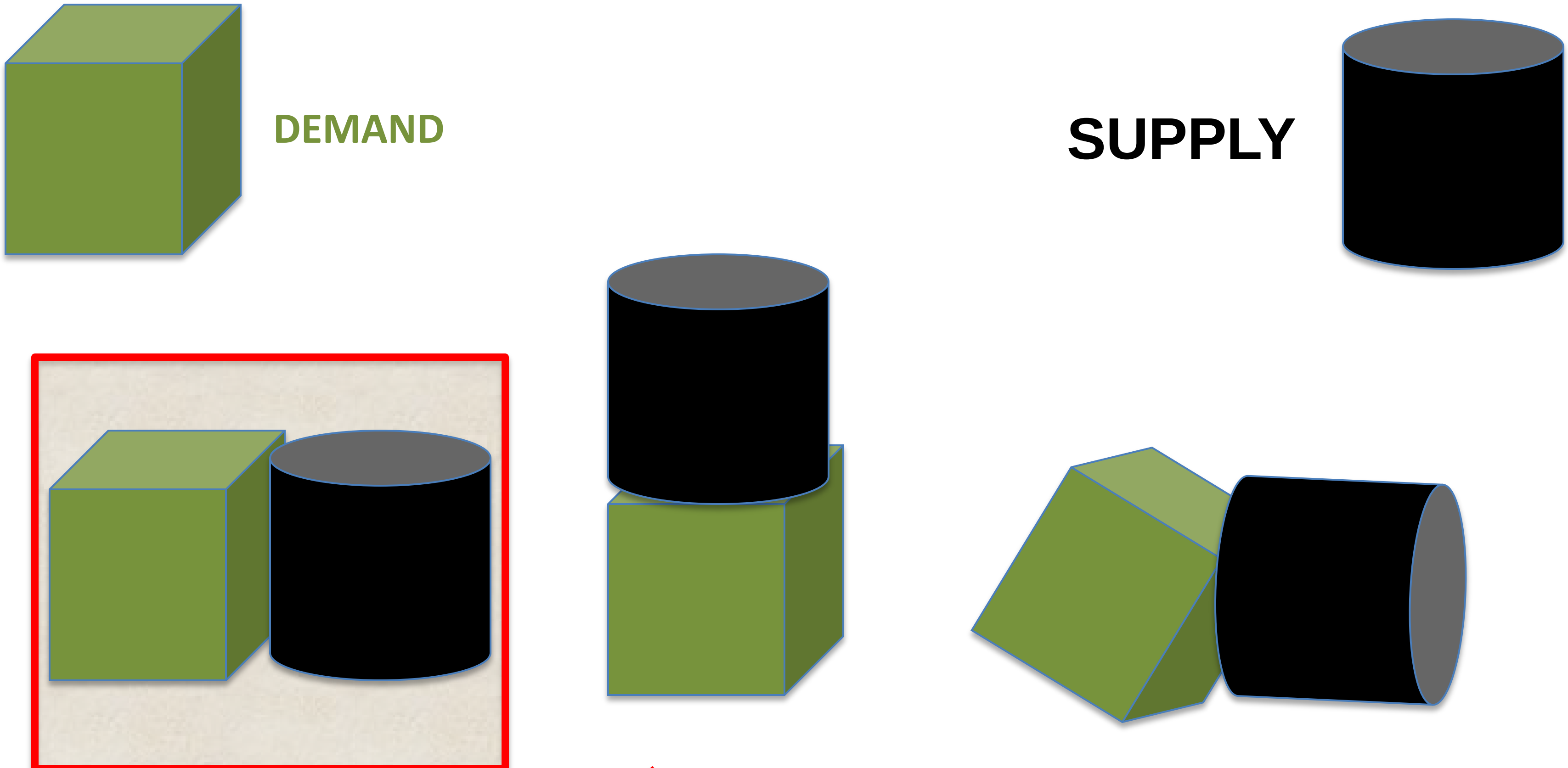
- Present in valuation of key attributes, and risk attitudes
  - Value of schedule delay (early vs. late, relative to preferred arrival time), critical in departure time choice decisions.
  - Value of reliability.
  - Risk attitudes.

  Causes significant challenge in integrating behavioral models in network simulation/assignment platforms

Integration Issues

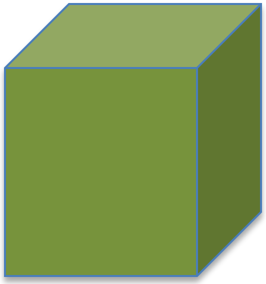


INTERFACE



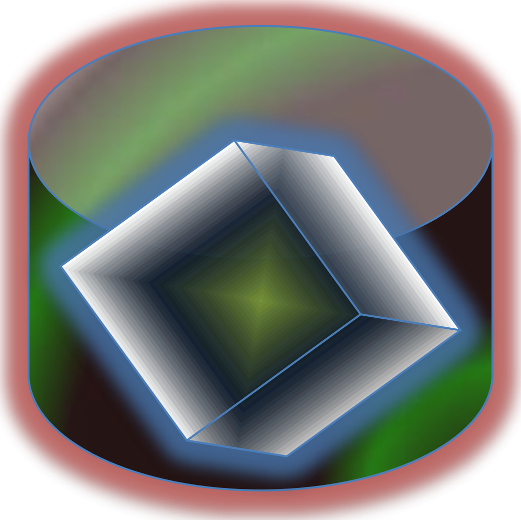
~~INTEGRATE~~ ?

JUXTAPOSE



DEMAND

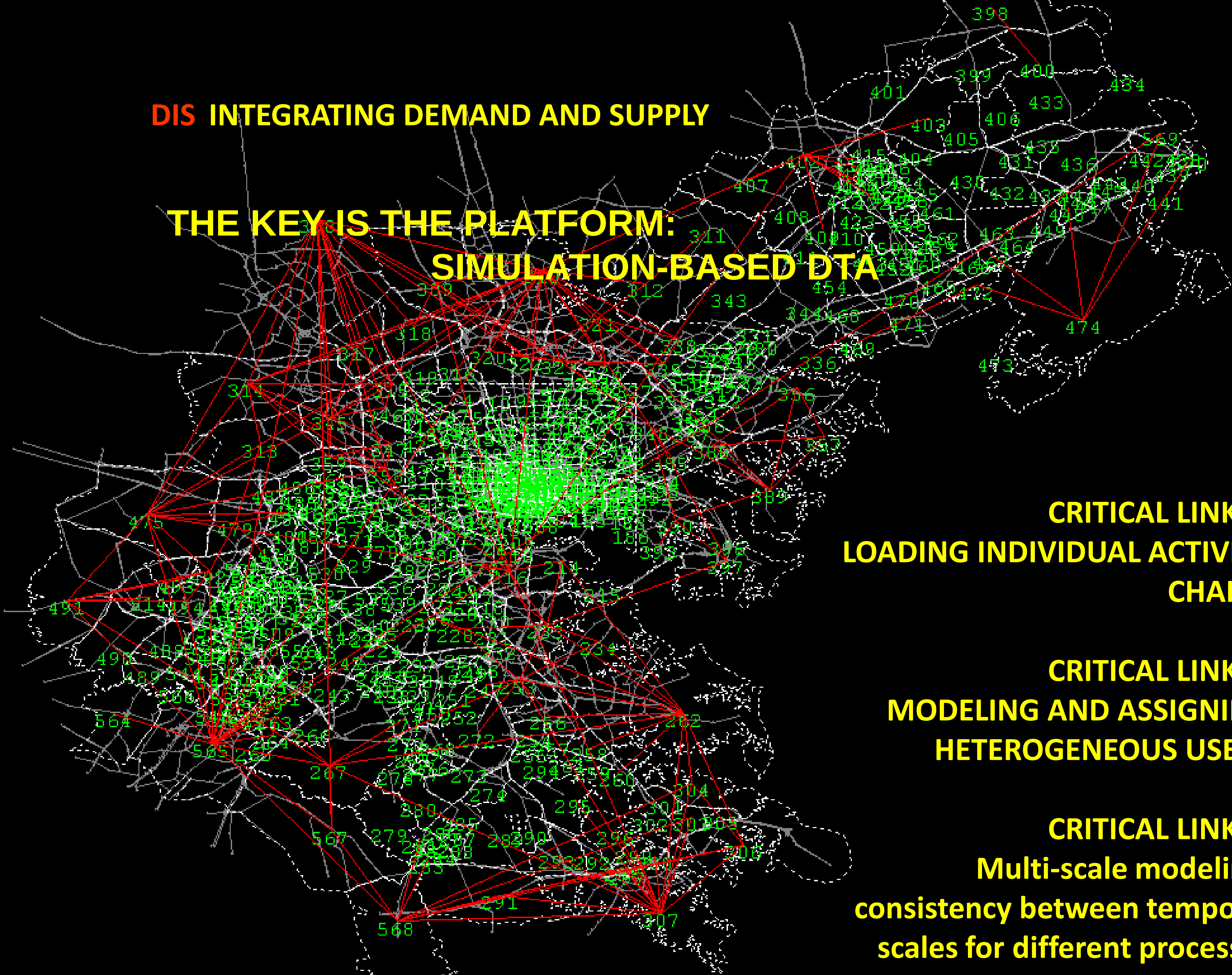
SUPPLY



INTEGRATE?

DIS INTEGRATING DEMAND AND SUPPLY

THE KEY IS THE PLATFORM:
SIMULATION-BASED DTA



CRITICAL LINK 1:
LOADING INDIVIDUAL ACTIVITY CHAINS

CRITICAL LINK 2:
MODELING AND ASSIGNING HETEROGENEOUS USERS

CRITICAL LINK 3:
Multi-scale modeling:
consistency between temporal scales for different processes

METHODOLOGICAL FRAMEWORK

- Simulation-based DTA, e.g. DYNASMART-P : A dynamic network modeling capability, to represent demand and supply dynamics, along with operational measures
- Overcomes limitations of conventional planning tools, and provides combined network assignment and traffic simulation capability for large networks, with micro-level representation of agent decisions
- Meso simulation enables application to practical large networks

Dealing with Heterogeneity in Existing Network Models

1. Ignore: route choice main dimension captured; replace travel time by travel cost in shortest path code, assuming constant VOT.

2. When multiple response classes recognized, discrete classes with specific coefficient values are used; number of classes can increase rapidly; not too common in practice.

2. Recent developments with simulation-based DTA:

Heterogeneous users with continuous coefficient values; made possible by

Breakthrough in parametric approach to bi-criterion shortest path calculation.

Include departure time and mode, in addition to route choice, in user responses, in stochastic equilibrium framework

Efficient implementation structures for large networks: Application of integrated model to New York Regional Network.

- Multi-criterion Stochastic Dynamic User Equilibrium (MSDUE) model, which **integrates**:
    - Traffic Flow Dynamics;
    - Heterogeneous Users
    - Three essential decision attributes: travel time, out-of-pocket cost, and travel time reliability in path choice framework
    - Higher-level mode choice and activity timing dimensions
- **Applicable** to transportation networks of practical size.

Model Challenges

- **Reliability Measure in path choice framework ➔** increase complexity of the path finding/calculation procedure

- **Heterogeneous Users** in terms of continuously distributed VOT and/or VOR ➔ create an infinite-dimensional problem

- **Large-Scale Network Applications ➔** impose computational burdens on the solution algorithm

Divide and Conquer I: Generate Reliability Measures

- Foundation: a robust relation between s.d. and mean values of the TT per unit distance at **path level**.
- In this study: $$TTSD_{odp}^{\tau,m} = a + b \times \frac{TT_{odp}^{\tau,m}}{TD_{odp}^{\tau,m}}$$
  - ➢ Future improvements: actual observations of vehicle trajectories
- Generally, any relation relying on path-level attributes, could be incorporated in the procedure followed.

based on Herman, Mahmassani and co-workers' research

Travel Time Reliability

- **Model: standard deviation vs. mean**

$$\sigma(t) = a + b \times E(t)$$

where

t =	travel time per unit distance
$\sigma(t)$	= standard deviation of t
$E(t)$	= mean value of t
a, b	= coefficients

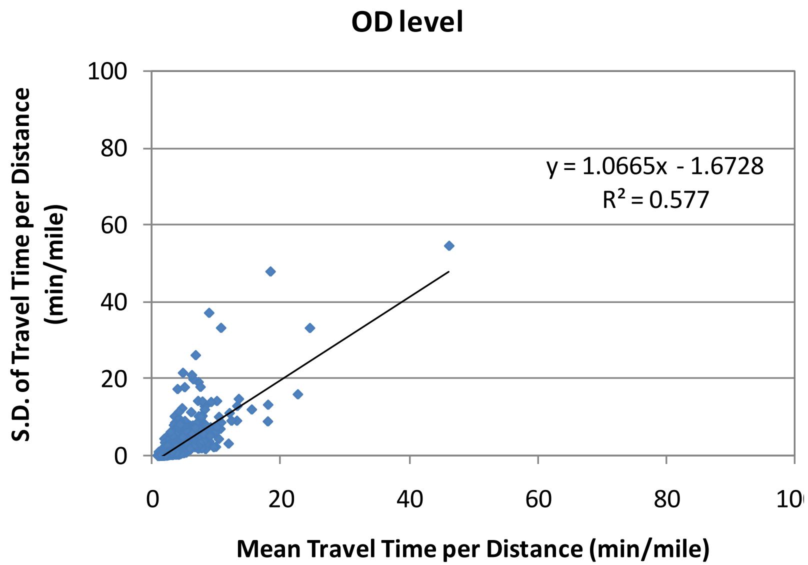
- **Model calibration**
  - GPS probe data
  - Vehicle trajectory data output from simulation

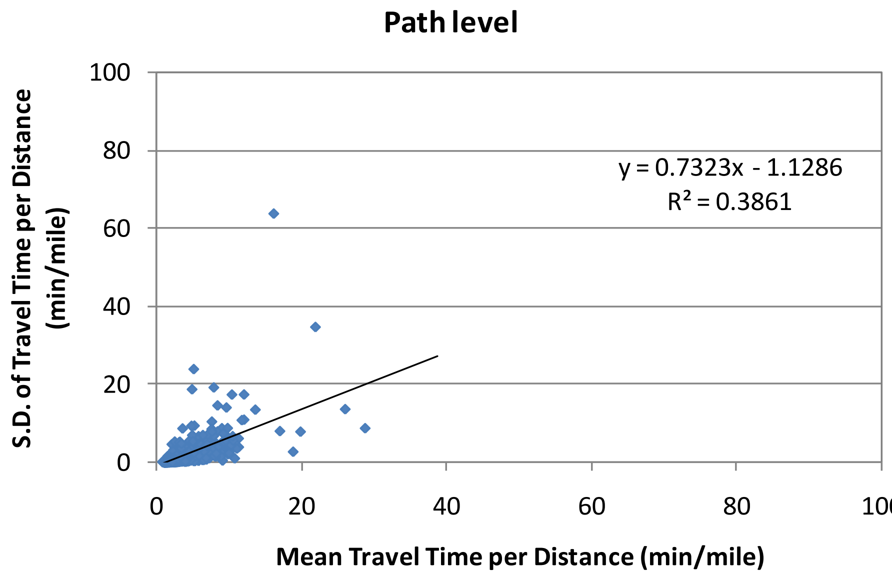
based on Herman, Mahmassani and co-workers' research in '80's
Hou, Mahmassani and Dong (2012)

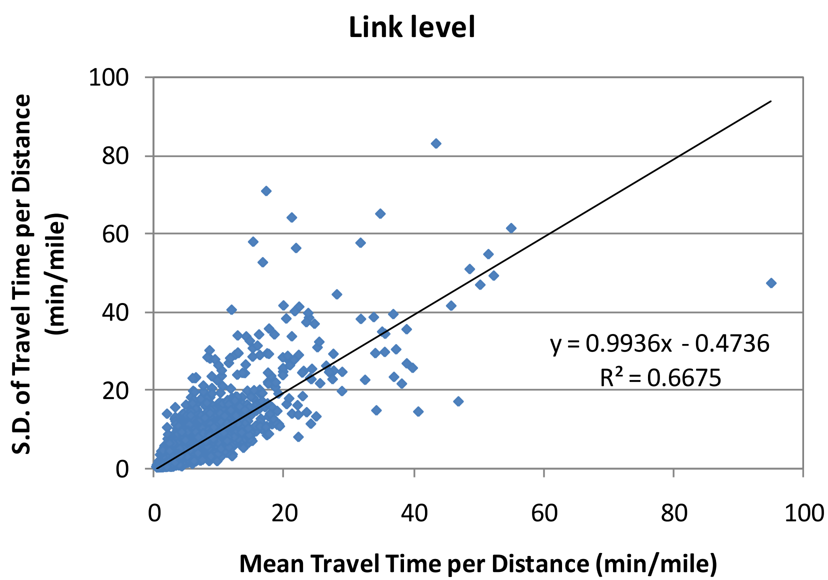
GPS probe data analysis

- GPS data from Traffic Choice Study at Puget Sound area (Seattle)
- Data from July 2005 to March 2007 (~18 months)
- 275 households, 415 vehicles involved
- Network size:
  - ~3000 OD pairs
  - ~1700 paths
  - ~6000 links

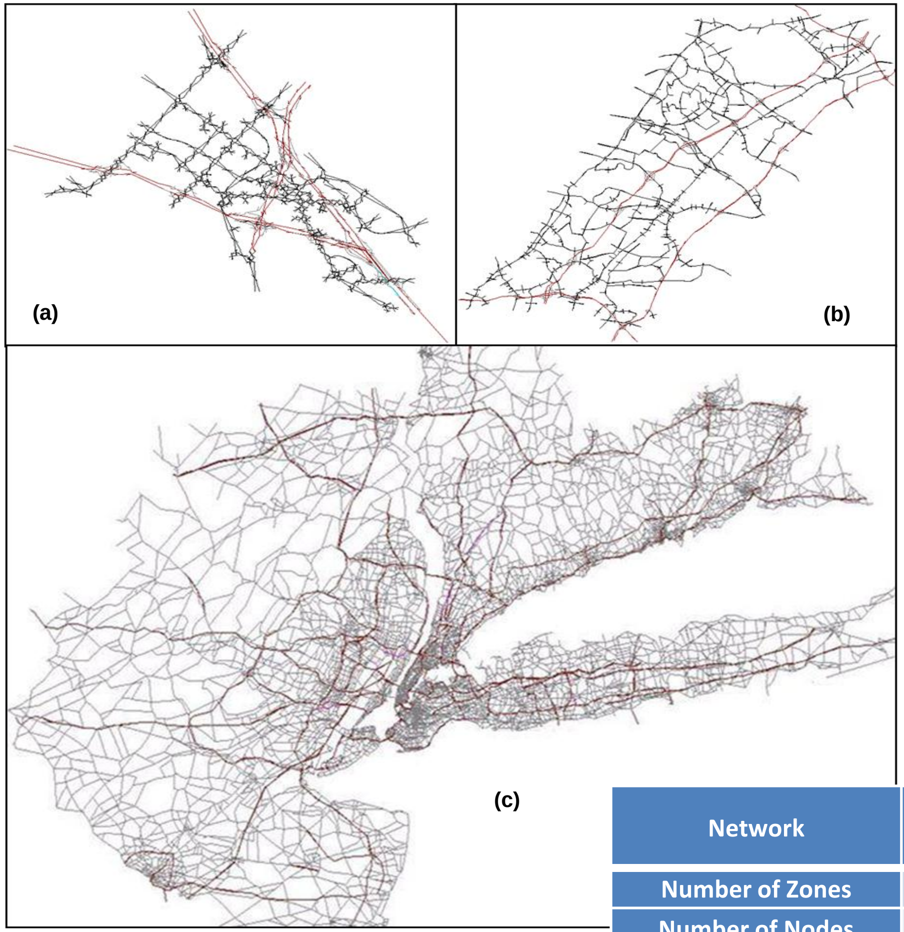
GPS probe data analysis







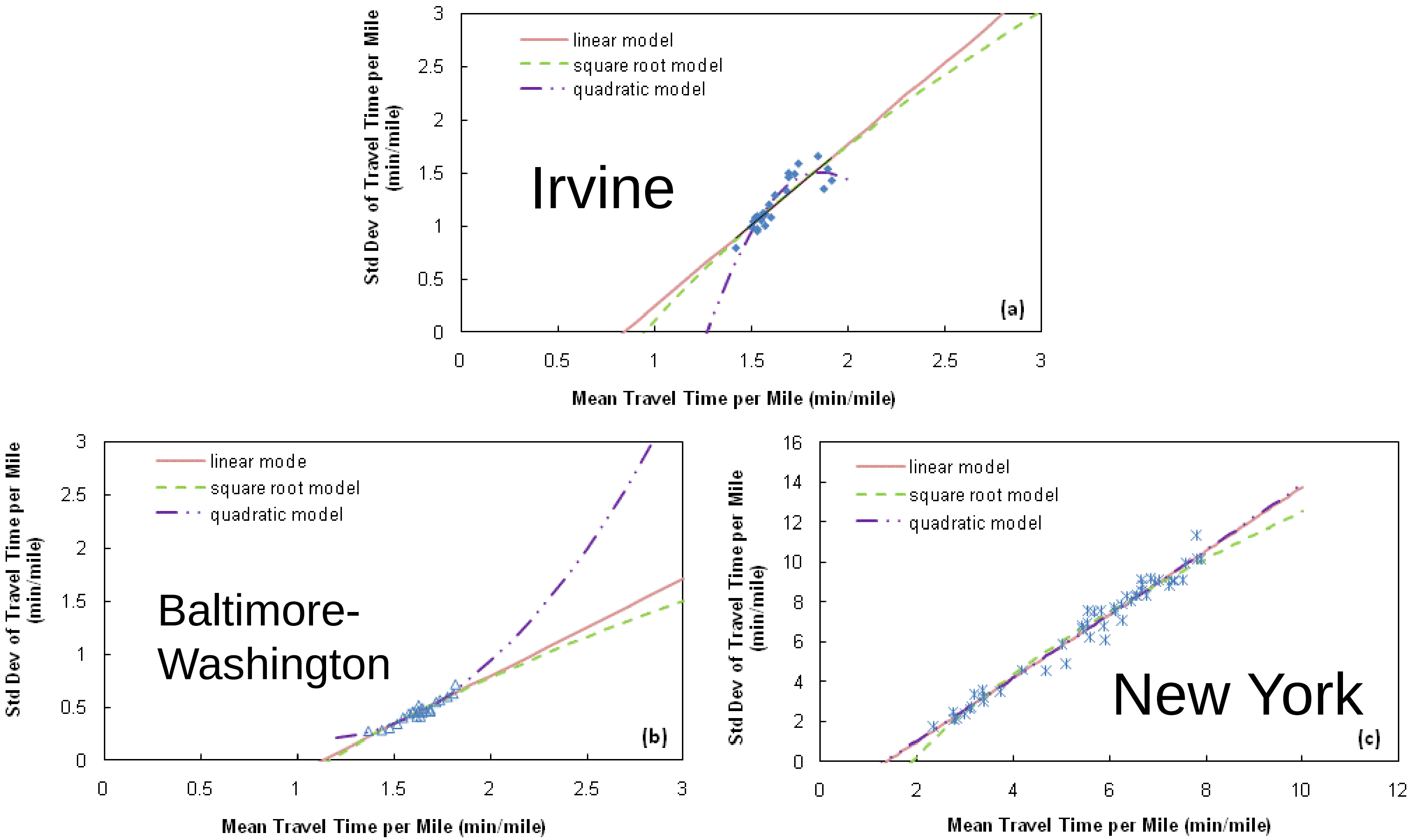
Robust Relation



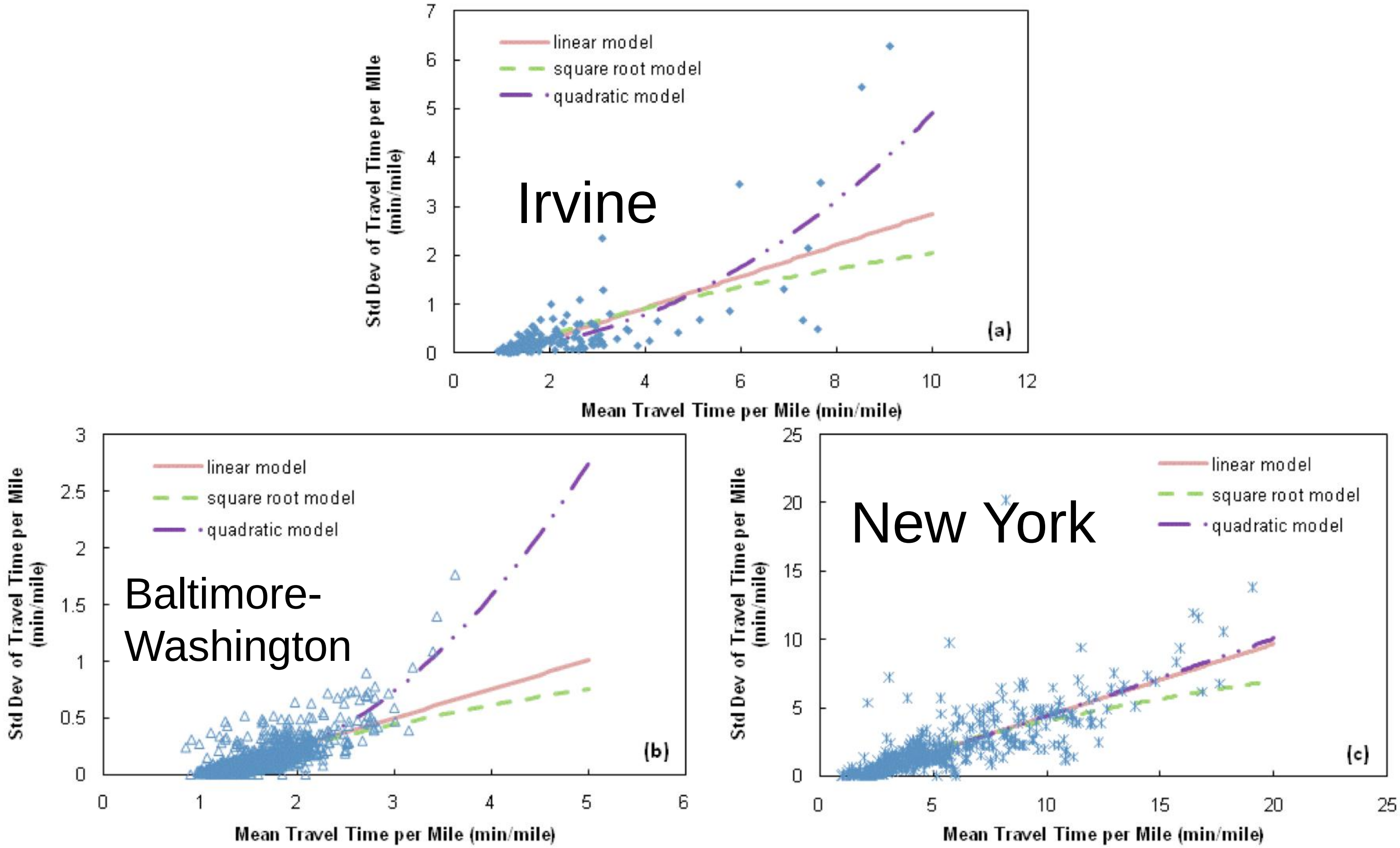
- Models are calibrated for different sizes of networks at different aggregation levels
- Three model forms are tested
  - Linear model
  - Square root model
  - Quadratic model
- Linear model gives best results
- Model parameters are estimated by Weighted Least Square (WLS) to accommodate heteroscedasticity

Network	Irvine	CHART	New York City
Number of Zones	61	111	3697
Number of Nodes	326	2182	28406
Number of Links	626	3387	68490
Number of Vehicles	58385	151973	6766805
Demand Duration (hr)	2	2	4

Network-Level SD vs. Mean of Trip Time per Mile



Path-Level SD vs. Mean of Trip Time per Mile



Model Challenges

- **Reliability Measure in path choice framework** ➔ increase complexity of the path finding/calculation procedure

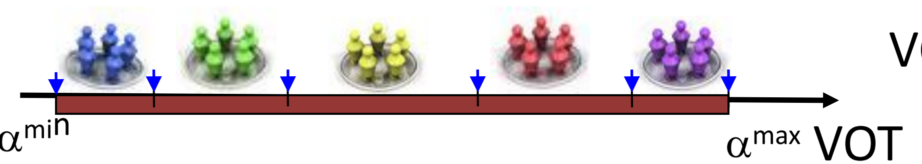
- **Heterogeneous Users** in terms of continuously distributed VOT and/or VOR ➔ create an infinite-dimensional problem

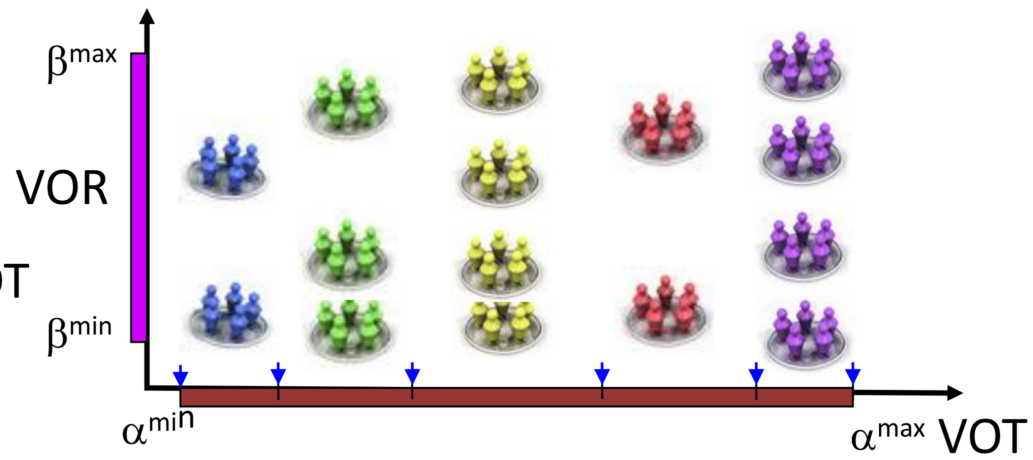
- **Large-Scale Network Applications** ➔ impose computational burdens on the solution algorithm

Divide and Conquer II:
Solve for Random Coefficients (VOR and VOT)

Parametric Analysis Method (PAM)[1]

- Solves multi-objective shortest path problems with random variables.
- Outputs: Segments of random variables **on the run** instead of given a priori and time-dependent shortest path trees.





[1] *Mahmassani et al. (2006); Lu, & Mahmassani, (2008).*

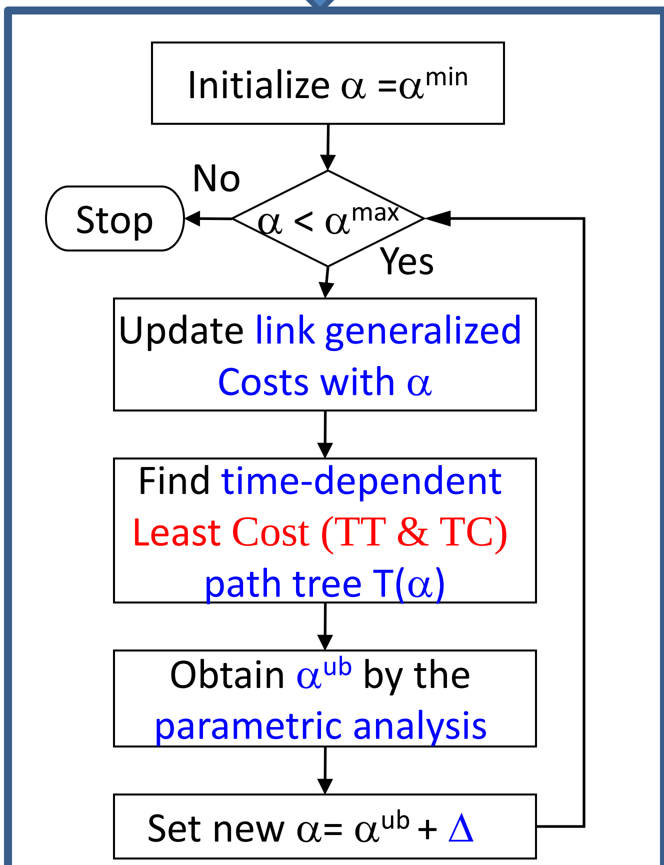
Parametric Analysis Method (PAM)

Input: from traffic simulator

-Time-dependent travel time (TT)

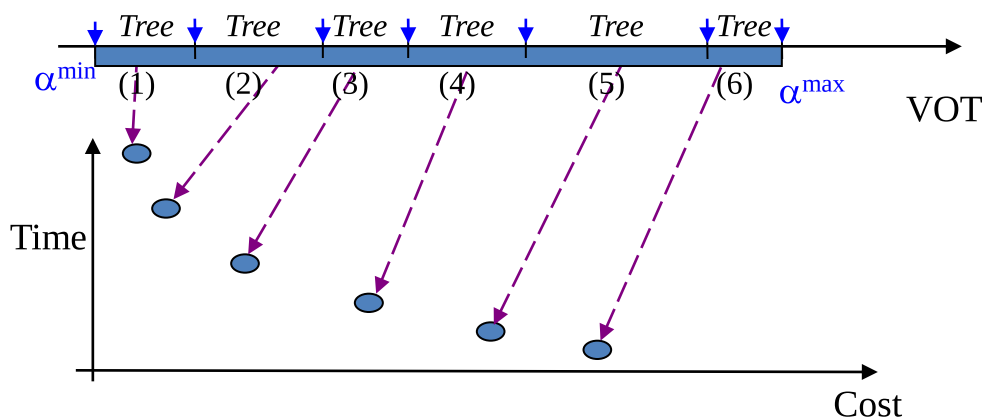
-Time-dependent travel cost (TC)

$$c'^{\tau}_{odp}(\alpha) = TC^{\tau}_{odp} + \alpha \times TT^{\tau}_{odp}$$



Output: for each dest. j

- A path tree
- VOT Breakpoints



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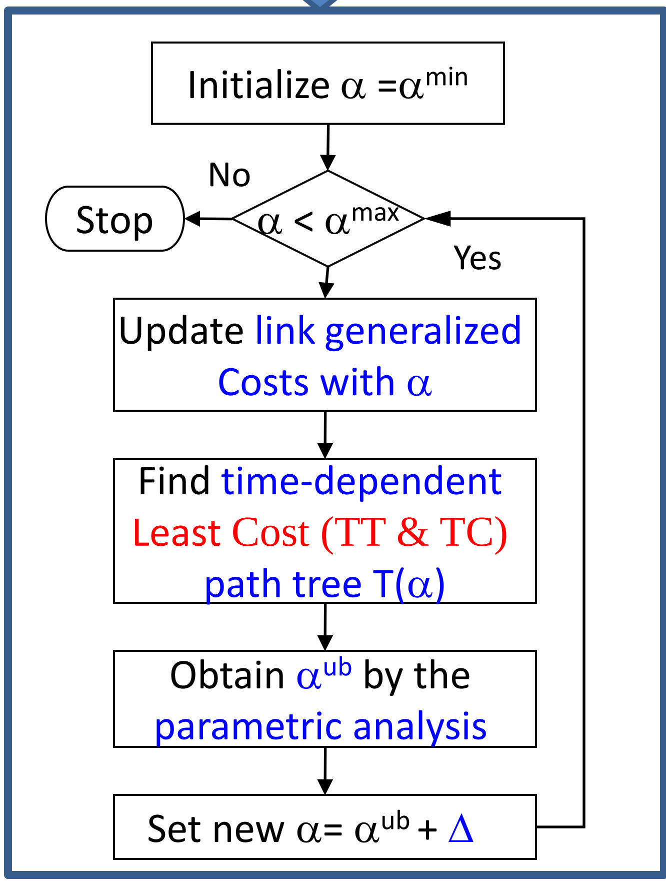
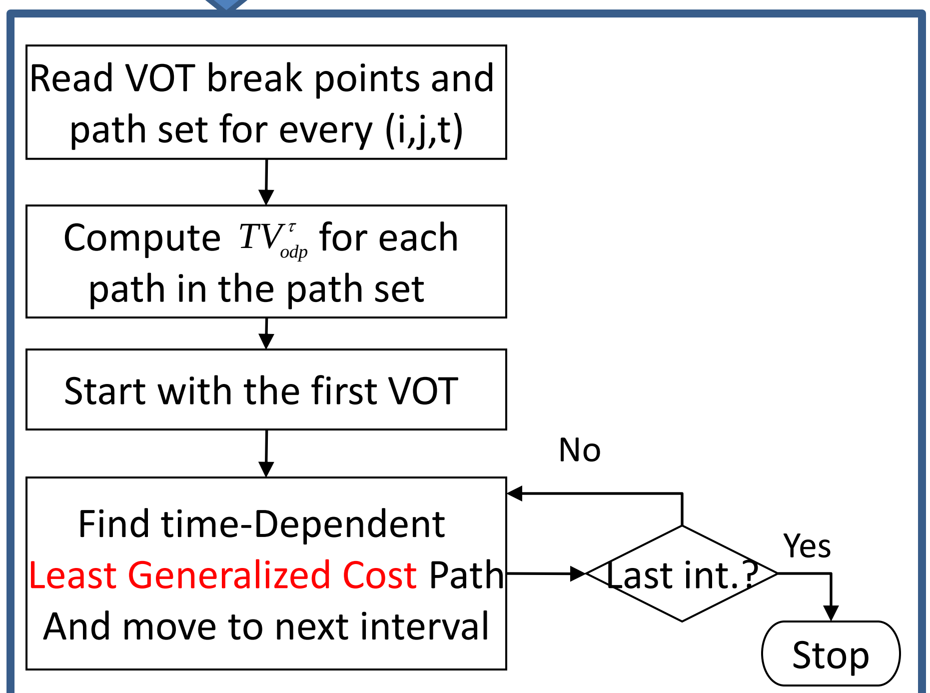


$$c_{odp}^{\tau}(\alpha,\beta) = TC_{odp}^{\tau} + \alpha \times TT_{odp}^{\tau} + \beta \times TV_{odp}^{\tau}$$

Output: for each dest. j

- A path tree
- VOT Breakpoints



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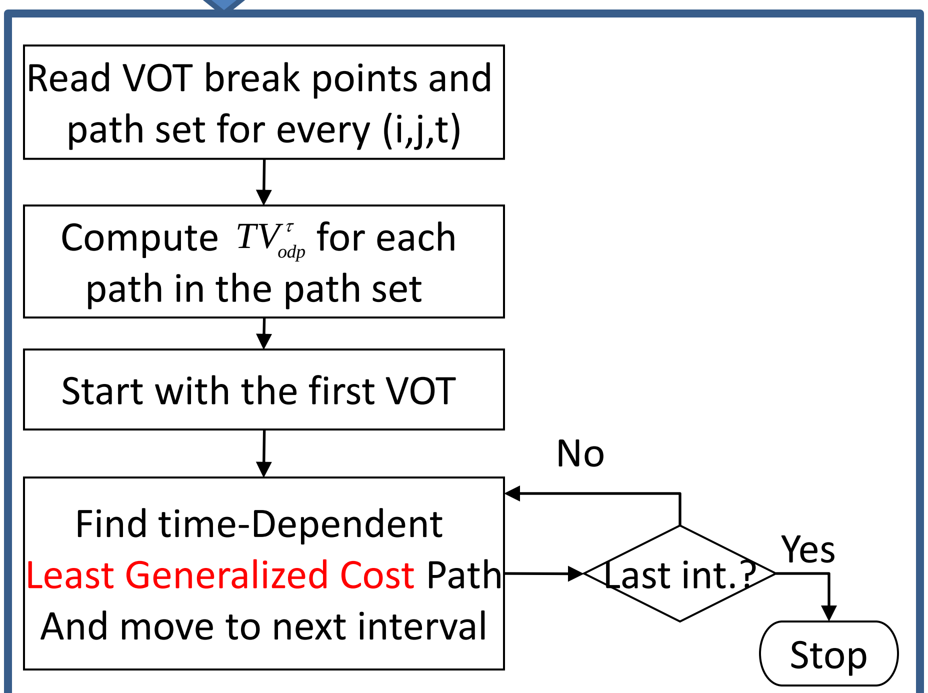

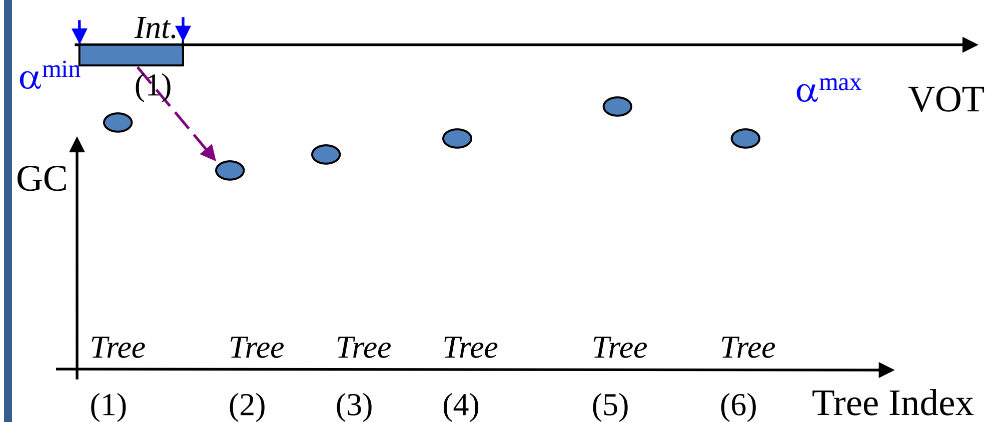

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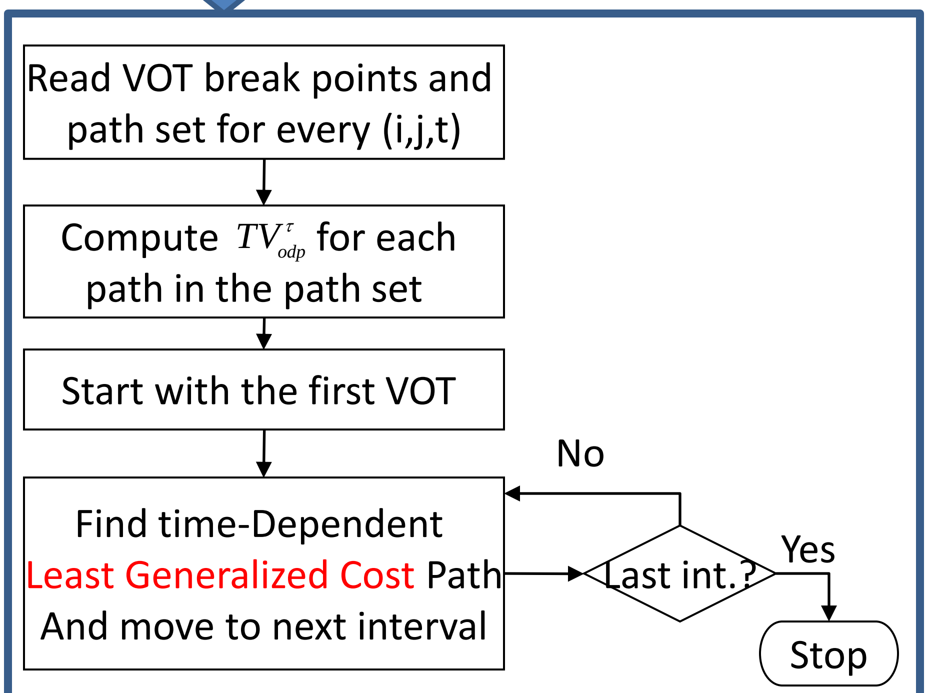

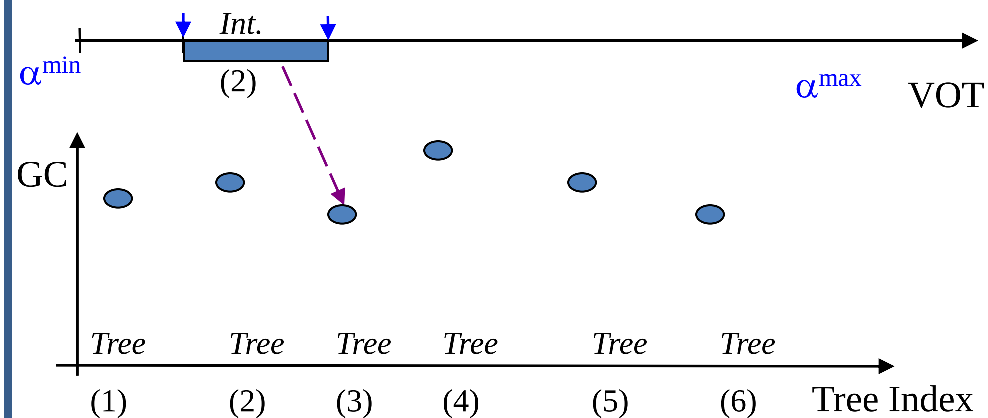

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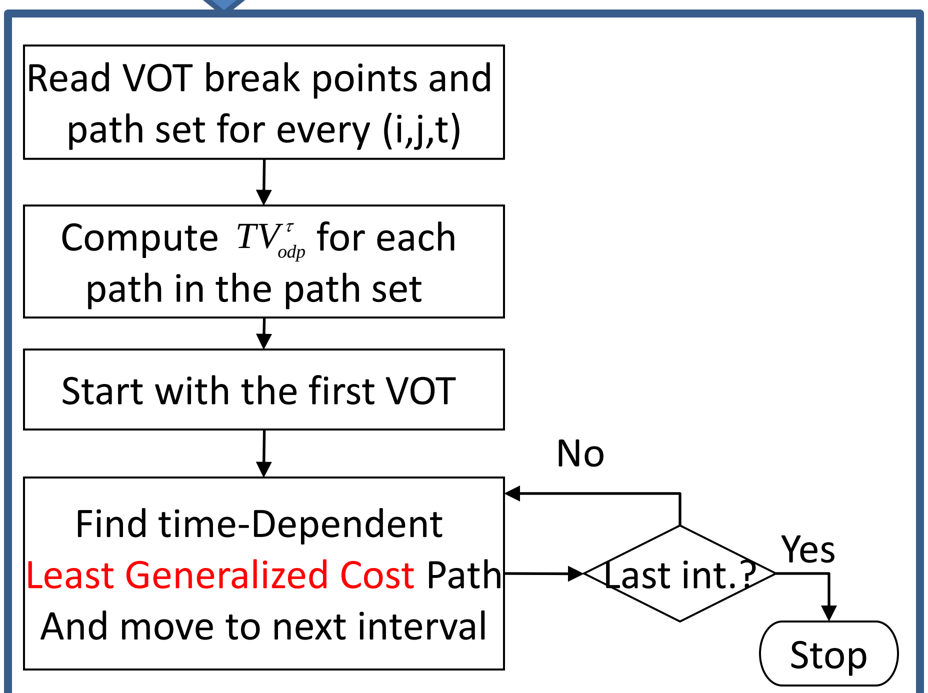
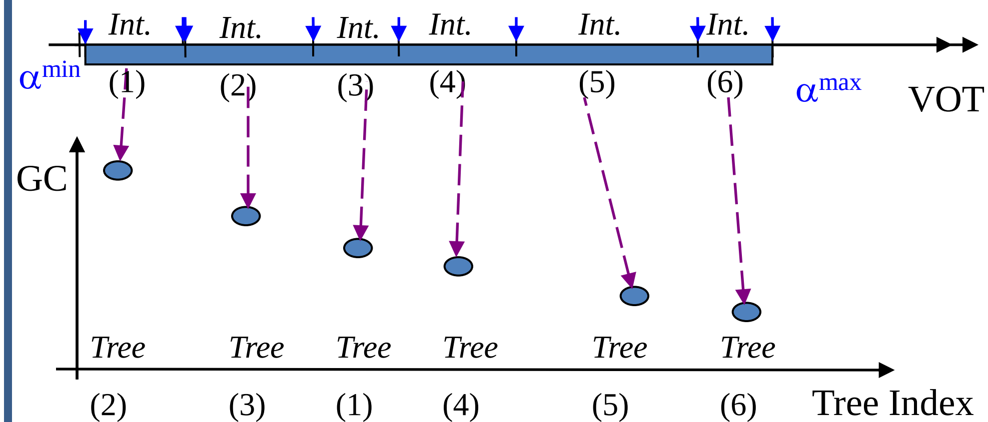
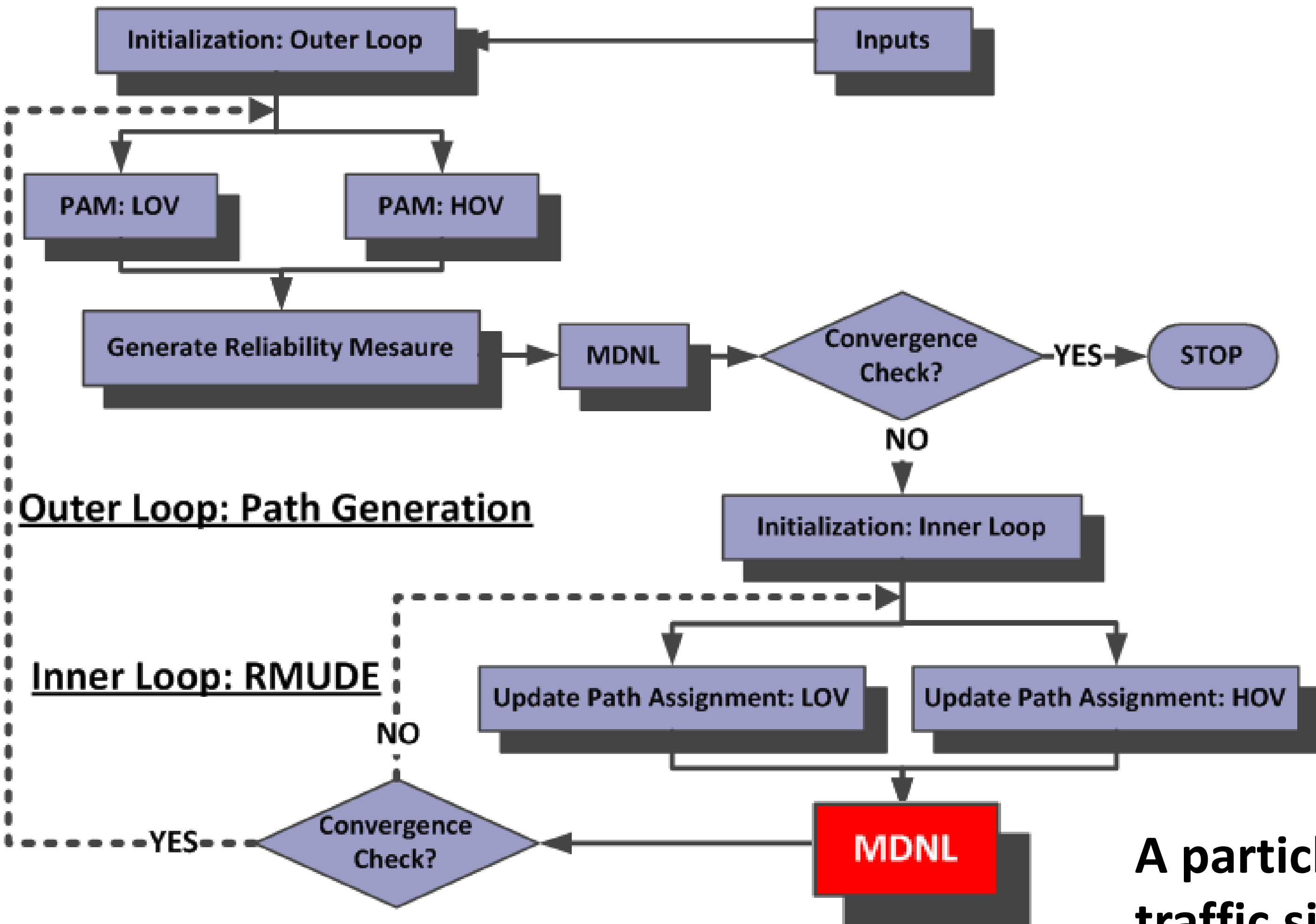




Column Generation-based Algorithm



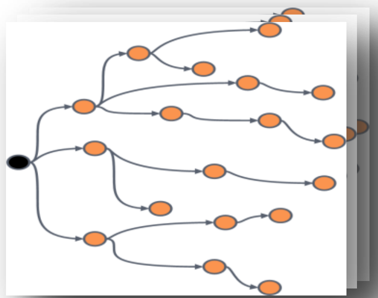
A particle-based traffic simulator

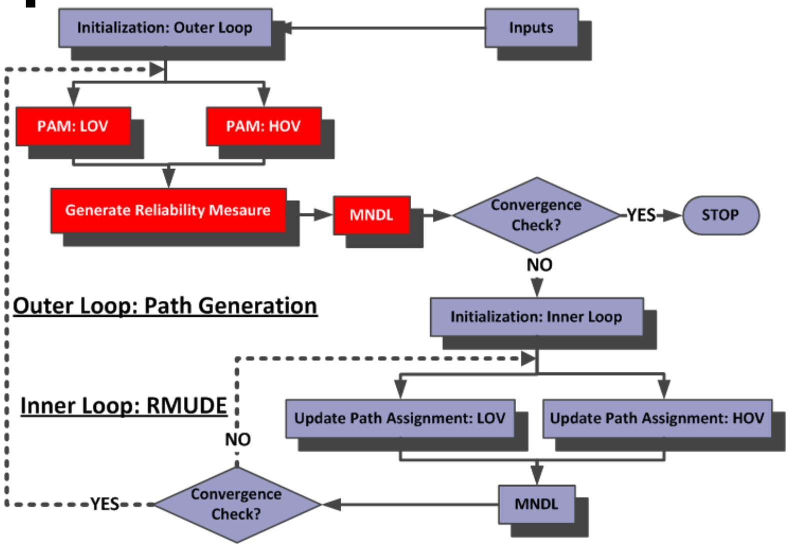
Jiang, Mahmassani and Zhang (2011): Multi-Criterion DUE model

Algorithm: Outer Loop

PAM: LOV

PAM: HOV



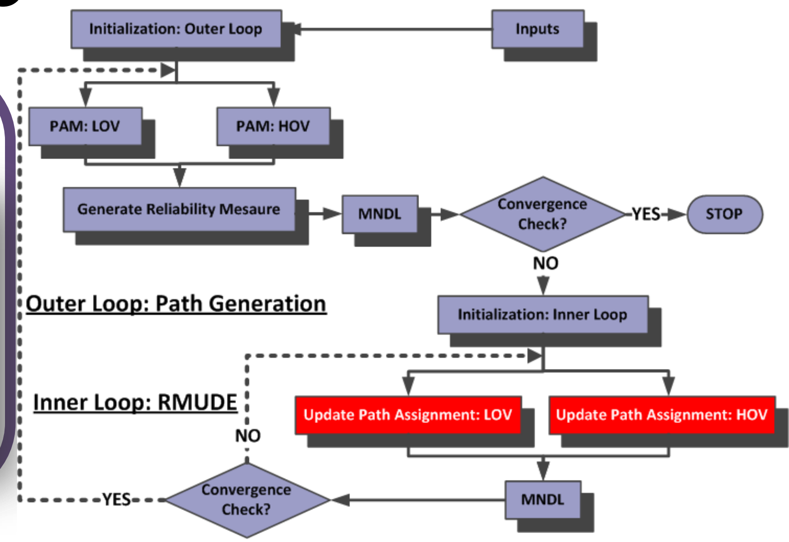


Generate Reliability Mesaure

$$TTSD_{odp}^{\tau,m} = a + b \times \frac{TT_{odp}^{\tau,m}}{TD_{odp}^{\tau,m}}$$

$$GC_{odp}^{\tau,m}(\alpha,\beta) = TC_{odp}^{\tau,m} + \alpha \times TT_{odp}^{\tau,m} + \beta \times TTSD_{odp}^{\tau,m}$$

Algorithm: Inner Loop



Outputs from Outer Loop:



Update Path Assignment: LOV

Update Path Assignment: HOV

MDNL

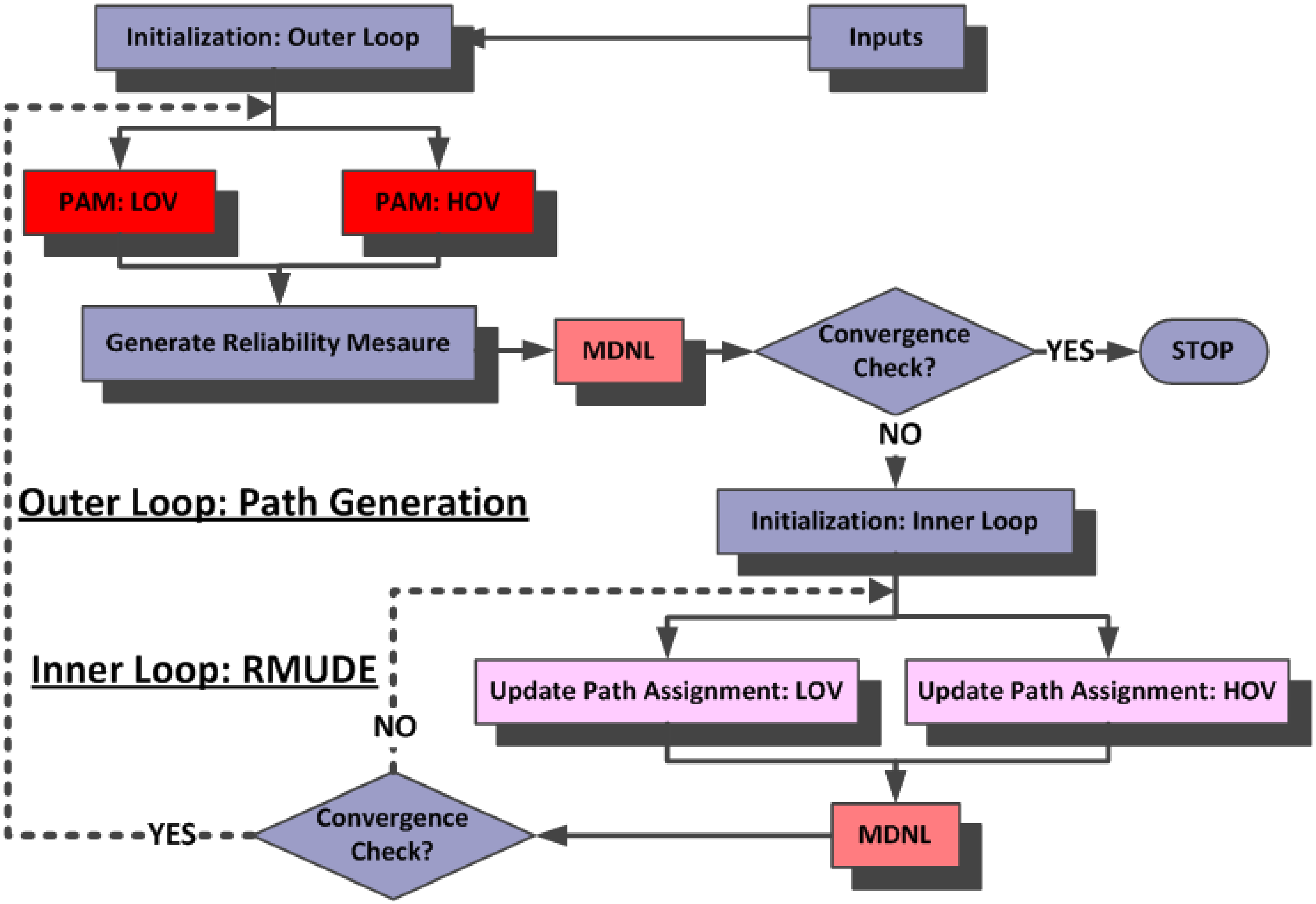
$$TTSD_{odp}^{\tau,m} = a + b \times \frac{TT_{odp}^{\tau,m}}{TD_{odp}^{\tau,m}}$$

$$GC_{odp}^{\tau,m}(\alpha,\beta) = TC_{odp}^{\tau,m} + \alpha \times TT_{odp}^{\tau,m} + \beta \times TTSD_{odp}^{\tau,m}$$

Model Challenges

- **Reliability Measure in path choice framework ➔** increase complexity of the path finding/calculation procedure
- **Heterogeneous Users** in terms of continuously distributed VOT and/or VOR ➔ create an infinite-dimensional problem
- **Large-Scale Network Applications ➔** impose computational burdens on the solution algorithm

Bottlenecks of the Algorithm



Divide and Conquer III: Implementation Techniques for Large Network Applications

- **Gap-based Technique**: only activate PAM for a subset of destination nodes where the gaps are worse.
- **Adjust Step Size in PAM**: reduce the upper bound of number of segments found by PAM for each destination node.

OUTLINE

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   - Challenges
   - Formulation and Algorithms
   - Large-Scale Issues
3. **Application to NY Regional Network**

4. Concluding Remarks

Application of Integrated Procedures to New York Regional Network

Apply demand and user response models developed
In SHRP-2 Project C04 (w. P. Vovsha, PB Inc.) for NY Metro network:

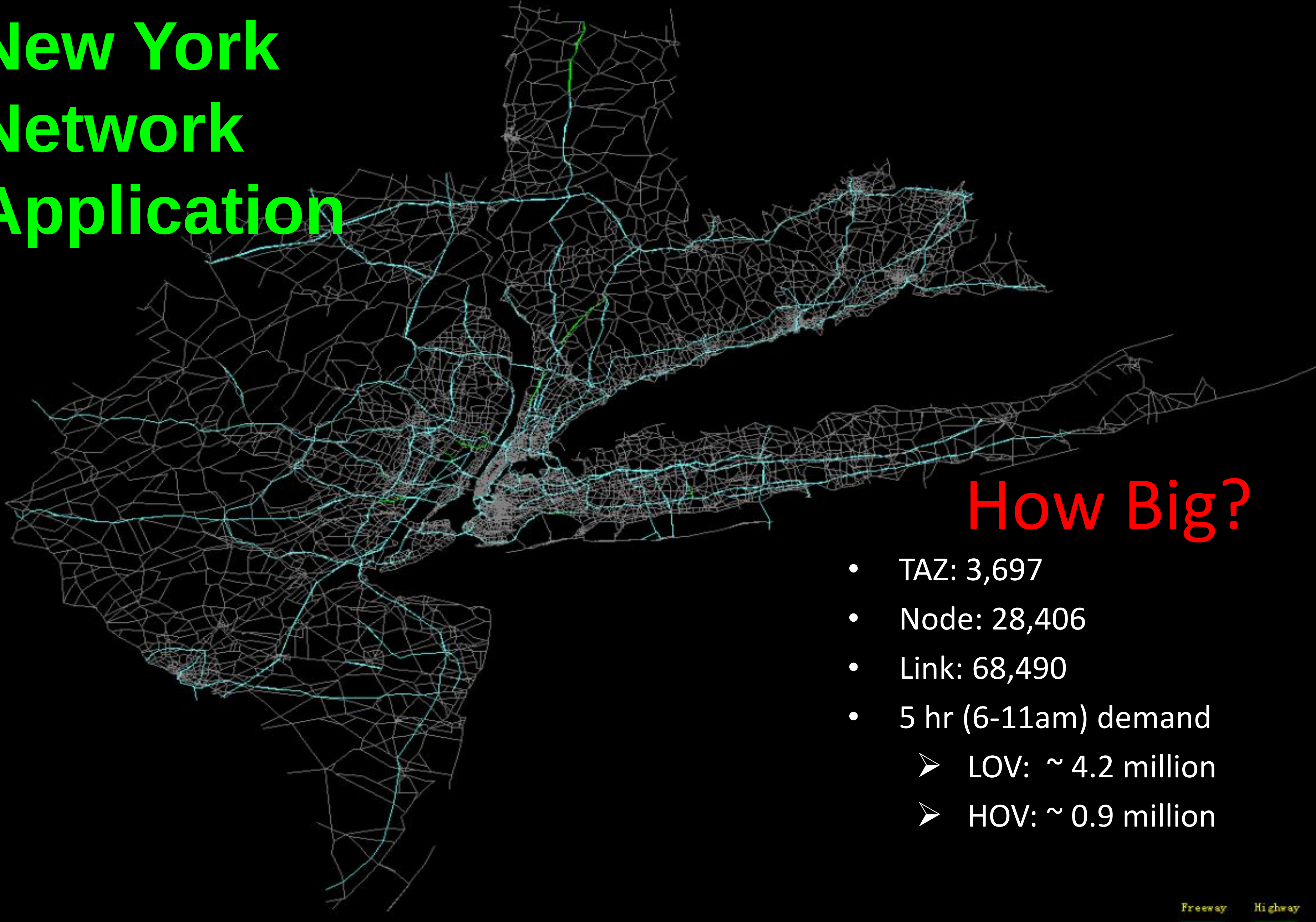
- route choice model includes time-varying prices, and travel reliability measure
- random value of time (distributed across users)
- mode choice and departure time choice models

in conjunction with
MDUE (multi-criteria Dynamic User Equilibrium) with
heterogeneous users and very large scale network

~30,000 Nodes
70,000 Links
3,700 Zones

5-hour AM peak period
5.2 M simulated vehicles

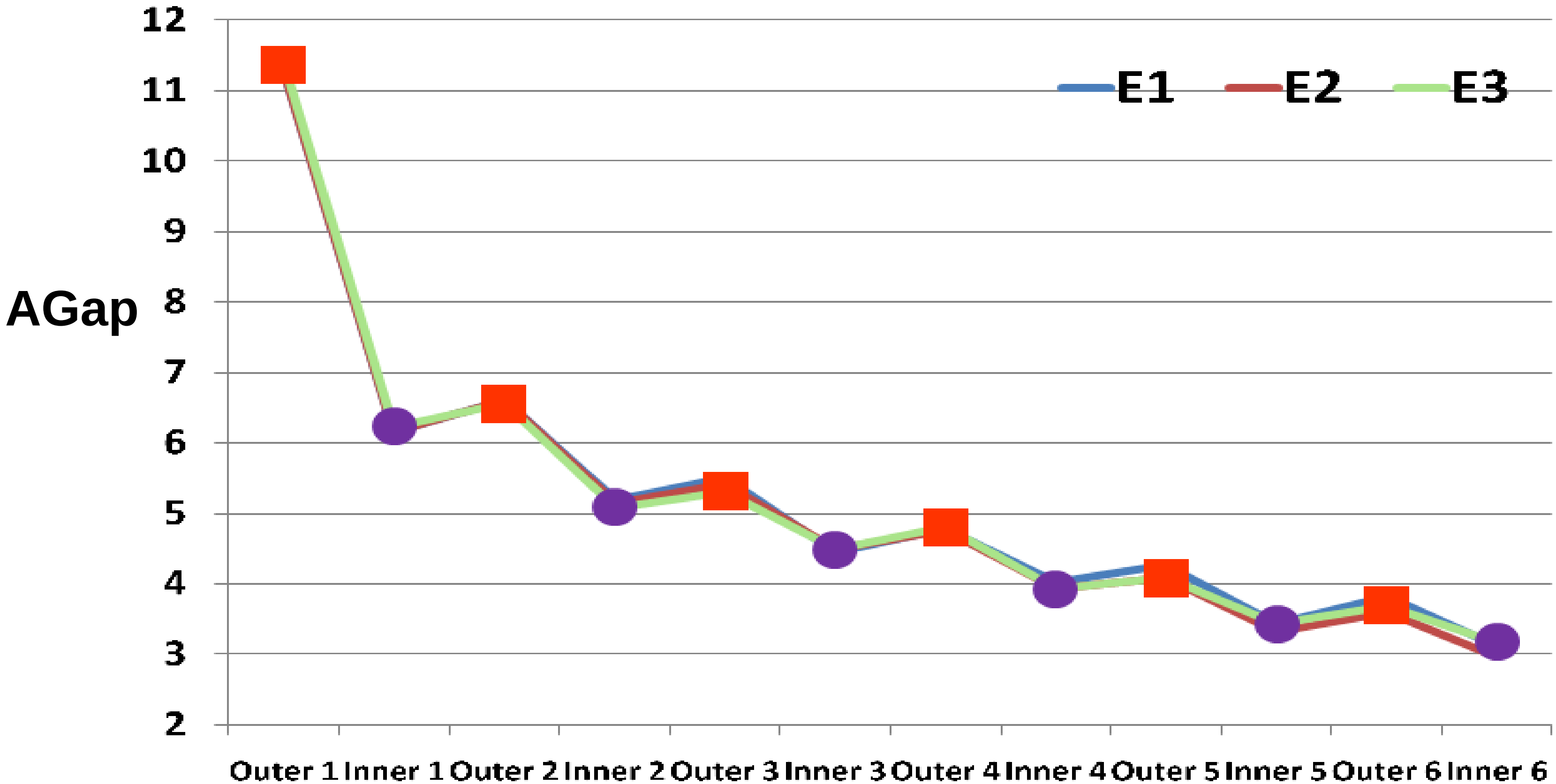
New York Network Application



How Big?

- TAZ: 3,697
- Node: 28,406
- Link: 68,490
- 5 hr (6-11am) demand
  - LOV: ~ 4.2 million
  - HOV: ~ 0.9 million

Convergence Patterns

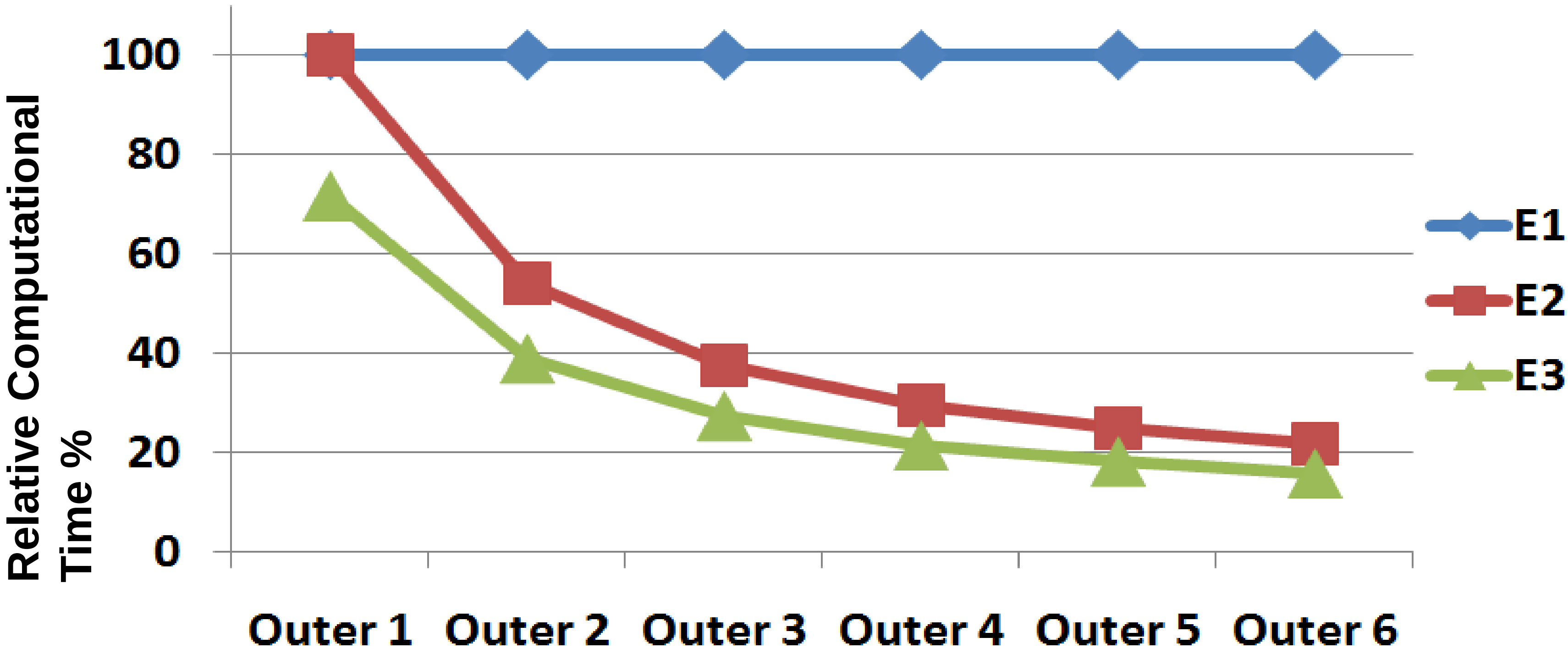


AGap reduction at final iteration:

- E1: 72.36%; E2: 73.69%, and E3:72.10%

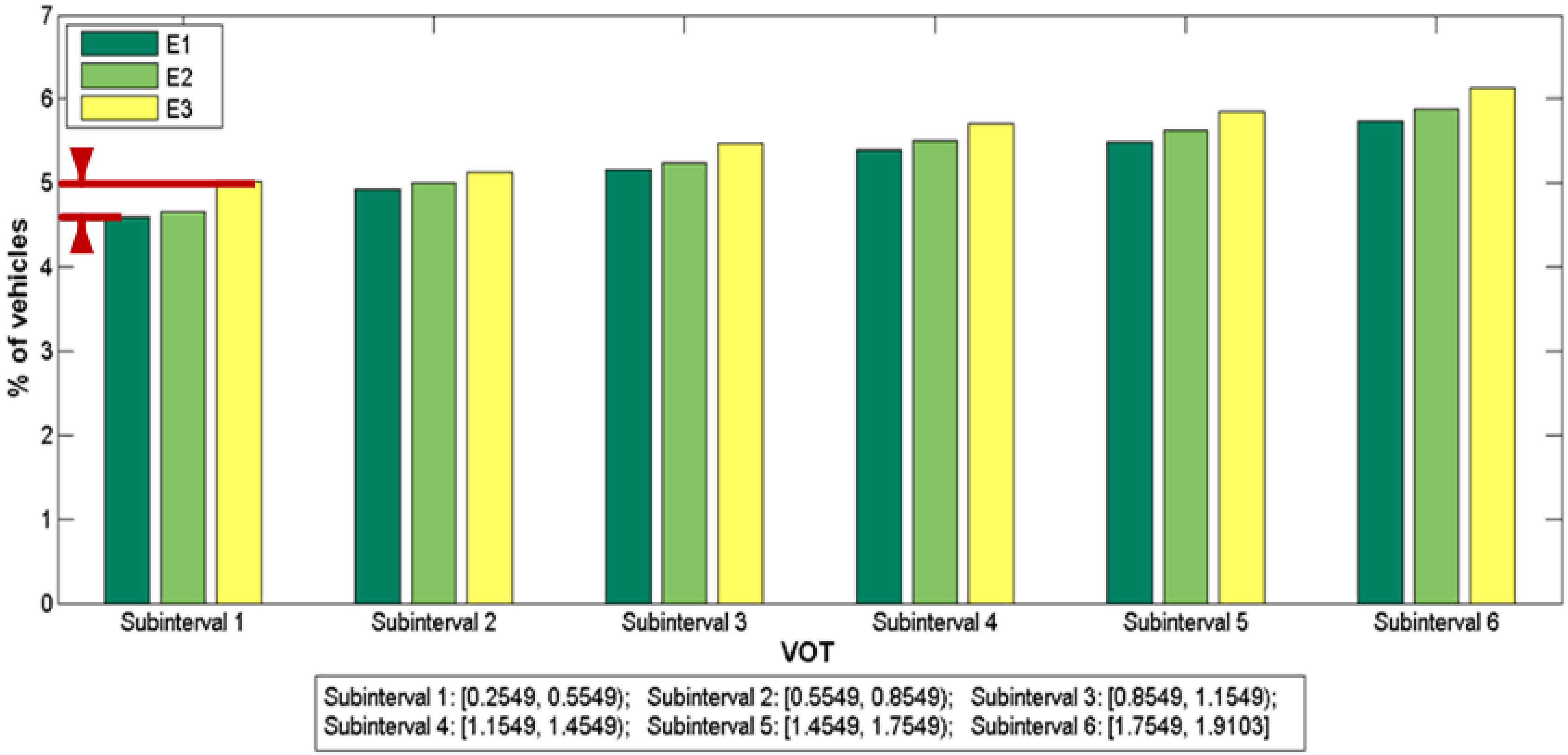
	Gap-based Technique	Step Size (Δ)	Outer Loop	Inner Loop
Experiment 1	NO	0.3	5 iterations	1 iteration
Experiment 2	YES	0.3	5 iterations	1 iteration
Experiment 3	YES	0.5	5 iterations	1 iteration

Computational Time: PAM



E1: ~7min for each destination;
E2: 53% reduction of total time in E1;
E3: 64% reduction of total time in E1.

Flow Prediction: Toll Road Usage

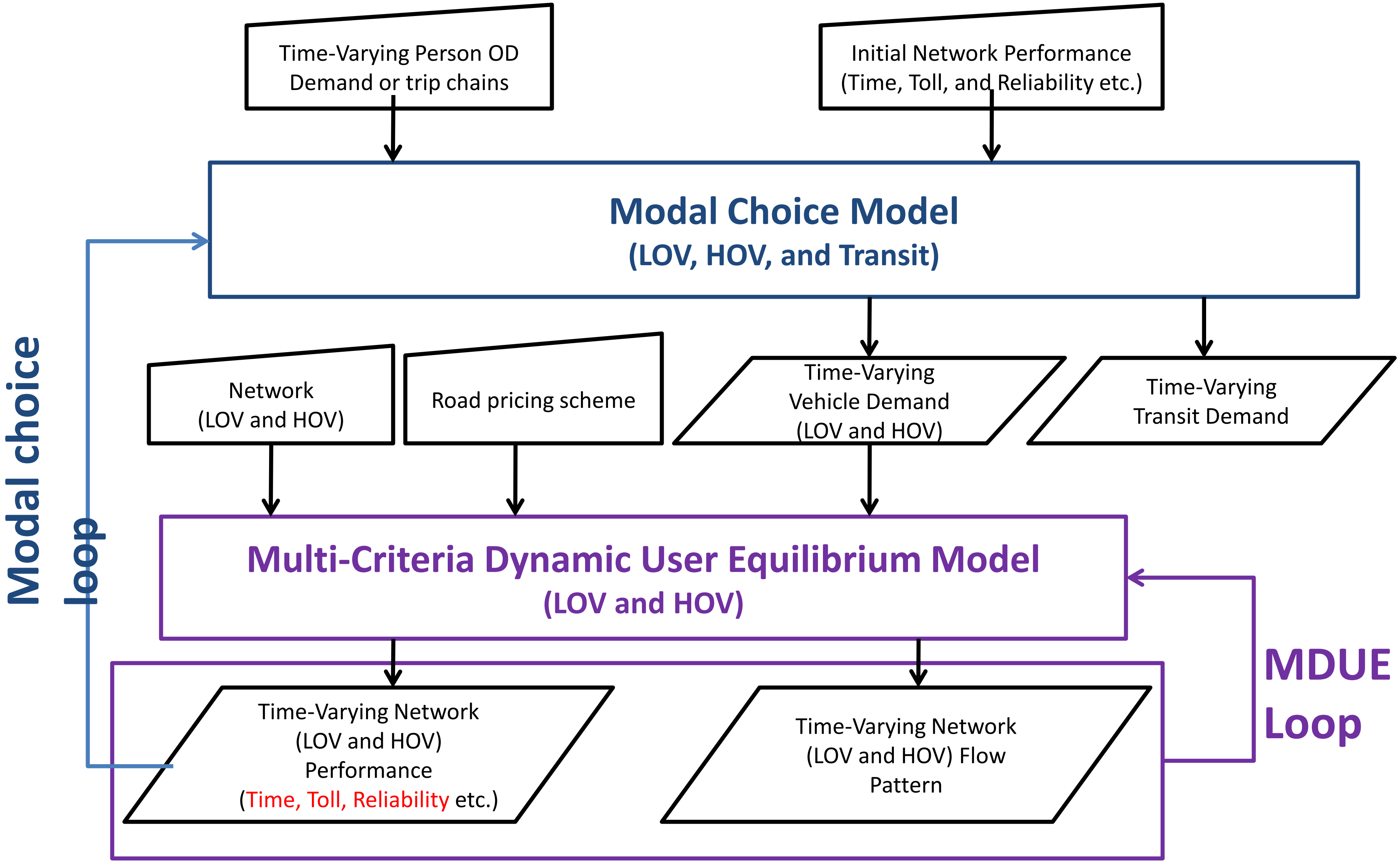


Max flow difference: ~ 0.31%

Integrating mode choice in multi-criteria dynamic user equilibrium model

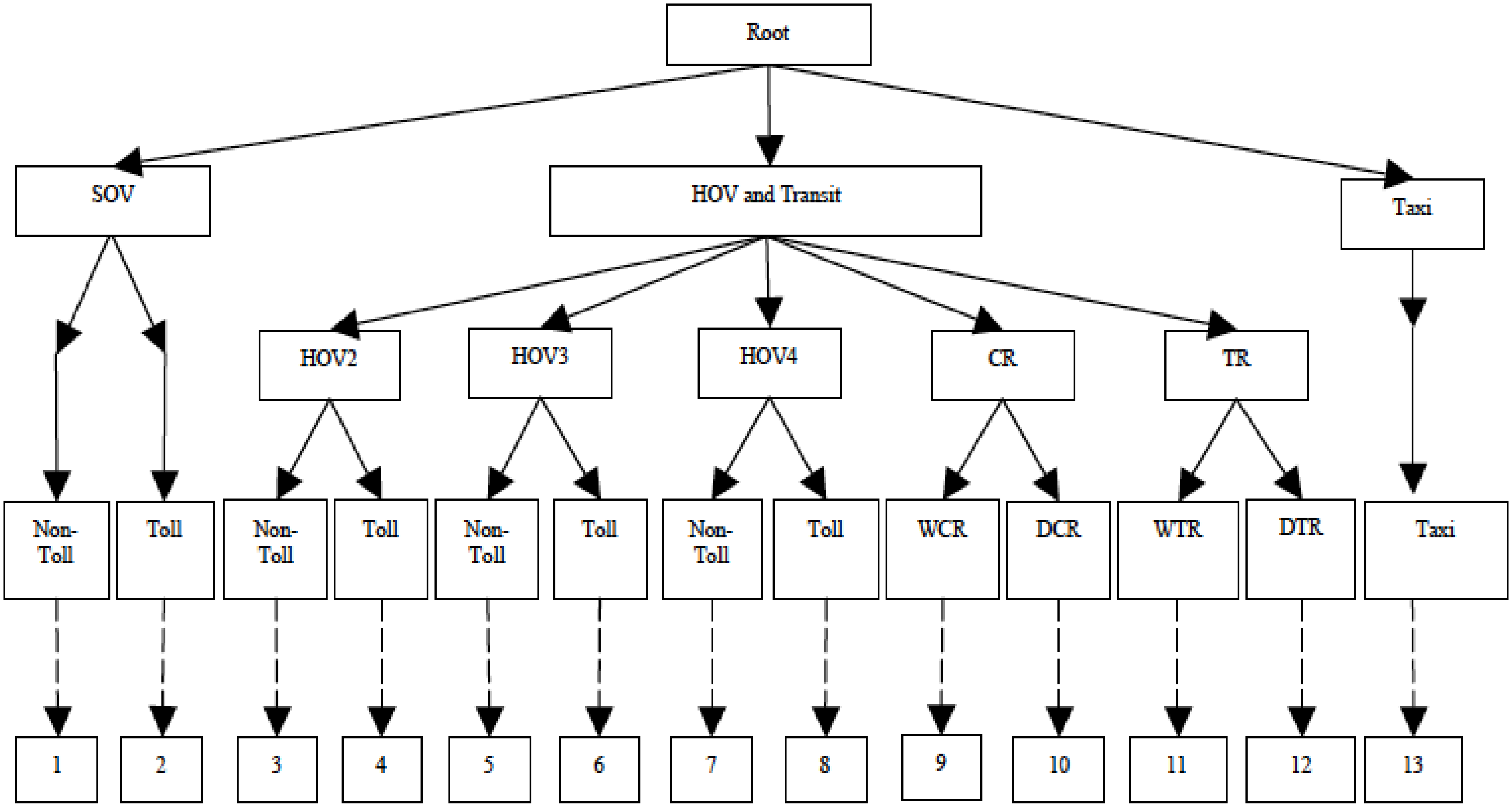
- Assumptions:
  - Given network with discretized planning horizon
  - Given time-dependent OD person demand
  - Given calibrated mode choice model (LOV, HOV, and Transit)
  - Given VOT distribution
  - Given road pricing scheme
- Solve for:
  - Modal share for each mode (e.g., LOV, HOV, and Transit)
  - Assignment of time-varying travelers for each mode (LOV, HOV) to a congested time-varying multimodal network under multi-criteria dynamic user equilibrium (MDUE) conditions
- Methodology:
  - Descent direction method for solving the modal choice problem
  - Simulation-based column generation solution framework for the MDUE problem

Modeling framework

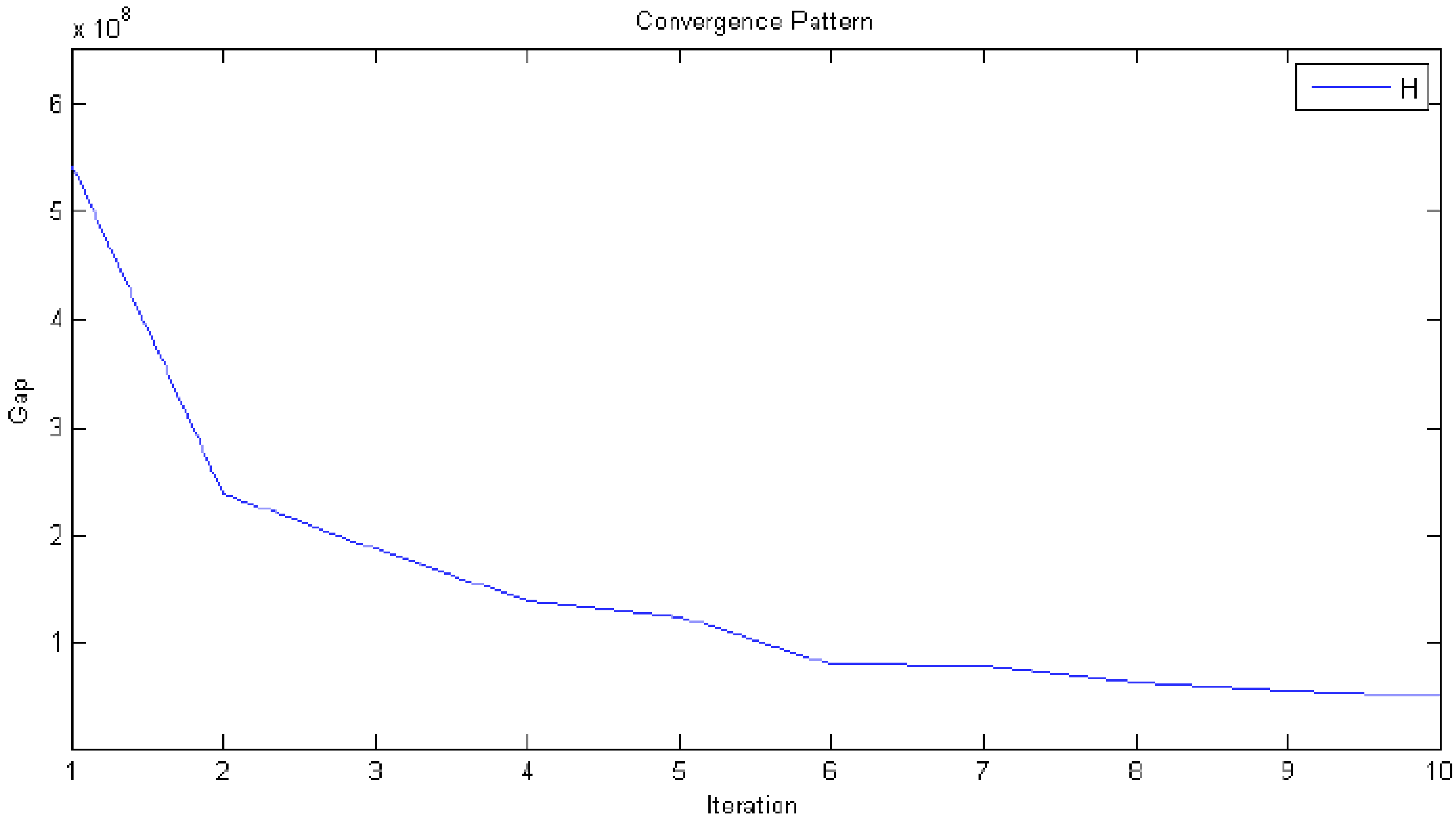


Zhang, Mahmassani, and Vovsha (2011): Integrated Nest-Logit Mode Choice model

Nested Logit Mode Choice Model



Outer Loop Convergence Pattern: New York Regional Network



CONCLUDING COMMENTS

- We have seen advances in state-of-the-art in integrating user responses to dynamic pricing, congestion and unreliability in network modeling procedures.
- New methodologies are software independent and can be applied with any simulation-based DTA tool (caveats…)
- Application to very large New York regional network first successful application to network of this size of equilibrium DTA with heterogeneous users.
- Integration process could be improved with additional choice dimensions, and eventually fully-configured activity-based model.

KEY ISSUES and OPPORTUNITIES

- Theoretical constructs:
  - Notions of consistency in stochastic dynamic context
    ➔ convergence measures?
  - Path dependence in dynamic simulation forecasts
  - Consistency of attribute valuation throughout activity submodels– e.g. should travel time be valued similarly in route vs mode vs departure time choices?
- Methodological issues: multi-scale modeling, path finding, activity scheduling combinatorics, cooperation and competition in multi-agent system
- Application issues: **Planning and Operations Decision Support System**
  - Different applications/problems call for different capabilities: plug-and-play built on basic platform
- Major opportunity: more active tie in with trajectory data from probes and sensor information– responsive, calibrated, relevant platform for decision support