McCormick

Northwestern Engineering

Northwestern University Transportation Center

Developments in Integrated Modeling of Activity-Travel Demand and Dynamic Network Flows

Hani Mahmassani

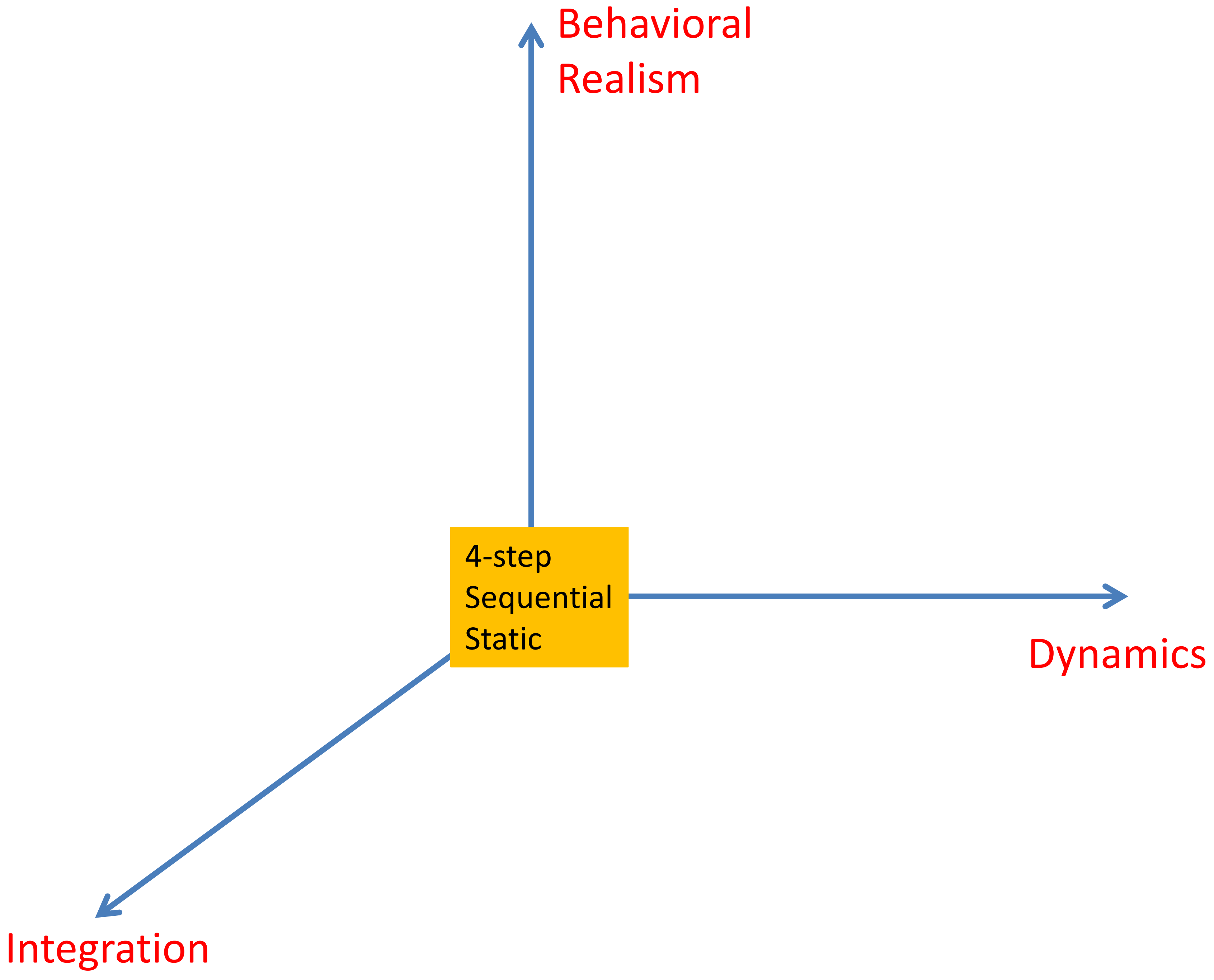
3rd Innovations in Travel Modeling Conference, Phoenix, AZ - May 11, 2010

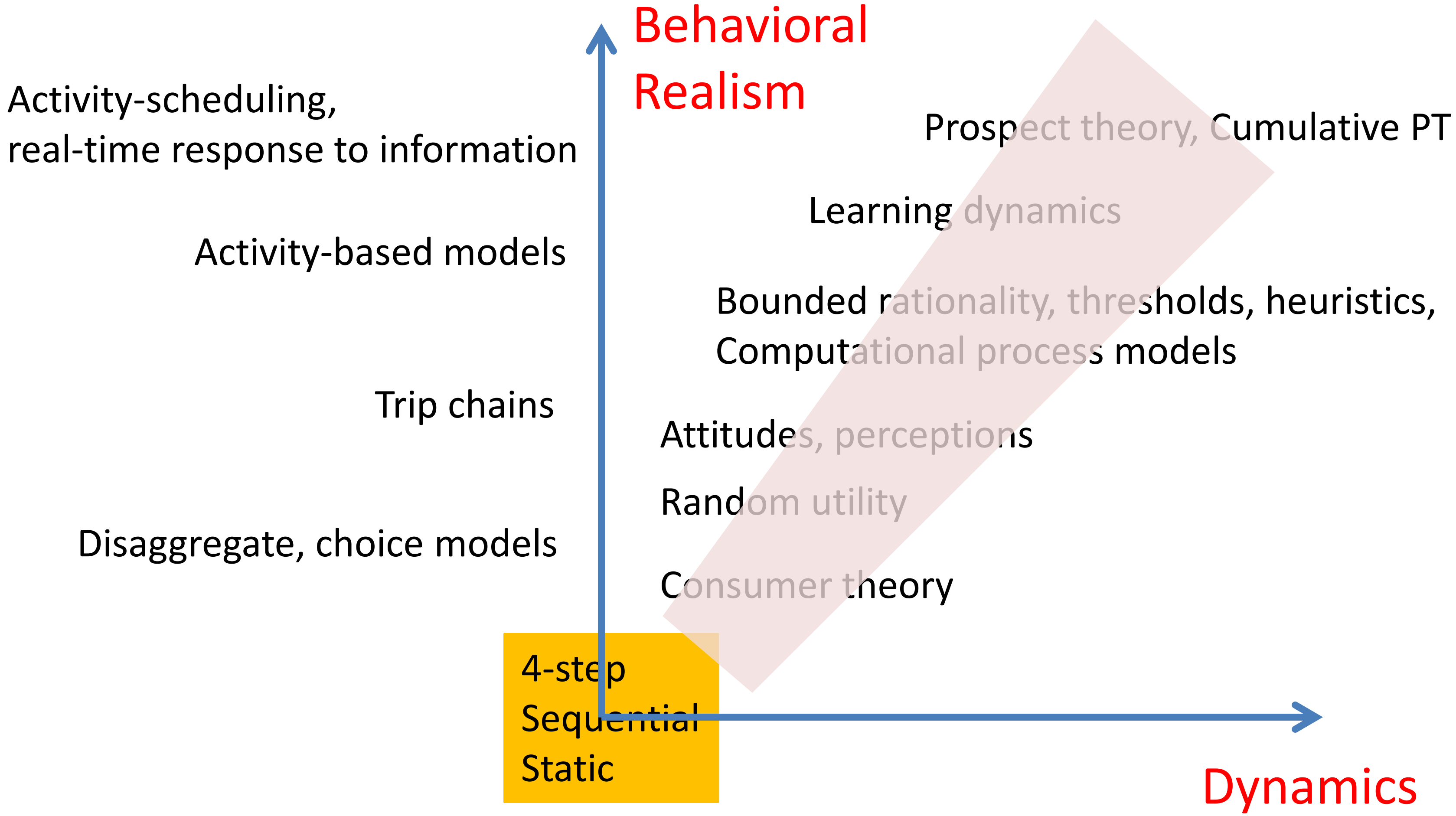
EXECUTIVE SUMARY

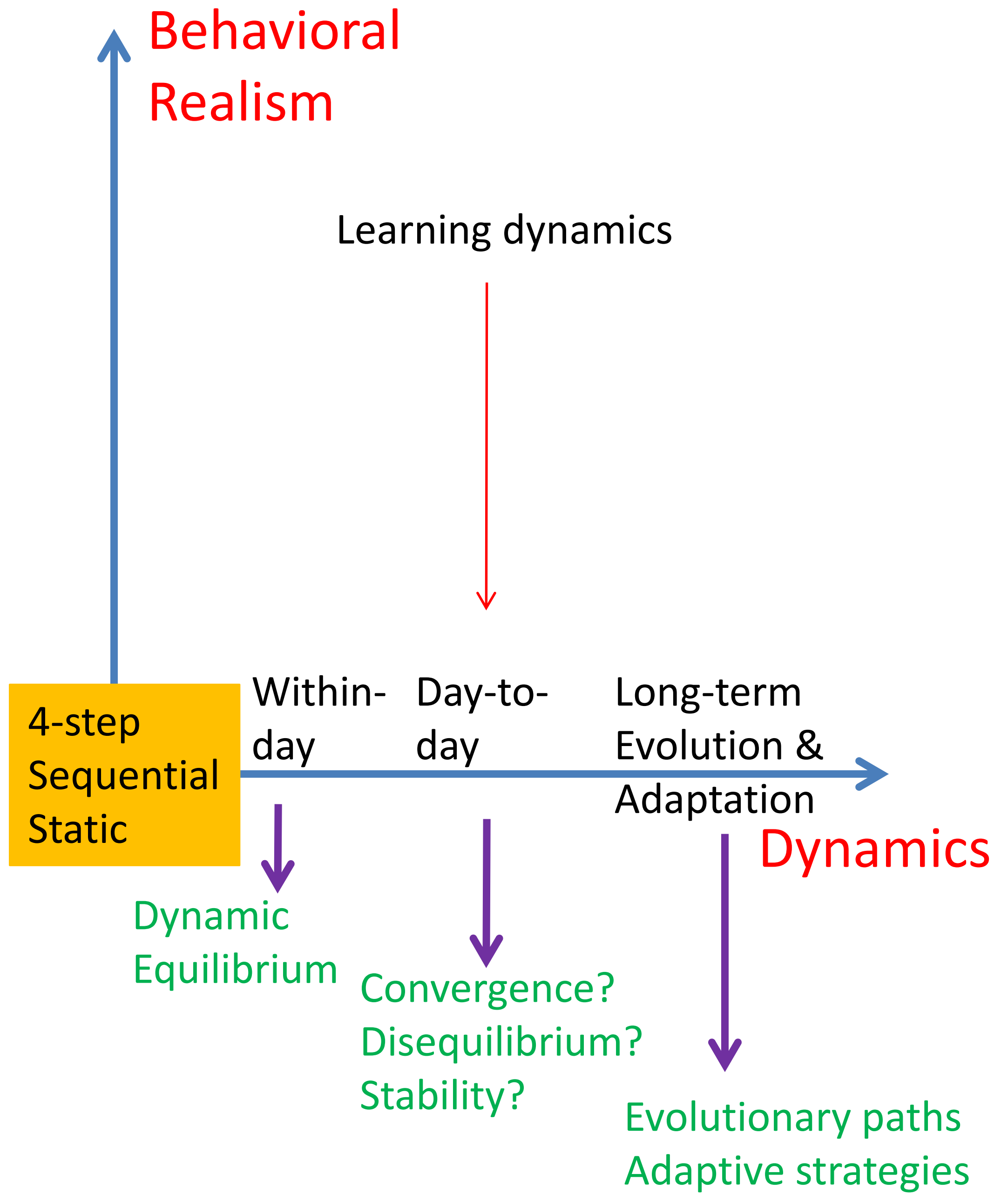
- Existing static assignment tools inadequate for incorporating user responses (e.g. to dynamic prices, reliability) and activity models: require time-varying representation of flows in networks
- Simulation-based DTA methods provide appropriate platform for integrating advanced user travel-activity behavior models
- DTA tools used in practice still lack several key features
  - Limited to route choice as only user choice dimension
  - Do not capture user heterogeneity
  - Cannot generate travel time reliability measures as path LOS attributes
  - Do not produce distributional impacts of contemplated projects/ measures (social justice)
  - Limited applicability of dynamic equilibrium procedures to large-scale regional networks

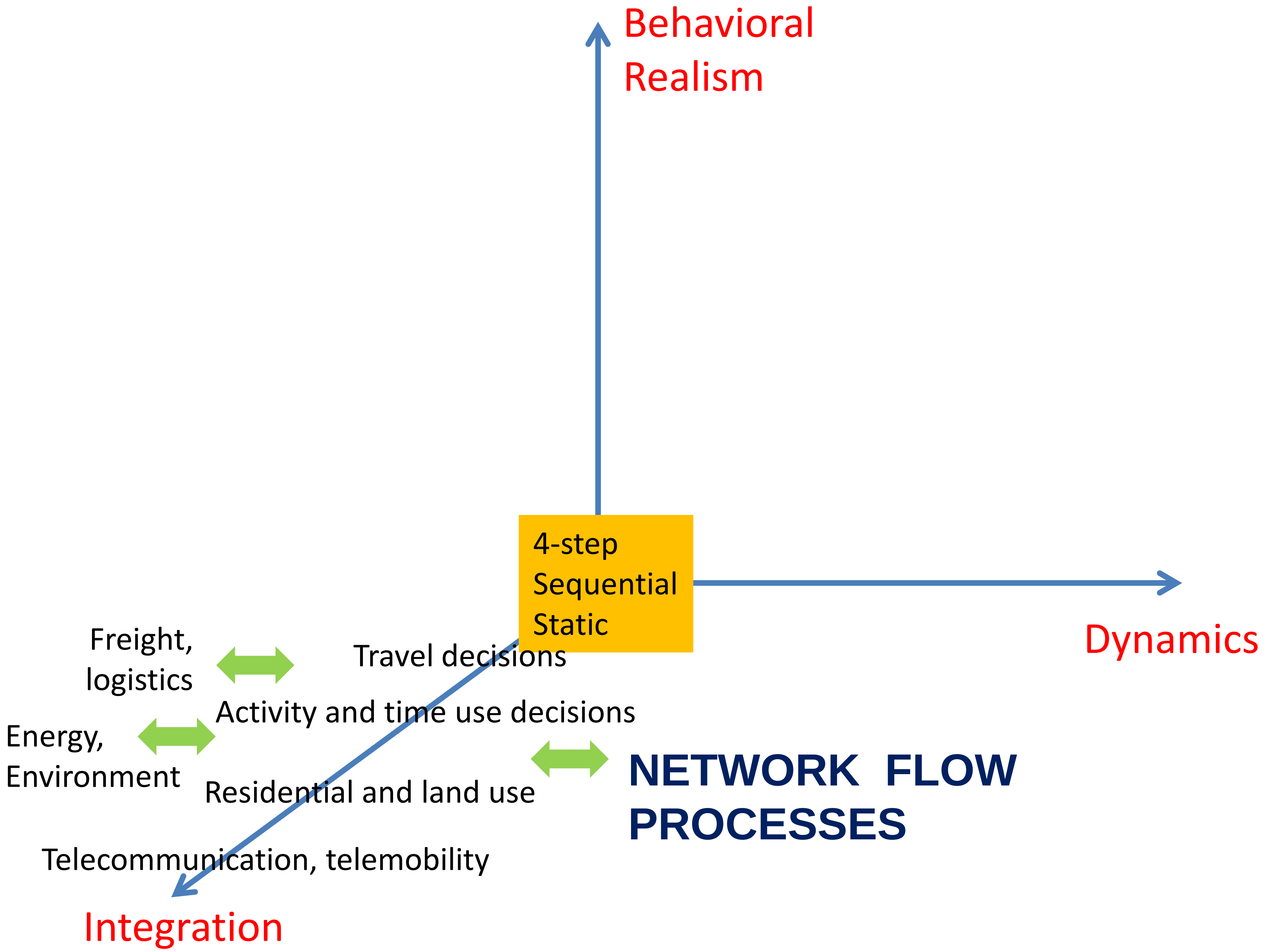
EXECUTIVE SUMARY II

- Recent SHRP-2 projects (e.g. C04, L04) have developed the methodologies to integrate user response models in network simulation procedures, for application over the near, medium and long terms
- The algorithms solve for a multi-criterion dynamic stochastic user equilibrium with heterogeneous users in response to dynamic prices, and congestion-induced unreliability
- The integrated procedures are demonstrated on the New York regional network, using advanced demand models developed in Project SHRP-2 C04 on the basis of actual data, coupled with the algorithmic procedures developed and adapted for large-scale network implementation.

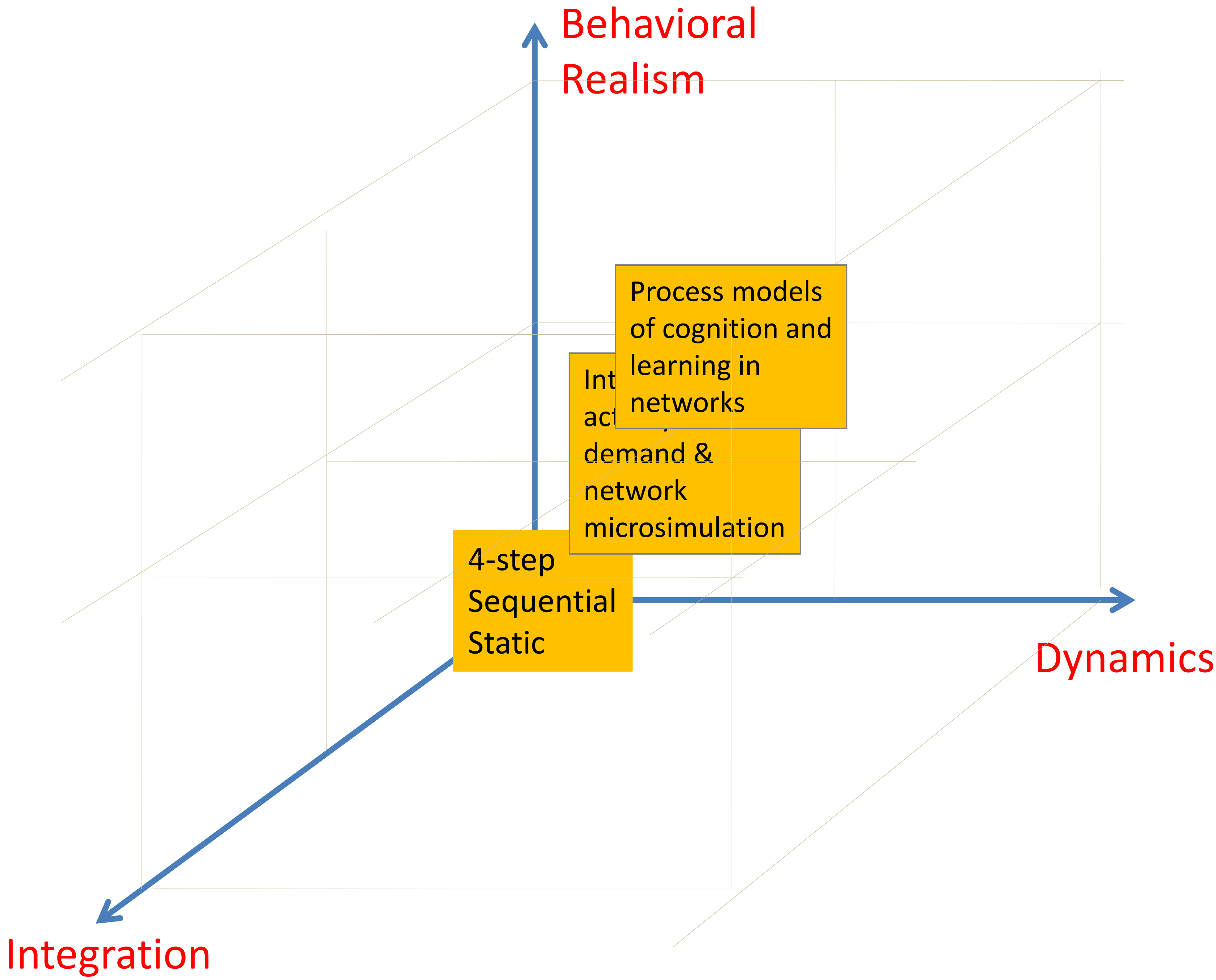

Behavioral
Realism
4-step
Sequential
Static
Dynamics
Integration


Behavioral
Realism
Activity-scheduling,
real-time response to information
Activity-based models
Trip chains
Disaggregate, choice models
Prospect theory, Cumulative PT
Learning dynamics
Bounded rationality, thresholds, heuristics,
Computational process models
Attitudes, perceptions
Random utility
Consumer theory
4-step
Sequential
Static
Dynamics


Behavioral
Realism
Learning dynamics
4-step
Sequential
Static
Within-
day
Day-to-
day
Long-term
Evolution &
Adaptation
Dynamics
Dynamic
Equilibrium
Convergence?
Disequilibrium?
Stability?
Evolutionary paths
Adaptive strategies



Behavioral
Realism
4-step
Sequential
Static
Dynamics
Freight,
logistics
Travel decisions
Activity and time use decisions
Energy,
Environment
Residential and land use
NETWORK FLOW
PROCESSES
Telecommunication, telemobility
Integration


Behavioral
Realism
Process models
of cognition and
learning in
networks
demand &
network
microsimulation
4-step
Sequential
Static
Dynamics
Integration

State of Practice in Network Modeling

1. Most agencies use static assignment models, often lacking formal equilibration, with very limited behavioral sensitivity to congestion-related phenomena (incl. reliability)

2. Some agencies use traffic microsimulation models downstream from assignment model output, primarily for local impact assessment

3. Time-dependent (dynamic) assignment models continuing to break out of University research into actual application– market growing, still fragmented, with competing claims and absence of standards:

- existing static players adding dynamic simulation-based capabilities,
- existing traffic microsimulation tools adding assignment (route choice) capability, often in conjunction with meso-simulation
- standalone simulation-based DTA tools

State of Practice in Network Modeling (ctd.)

4. Applications to date complementary, not substitutes, for static assignment; primary applications for operational planning purposes: work zones, evacuation, ITS deployment, HOT lanes, network resilience, etc… Still not introduced in core 4-step process, nor integrated with activity-based models

5. Existing commercial software differs widely in capabilities, reliability and features; not well tested. So-called open source is illusion for practice – no QA, nor accountability.

6. Equilibration for dynamic models not well understood, and often not performed

6. Dominant features, first introduced by DYNASMART-P in mid 90's:

- Micro-assignment of travelers; ability to apply disaggregate demand models
- Meso-simulation for traffic flow propagation: move individual entities, but according to traffic flow relations among averages (macroscopic speed-density relations): faster execution, easier calibration
- Ability to load trip chains (first tool with this capability, essential to integrate with activity-based models)

Responses to Pricing, in Existing Network Models

1. 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.

3. Reliability is almost never considered.

DELIVERING THE METHODS: SIX KEY CHALLENGES

- ADVANCED BEHAVIOR MODELS C04
- HETEROGENEOUS USERS C04, C10?
- INTEGRATION WITH NETWORK MODELS:
  THE PLATFORM– SIMULATION-BASED MICRO-ASSIGNMENT DTA C04, L04, C10
- GENERATE THE ATTRIBUTES: RELIABILITY IN NETWORK LEVEL OF SERVICE L04
- CONSISTENCY BETWEEN BEHAVIOR (DEMAND) AND PHYSICS (SUPPLY): EQUILIBRATION C04, C10?
- PRACTICAL LARGE NETWORK APPLICATION: INTELLIGENT IMPLEMENTATION C10?

User Heterogeneity

User Heterogeneity

- Trip-makers choose their paths based on many criteria, including travel time, travel reliability and out-of-pocket cost, and with heterogeneous perceptions.
- Empirical studies (e.g. Hensher, 2001; Cirillo et al. 2006) found that the VOT varies significantly across individuals.
- Lam and Small (2001) measured the value of reliability (VOR) of $15.12 per hour for men and $31.91 for women based on SP survey data.

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

Estimation Results Route Choice Model NYC Area

Model			Lognormal [-1.00,1.00]	
Description	Congested Time, Cost, Toll Bias and Std. Dev.		Congested Time, Cost, Toll Bias and Std. Dev.	
Number of Observations	1694		1694	
Likelihood with Zero Coefficients	-1174.1913		-1174.1913	
Likelihood at Convergence	-1017.4036		-1015.6495	
Parameter	**Coefficient**	**T-Statistic**	**Coefficient**	**T-Statistic**
Contant for Toll Route	-1.0155	-11.794	-1.0512	-14.041
Highway Cost (Dist*16+Tolls, cents) by Occupancy	-0.0010	-2.058	-0.0010	-2.350
Congested Time (minutes)	-0.0430	-5.569	-3.1732	-18.155
Congested Time on Highways (minutes)	---	---	---	---
Congested Time on Non-Highway Roads (minutes)	---	---	---	---
Congested Time on Roads with v/c => 0.9 (minutes)	---	---	---	---
Congested Time on Roads with v/c < 0.9 (minutes)	---	---	---	---
Standard Deviation - Congested Time per Mile	-0.7344	-0.650	-0.7333	-1.312
Error Term Parameters				
Varince log-Beta-Congested Time	---	---	1.0142	6.357
Values of Time ($/hr)				
Mean Based on Congested Time	25.80		28.92	
Standard Deviation Based on Congested Time	---		15.42	

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.

Selected Developments in Flow Simulation for Network Application

- Capturing user heterogeneity
- Convergence of micro and meso level models → *particle-based* models
- Incorporating sources of variability in both micro and meso levels
- Vehicle trajectories as unifying concept for output processing, measurement, and tying theoretical development to empirical validation
- Modeling flow breakdown: micro mechanisms, collective phenomenon

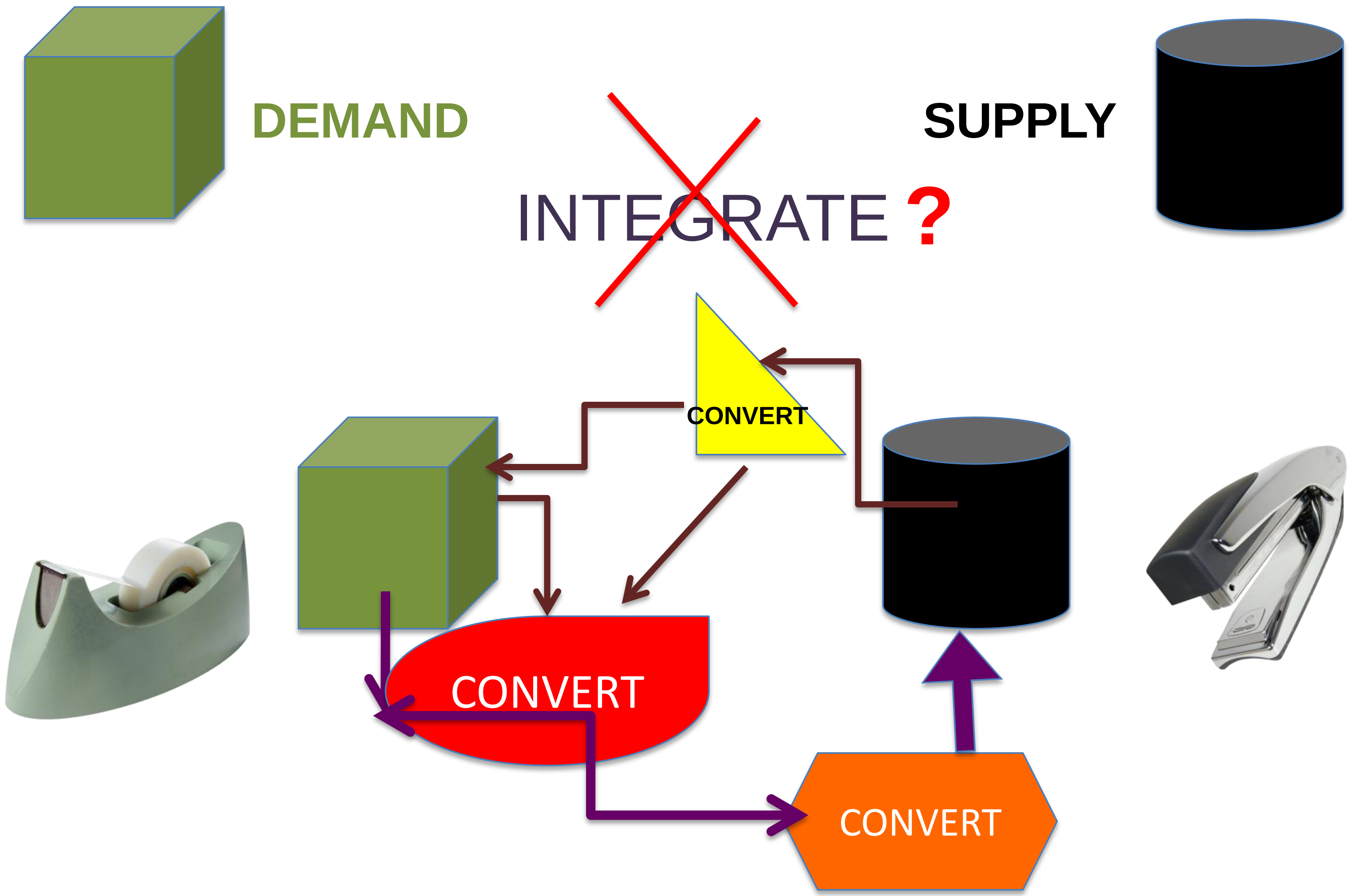
Integration Issues

Integration Issues

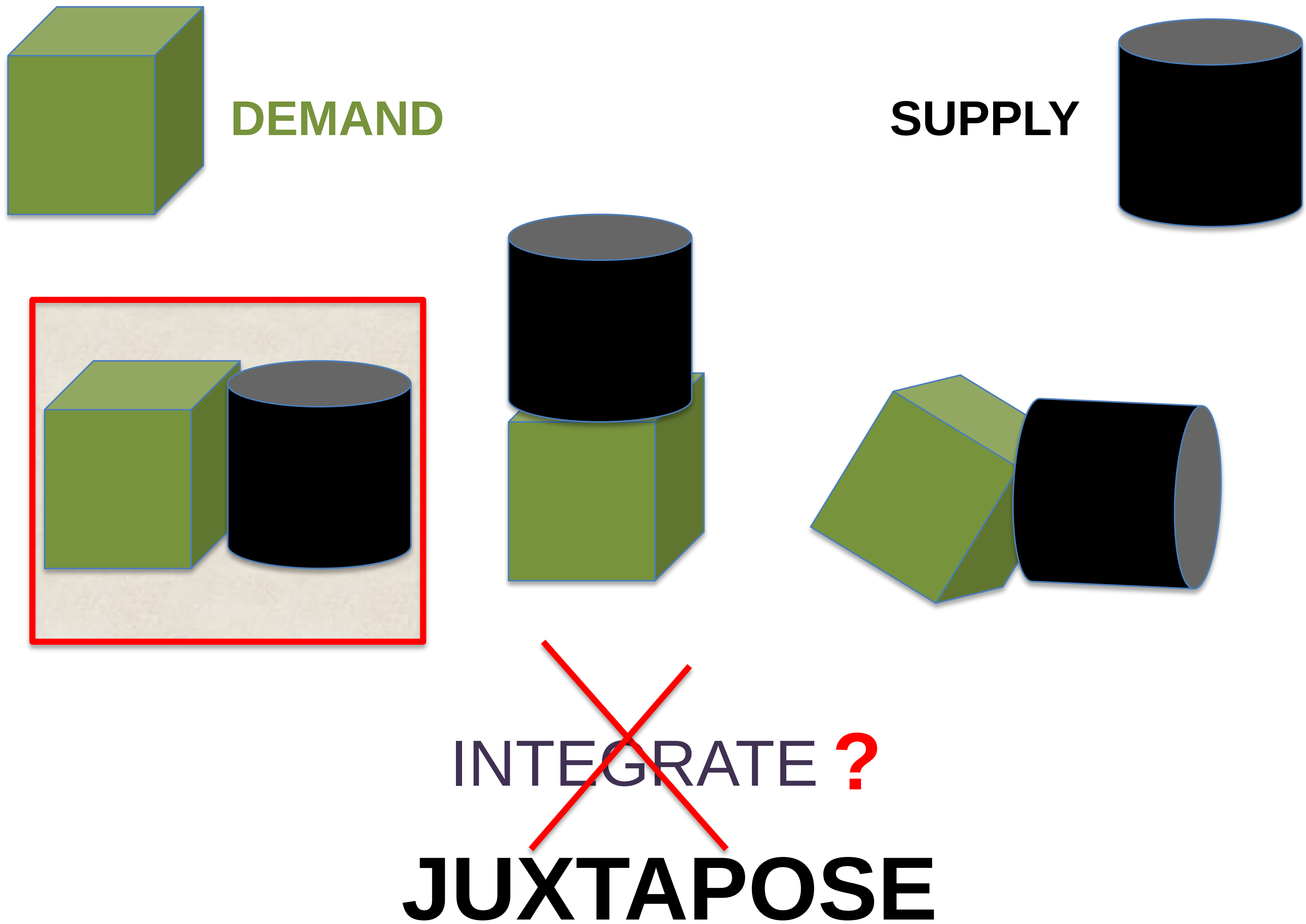
- As demand models reflect greater behavioral realism, supply side simulation models need to incorporate these improvements as well.

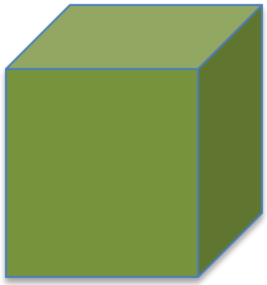
- Current travel choice models reflect the following:
  - Random heterogeneity and taste variations
  - Serial correlation among repeated choices
  - Non-IIA substitution pattern among alternatives; general error structures
  - Process models for activity choice and scheduling

- Incorporating these behavioral extensions into supply-side (network) models requires producing the attributes included in the estimated choice models ➔implications for core algorithms (e.g. path finding) and consistency-seeking (equilibrium) procedures.



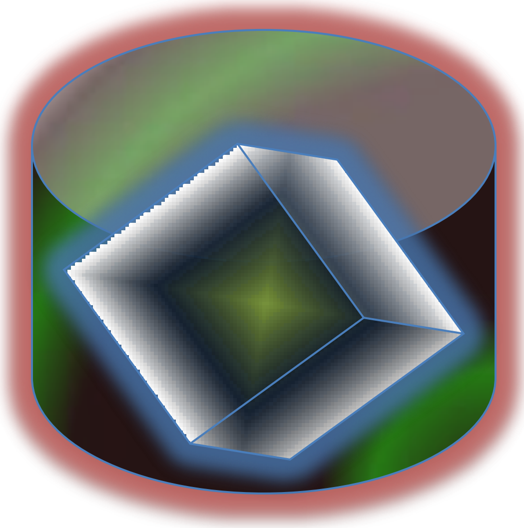
INTERFACE


DEMAND
SUPPLY
INTEGRATE ?
JUXTAPOSE



DEMAND

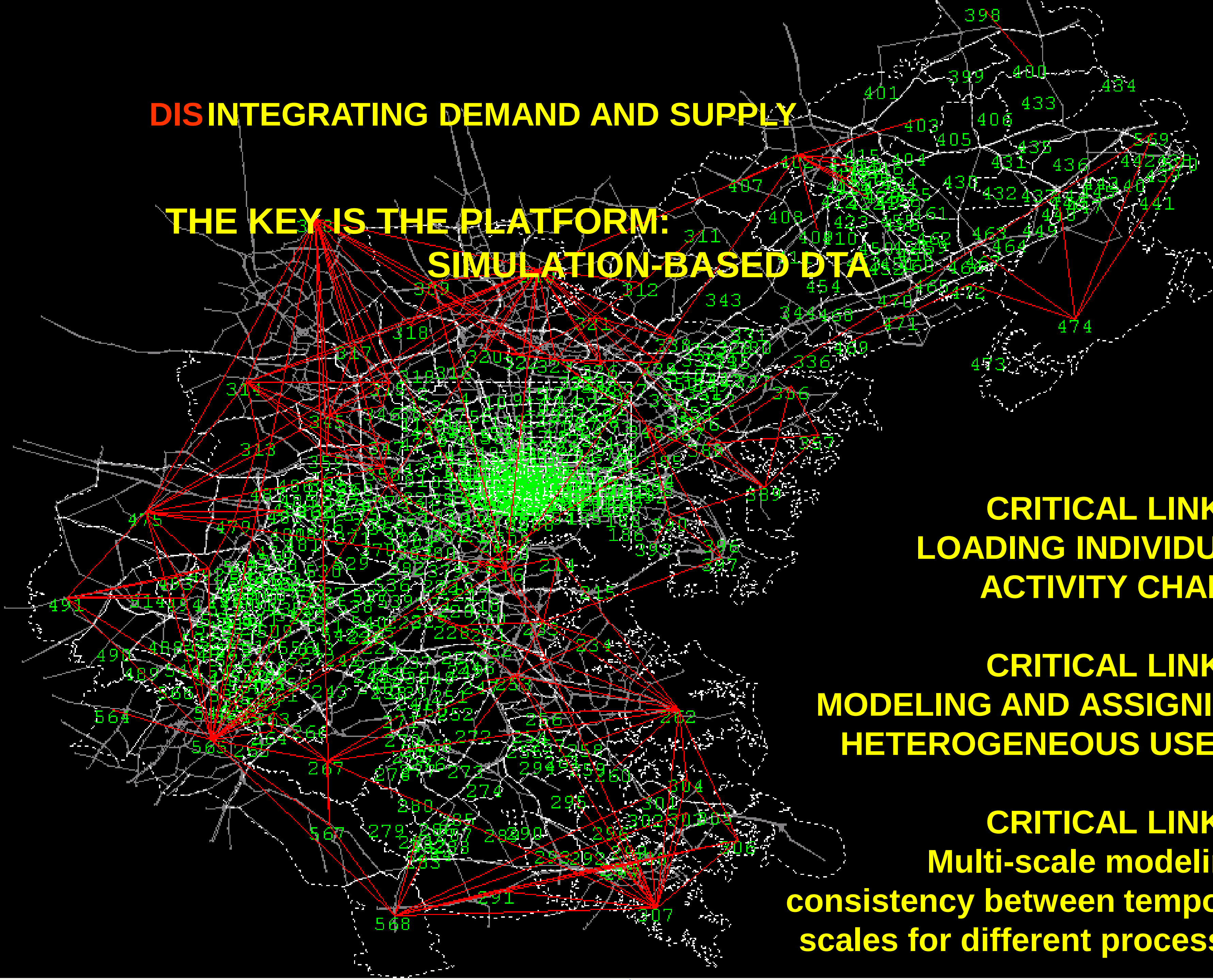
SUPPLY



INTEGRATE?

DISINTEGRATING DEMAND AND SUPPLY

THE KEY IS THE PLATFORM: SIMULATION-BASED DTA



CRITICAL LINK 1: LOADING INDIVIDUAL ACTIVITY CHAINS

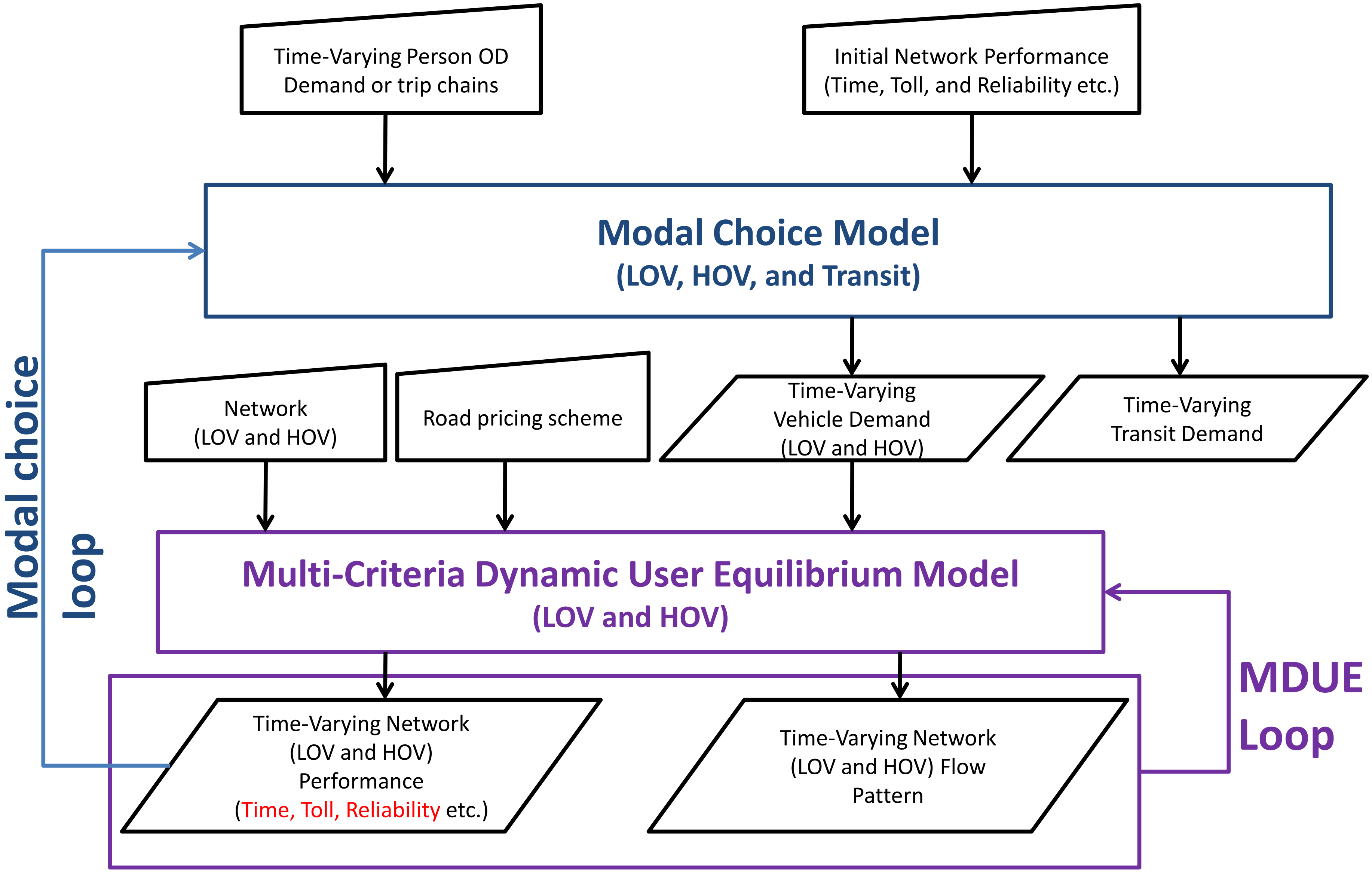
CRITICAL LINK 2: MODELING AND ASSIGNING HETEROGENEOUS USERS

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

Example: Mode choice and 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



Model implementation

- Short-term Integration
  - Mode choice loop integrated in model framework
  - MNL, GEV, and Mixed Logit (random coefficients) Mode Choice model
- Medium-term Integration
  - Departure time choice dimension; activity-based models
  - MNL, GEV, Mixed Logit (Random coefficients), and Mixed Logit (Serial Correlation) Choice Model
- Long-term Integration
  - Activity scheduling models, time use, process models

Solution Algorithm for MDUE–UE with random VOT and VOR

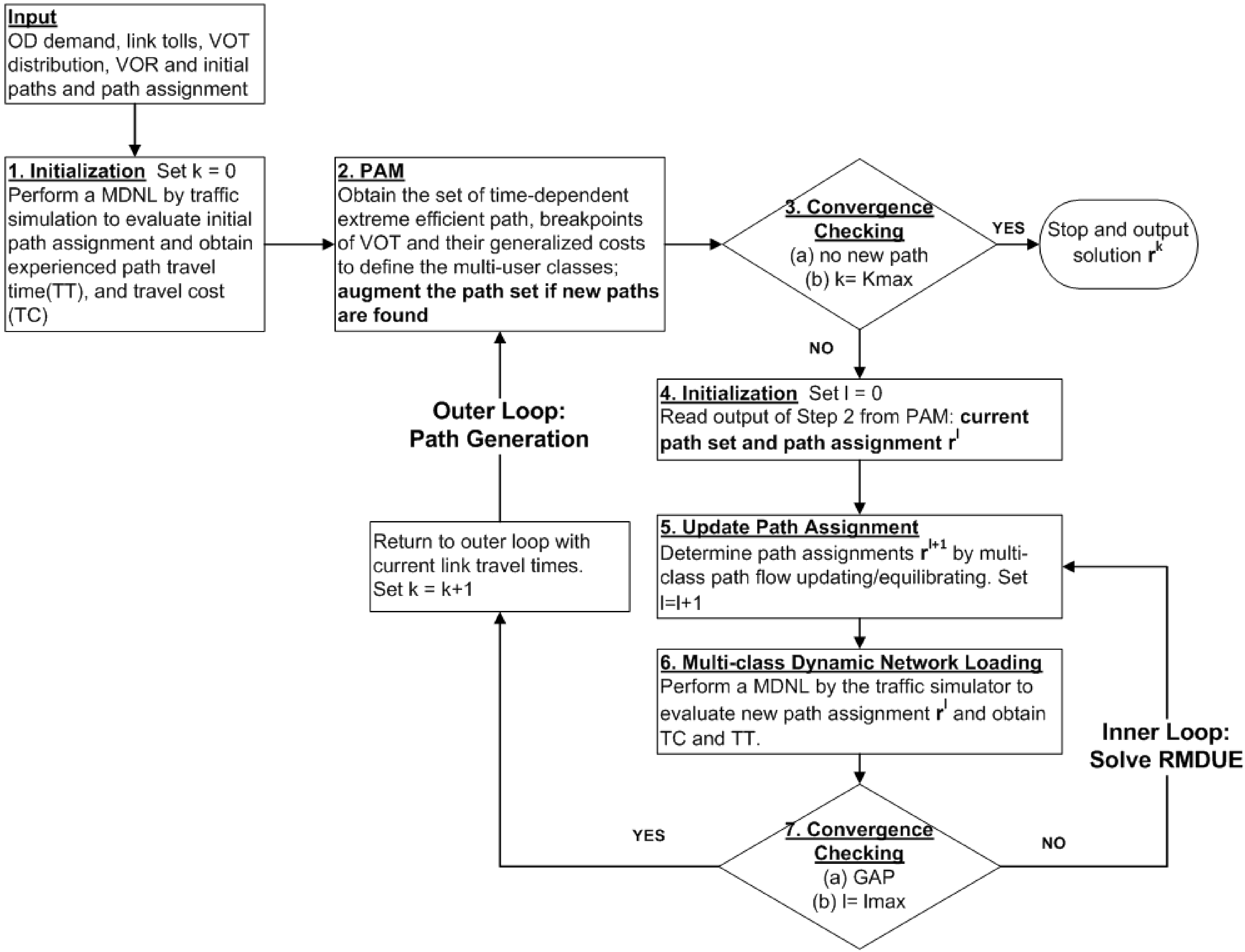
For short-term integration: incorporate MNL/GEV mode choice dimension and heterogeneous users for mode and route choices

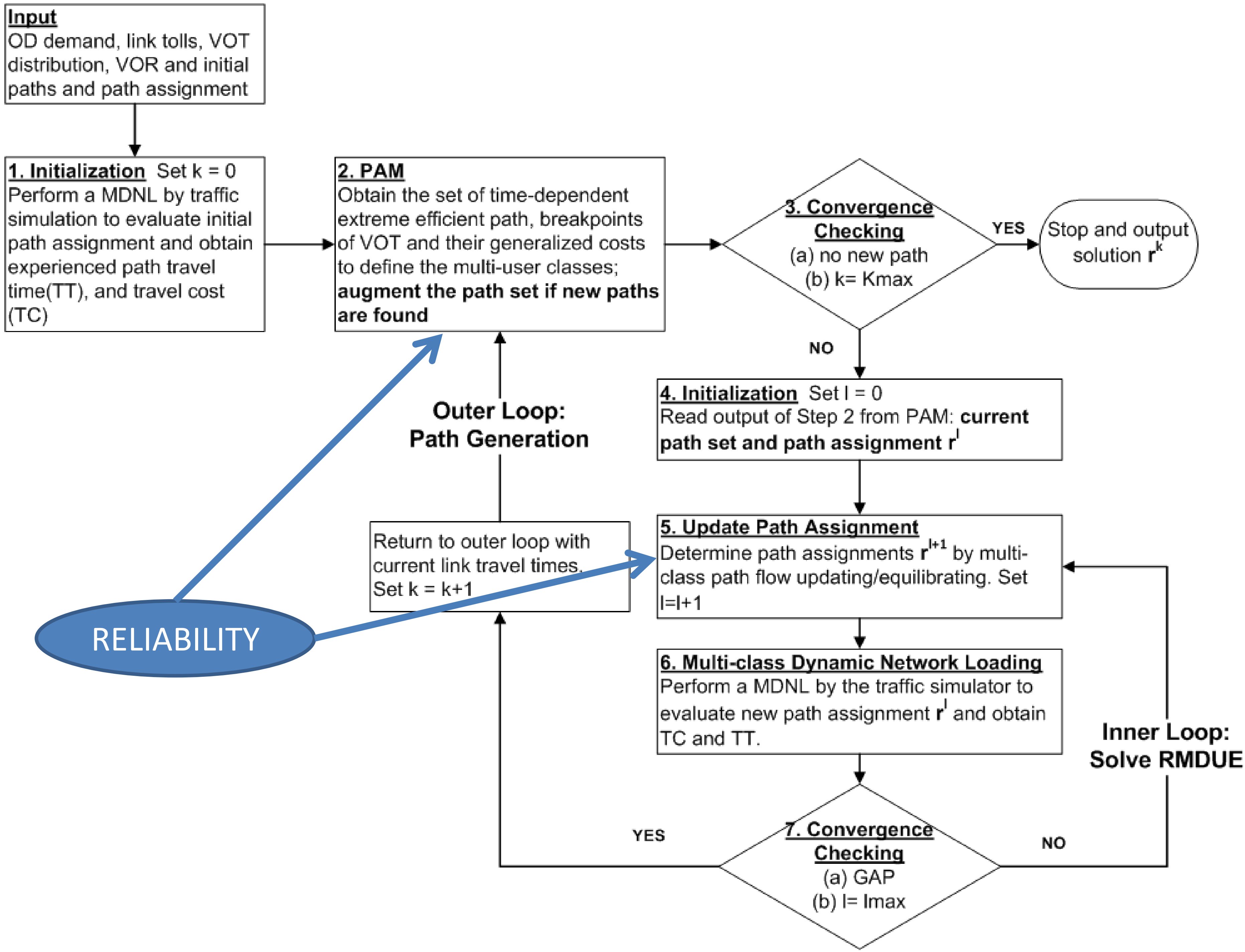
Generalized Cost

- Generalized cost is defined as a summation of travel monetary cost (**TC**), travel time (**TT**) and travel time variability/reliability (**TV**).

- VOT is considered as a continuous random variable distributed across the population of trip-makers with the density functions:

- VOR β is considered as a constant for all trip-makers


Input
OD demand, link tolls, VOT distribution, VOR and initial paths and path assignment
1. Initialization Set k = 0
Perform a MDNL by traffic simulation to evaluate initial path assignment and obtain experienced path travel time(TT), and travel cost (TC)
2. PAM
Obtain the set of time-dependent extreme efficient path, breakpoints of VOT and their generalized costs to define the multi-user classes; augment the path set if new paths are found
3. Convergence Checking
(a) no new path
(b) k= Kmax
YES
Stop and output solution r^k
NO
4. Initialization Set l = 0
Read output of Step 2 from PAM: current path set and path assignment r^l
Outer Loop: Path Generation
Return to outer loop with current link travel times. Set k = k+1
5. Update Path Assignment
Determine path assignments r^{l+1} by multi-class path flow updating/equilibrating. Set l=l+1
6. Multi-class Dynamic Network Loading
Perform a MDNL by the traffic simulator to evaluate new path assignment r^l and obtain TC and TT.
Inner Loop: Solve RMDUE
YES
7. Convergence Checking
(a) GAP
(b) l= lmax
NO

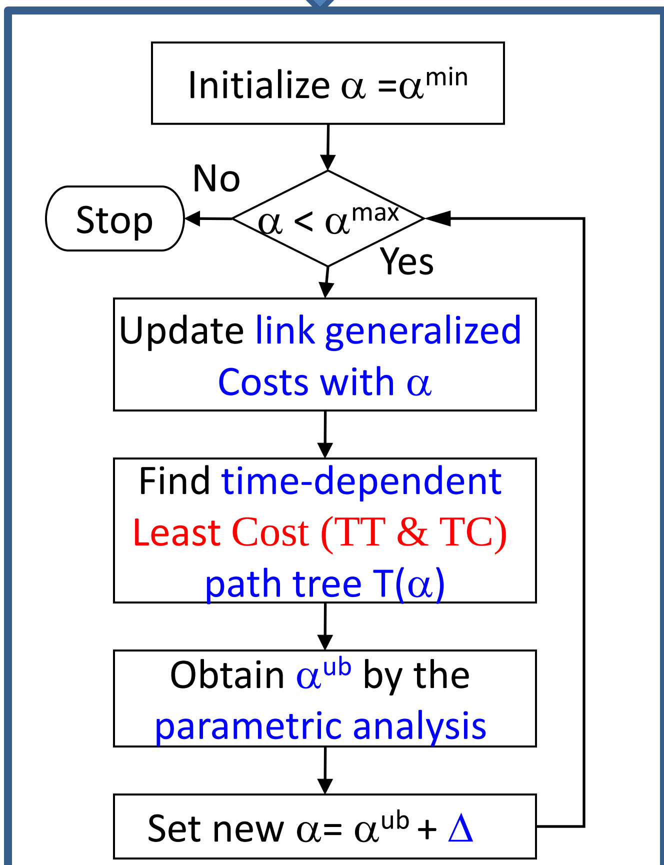

Input
OD demand, link tolls, VOT distribution, VOR and initial paths and path assignment
1. Initialization Set k = 0
Perform a MDNL by traffic simulation to evaluate initial path assignment and obtain experienced path travel time(TT), and travel cost (TC)
2. PAM
Obtain the set of time-dependent extreme efficient path, breakpoints of VOT and their generalized costs to define the multi-user classes; augment the path set if new paths are found
3. Convergence Checking
(a) no new path
(b) k= Kmax
YES
Stop and output solution r^k
NO
4. Initialization Set l = 0
Read output of Step 2 from PAM: current path set and path assignment r^l
Outer Loop: Path Generation
Return to outer loop with current link travel times. Set k = k+1
5. Update Path Assignment
Determine path assignments r^l+1 by multi-class path flow updating/equilibrating. Set l=l+1
RELIABILITY
6. Multi-class Dynamic Network Loading
Perform a MDNL by the traffic simulator to evaluate new path assignment r^l and obtain TC and TT.
Inner Loop: Solve RMDUE
YES
7. Convergence Checking
(a) GAP
(b) l= lmax
NO

Parametric Analysis Method (PAM)

Input: from traffic simulator

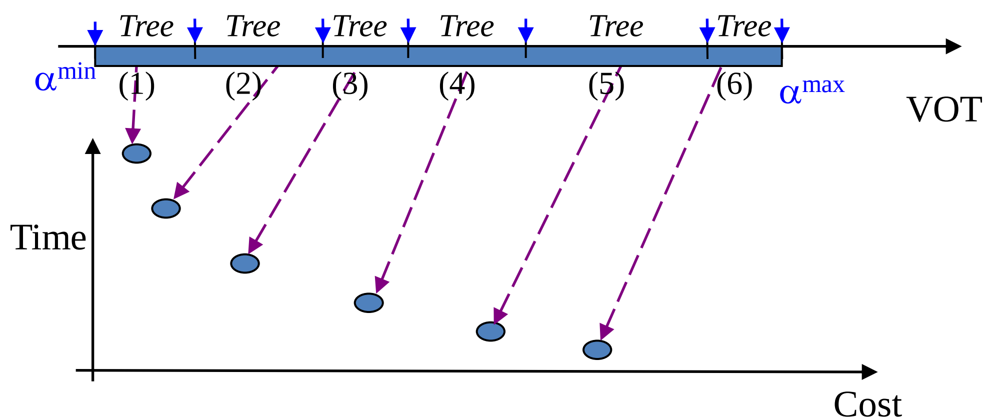
-Time-dependent travel time (TT)

-Time-dependent travel cost (TC)

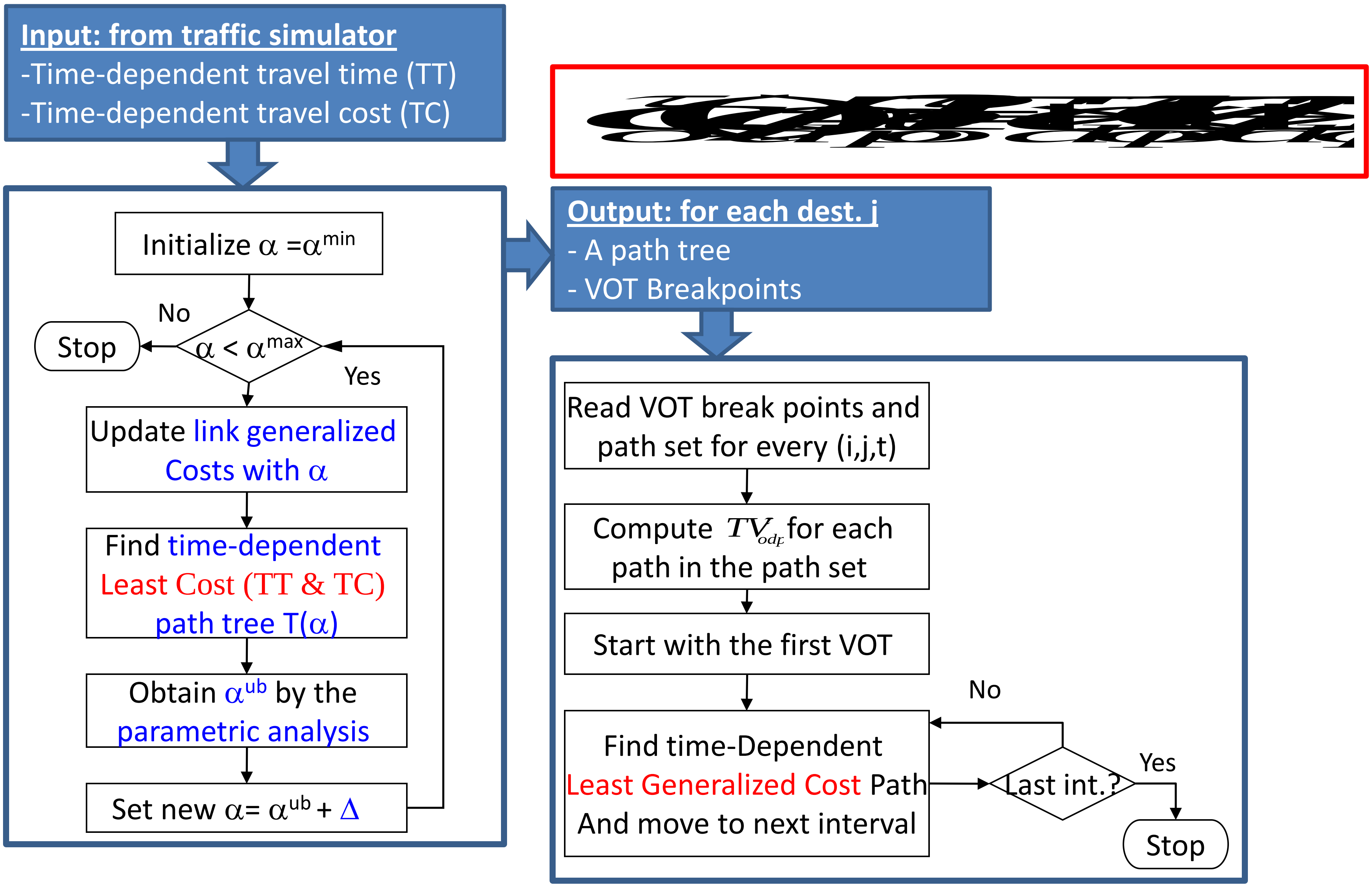


Output: for each dest. j

- A path tree
- VOT Breakpoints

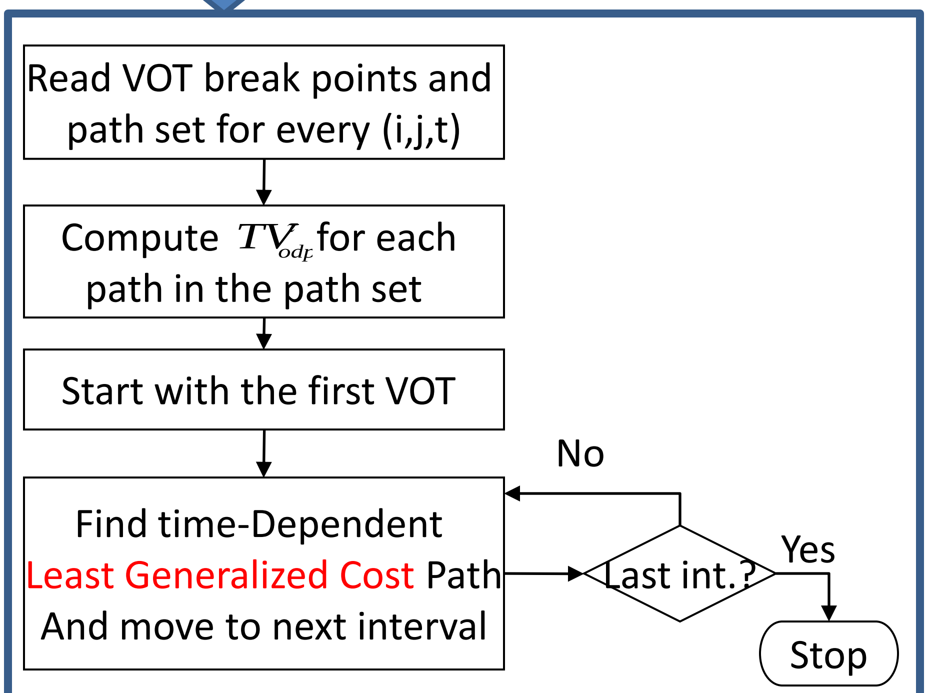


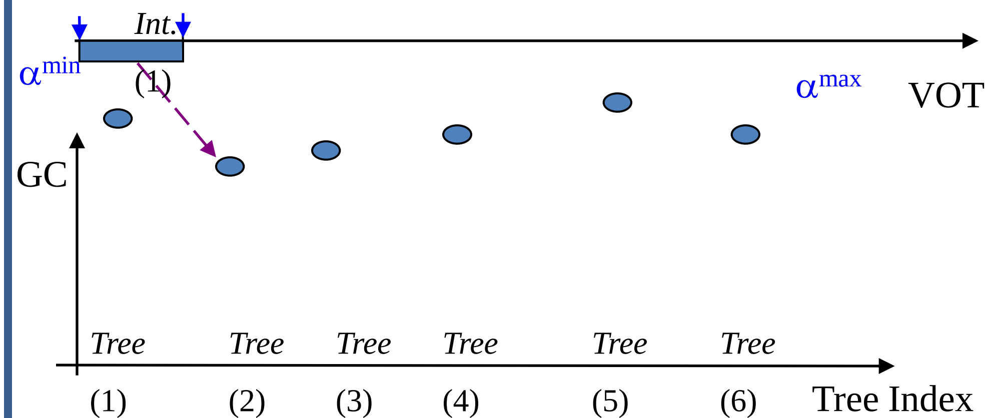
Parametric Analysis Method (PAM)



Parametric Analysis Method (PAM)

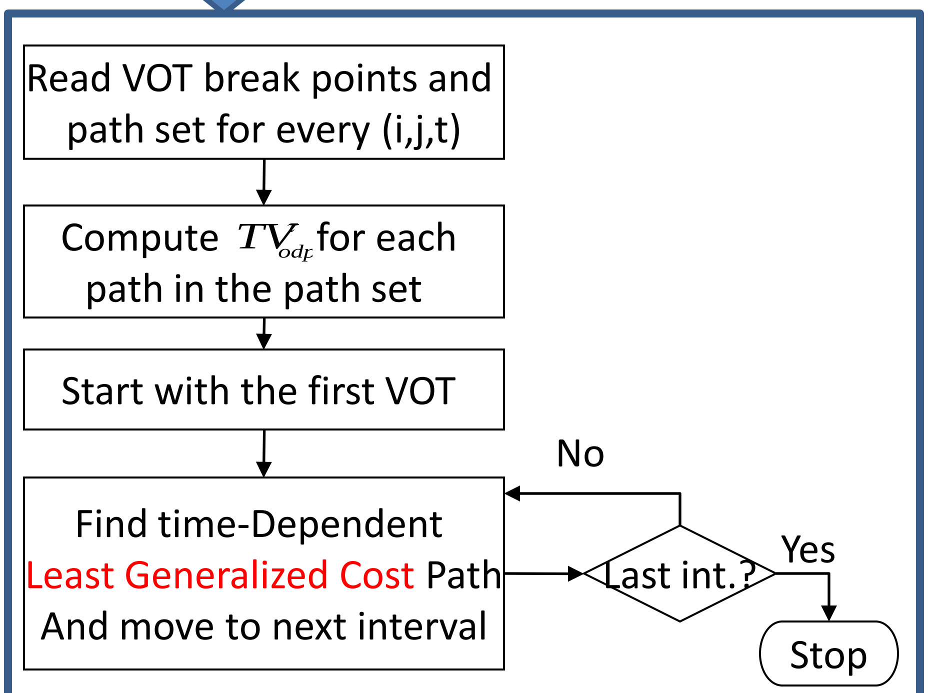
Output: for each dest. j
- A path tree
- VOT Breakpoints

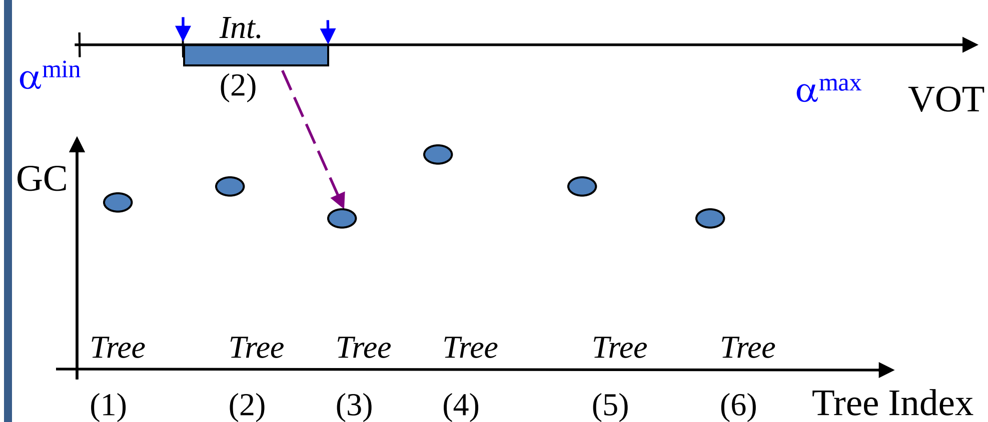




Parametric Analysis Method (PAM)

Output: for each dest. j
- A path tree
- VOT Breakpoints





Parametric Analysis Method (PAM)

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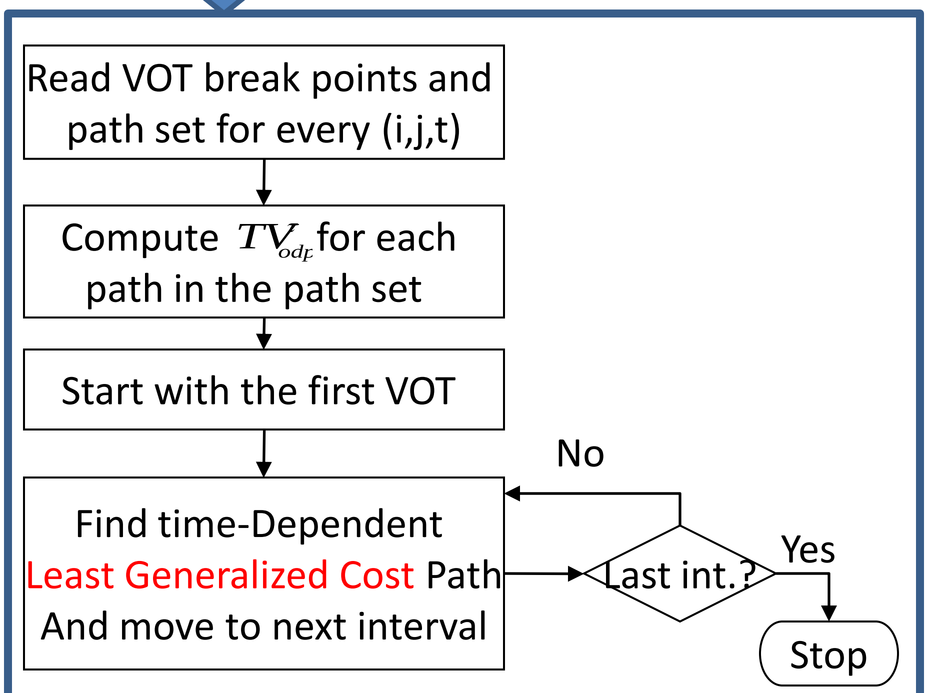
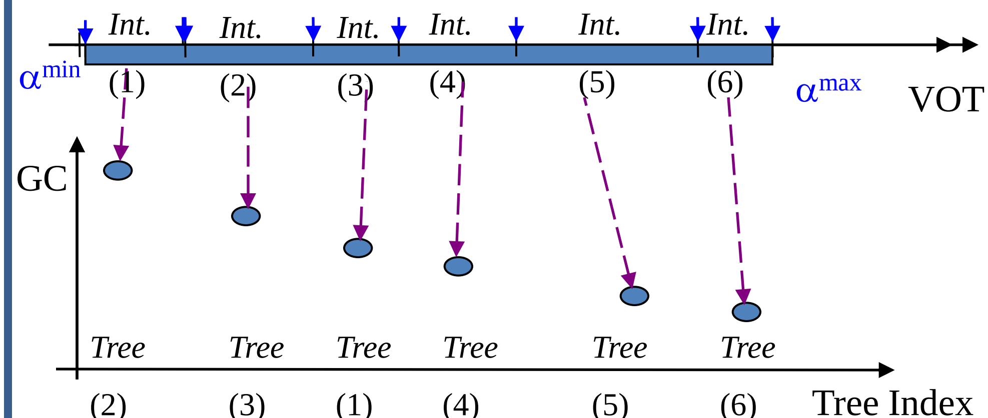
Output: for each dest. j
- A path tree
- VOT Breakpoints

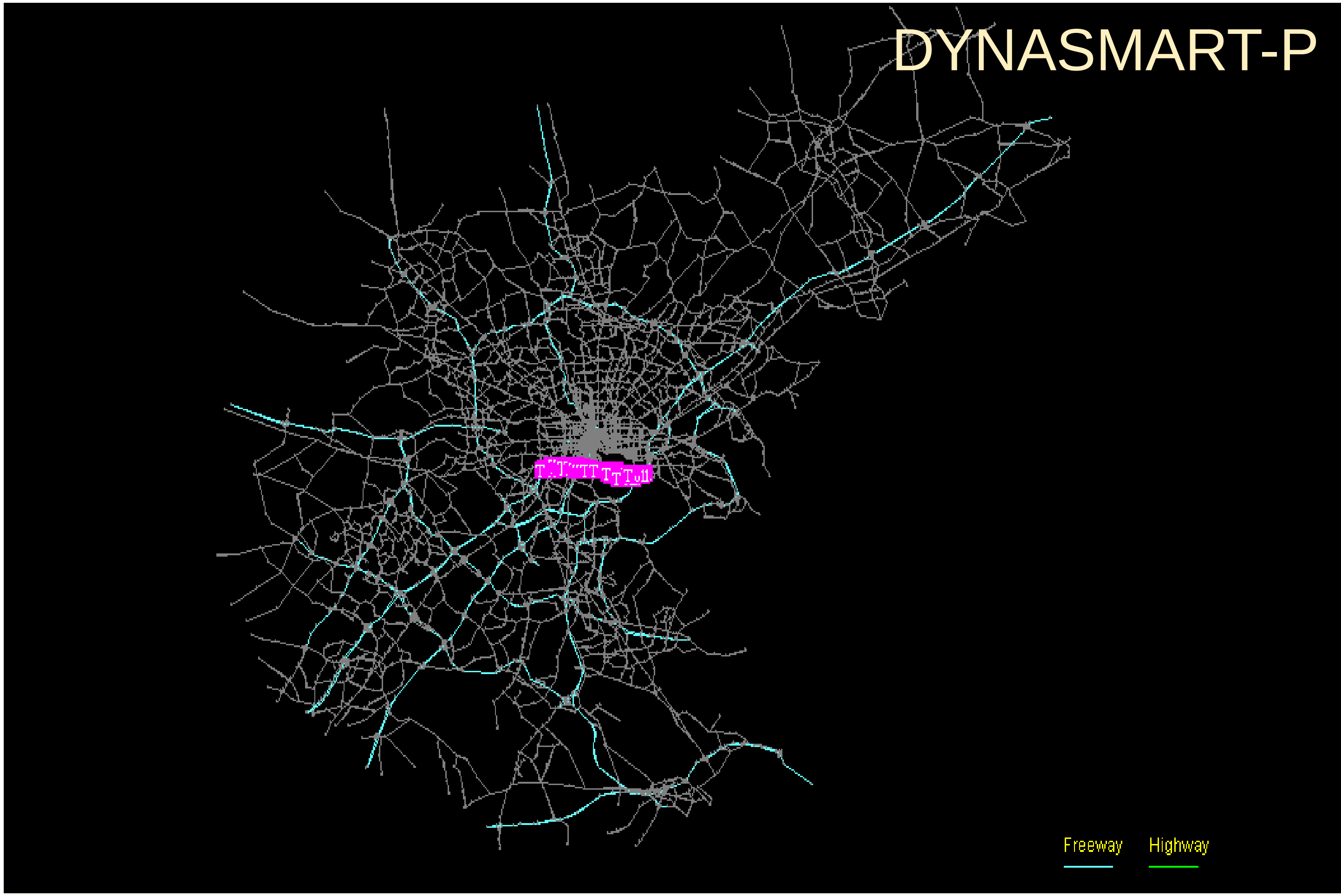




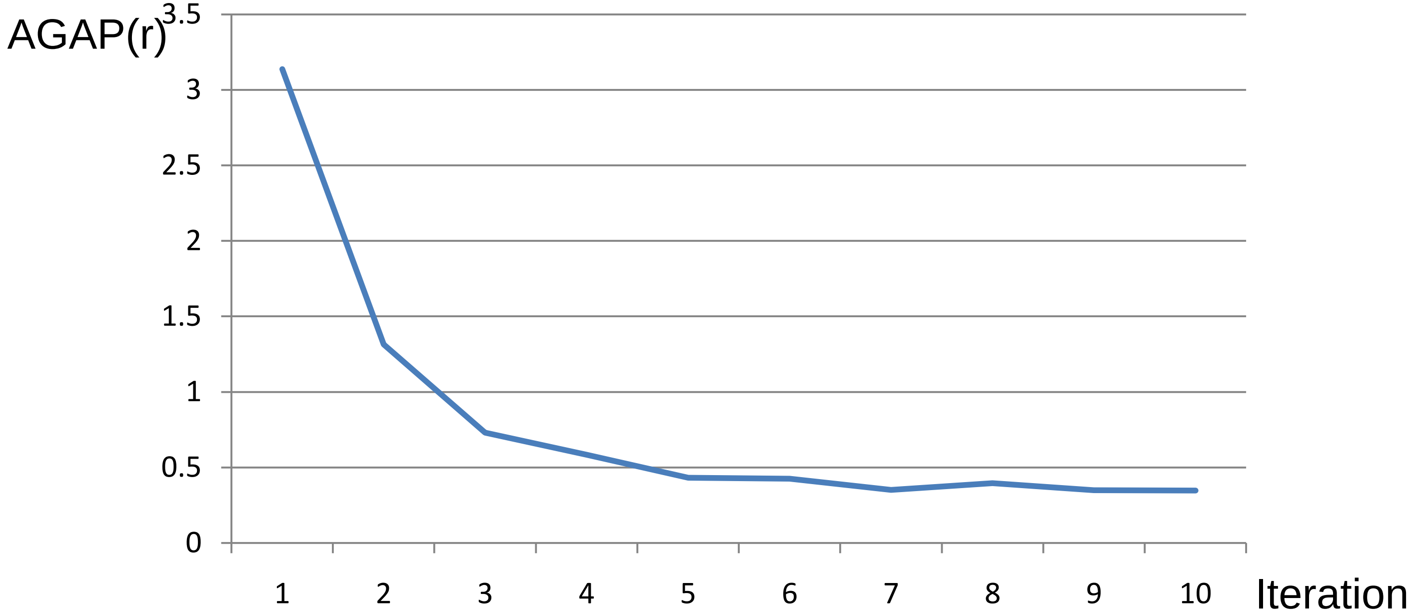
Numerical Results: Baltimore Network

Application of MDUE Procedure with Heterogeneous Users

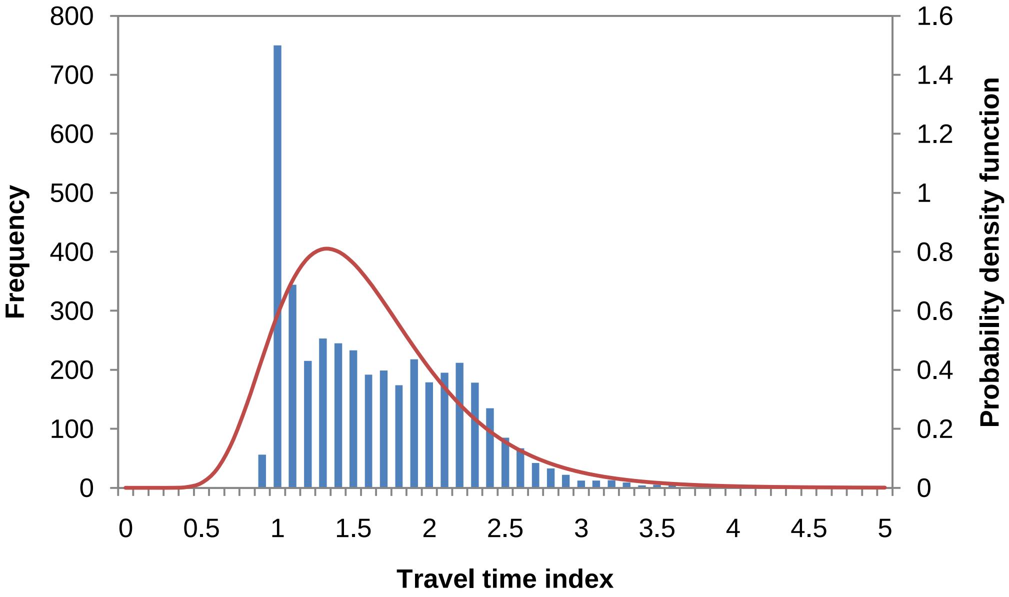
- 6,825 nodes
- 14,317 links
- 570 zones
- Dynamic toll on I-95
- 2-hour (7-9Am) morning peak time-varying OD demand with 898,878 vehicles



Convergence Pattern



Generate Reliability as Network LOS



Challenges in Characterizing Network Variability and Correlations

- Representation of the travel time variability through the network's links and nodes
  - Variability of link travel times
  - Variability of delays associated with movements through the intersections, particularly left-turns
- Strong correlation between travel times in different parts of the network
  - Adjacent links are more likely to experience high delays in the same general time period than unconnected links
  - Difficult to capture these correlation patterns when only link level measurements are available
  - Difficult to derive path-level and OD-level travel time distributions from the underlying link travel time distributions

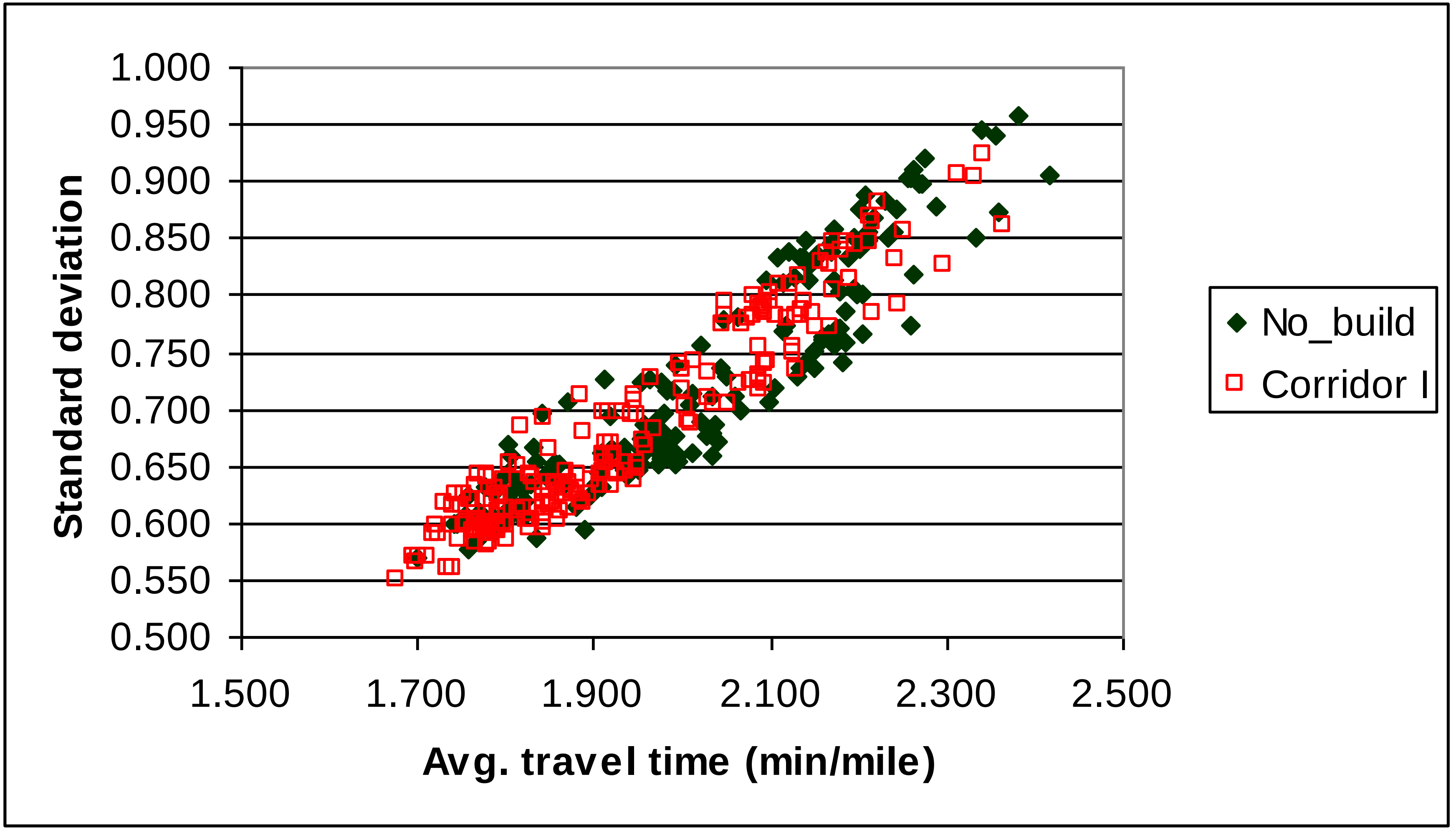
Travel Reliability Measure

- Given a path set for each (i,j,τ) for a given possible VOT range by PAM, we re-evaluate the path generalized cost by adding a travel time reliability measure $TV_{i,j}^{\tau}$
- In current implementation, exploit relation between std dev per unit distance and mean time per unit distance at network level
- In future work, could estimate std dev per unit distance and mean time per unit distance for specific O-D's and paths from simulation results

Travel Time Reliability

Standard Deviation vs. Average Travel Time (per mile)

(Greater Washington, DC network: OD level variability)

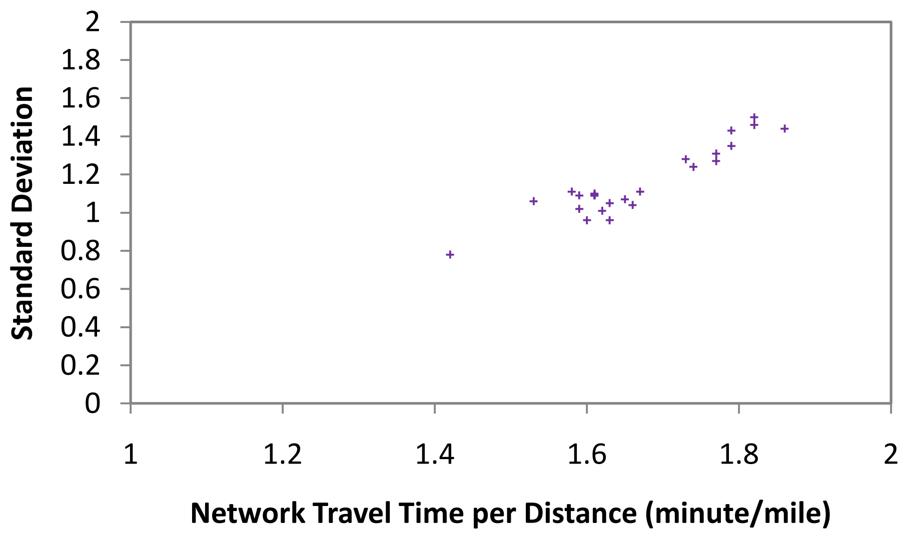


Irvine Network

- Network
  - Freeways I-405, I-5, state highway 133
  - 326 nodes
  - 626 links
  - 61 TAZs
- Demand
  - Two hours morning peak (7-9AM)

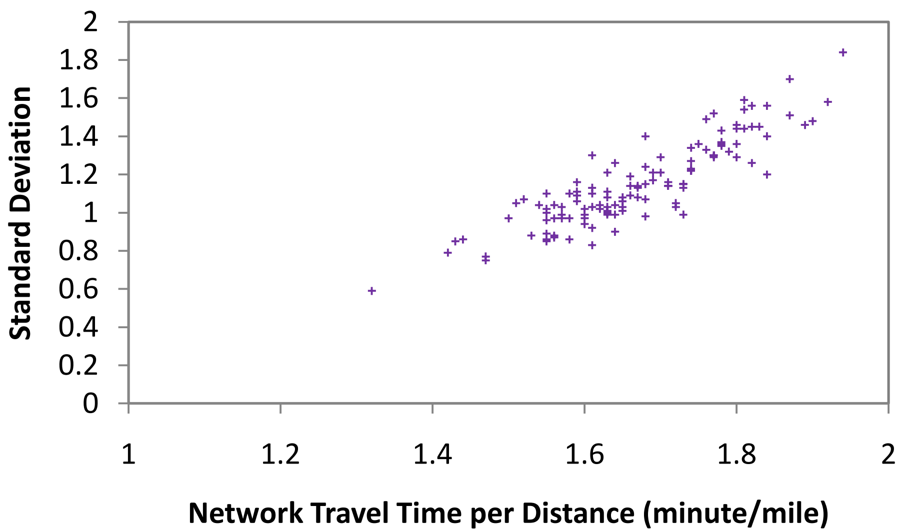
Network Travel Time per Unit Distance and Standard Deviation (5 minute interval)

- Each data point represents the mean and standard deviation of travel times per mile for all vehicles departing in 5-minute interval.
- 24 data points for 2-hour demand



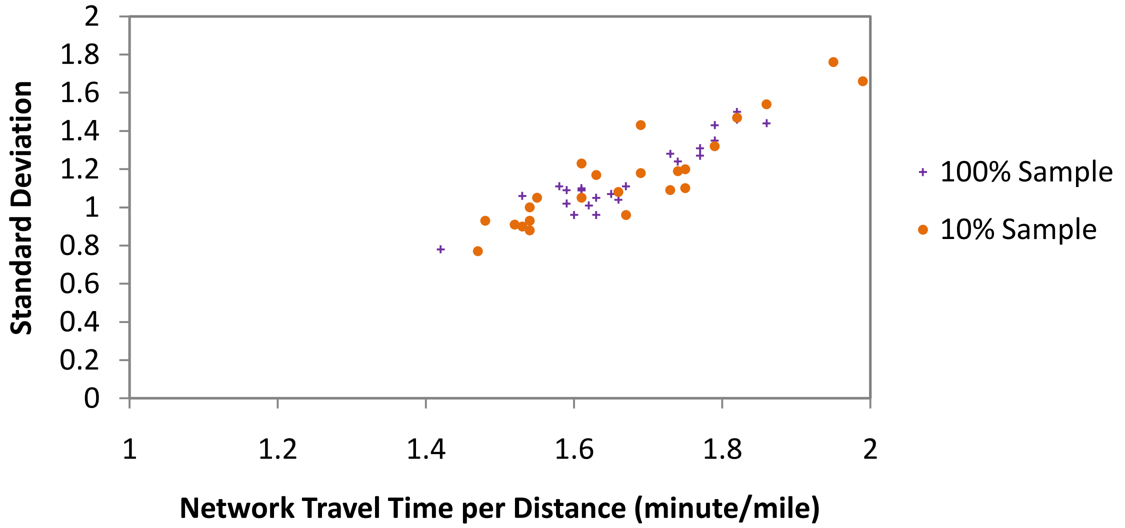
Network Travel Time per Distance and Standard Deviation (1 minute interval)

- Each data point represents the mean and standard deviation of travel times per mile for all vehicles departing in 1-minute interval.
- 120 data points for 2-hour demand



Network Travel Time per Distance with Sampling Vehicles

- Each data point represents the mean and standard deviation of travel times per mile for all vehicles departing in 5-minute interval.
- 24 data points for 2-hour demand



Vehicle Trajectories: Unifying Framework for Micro and Meso Simulation

- Vehicle trajectory contains the traffic information and itinerary associated with each vehicle in the transportation network, including
  - a set of nodes (describing the path)
  - the travel time on each link along the path
  - the stop time at each node
  - the cumulative travel/stop time
  - possibly lane information

```
****  Output file for vehicles trajectories   ****
==================================================
This file provides all the vehicles trajectories
Veh #   16645 Tag= 2 OrigZ=    5 DestZ=    9 Class= 5 UstmN=    103
DownN=     102 DestN=      11 STime=  70.20 Total Travel Time=
8.49 # of Nodes=  18 VehType 1 LOO 1
    102     160     102     103     151      97      89       4       3
24
      5      27      28      32      35      39      40      11
 ==>Node Exit Time Point
   0.80    0.90    1.60    2.20    3.00    3.40    3.80    5.00    5.50
5.90
   6.00    6.30    6.70    7.10    7.30    7.60    8.20    8.40
 ==>Link Travel Time
   0.80    0.10    0.70    0.60    0.80    0.40    0.40    1.20    0.50
0.40
   0.10    0.30    0.40    0.40    0.20    0.30    0.60    0.20
 ==>Accumulated Stop Time
   0.60    0.60    1.20    1.36    1.42    1.44    1.47    2.22    2.57
2.57
   2.57    2.57    2.57    2.57    2.57    2.57    2.57    2.57
```

Obtain Vehicle Trajectories from Simulation Models

- Vehicle trajectories could be obtained from all particle-based simulations, regardless of whether the physics underlying vehicle propagation and interactions are captured through microscopic maneuvers or through analytic forms
  - Microscopic simulation models move traffic by capturing individual driver maneuvers such as car following, overtaking, lane changing and gap acceptance decisions.
  - Mesoscopic simulation models move vehicles as individual particles, albeit according to (macroscopic) relations among average traffic stream descriptors (e.g. speed-density relations).
- The realm between micro and meso has narrowed considerably over time—and will continue to do so.
- Trajectories could also be obtained from direct measurement in actual networks: video camera, cell-phone/GPS probes, etc…
- This enables consistent theoretical development in connection with empirical validation (for L04)

Application of Integrated Procedures to New York Regional Network

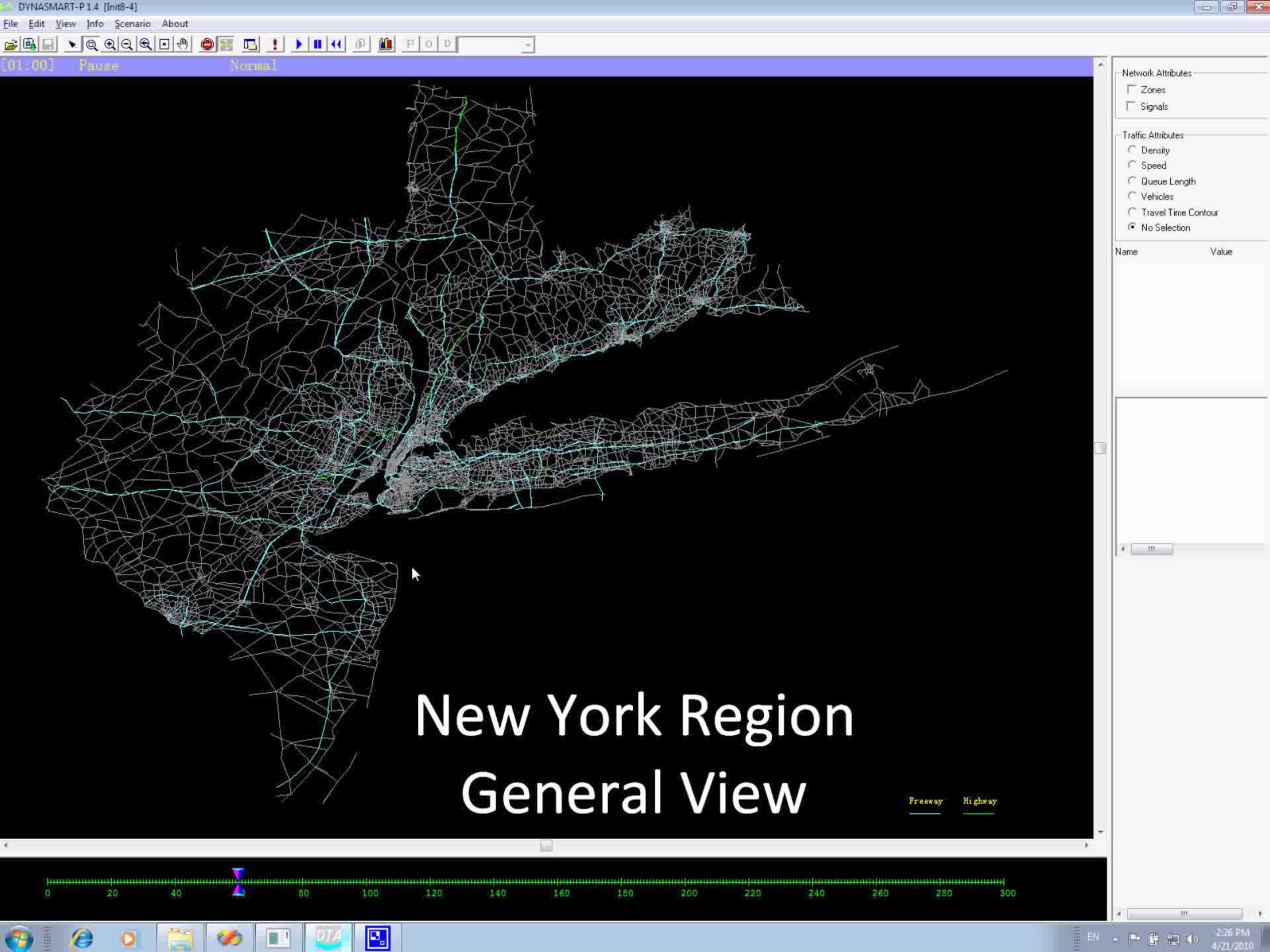
Apply demand and user response models developed
In SHRP-2 Project C04 (w. P. Vovsha, PB Inc.) for NY Metro network:

- 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 and heterogeneous users to very large scale network

~30,000 Nodes
95,000 Links
3,700 Zones

6-hour AM peak period
5.2 M simulated vehicles


DYNASMART-P 1.4 [Init8-4]
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[01:00] Pause Normal
Network Attributes
Zones
Signals
Traffic Attributes
Density
Speed
Queue Length
Vehicles
Travel Time Contour
No Selection
Name
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New York Region
General View
Freeway
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0
20
40
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4/21/2010

CONCLUDING COMMENTS

- We have seen advances in state-of-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

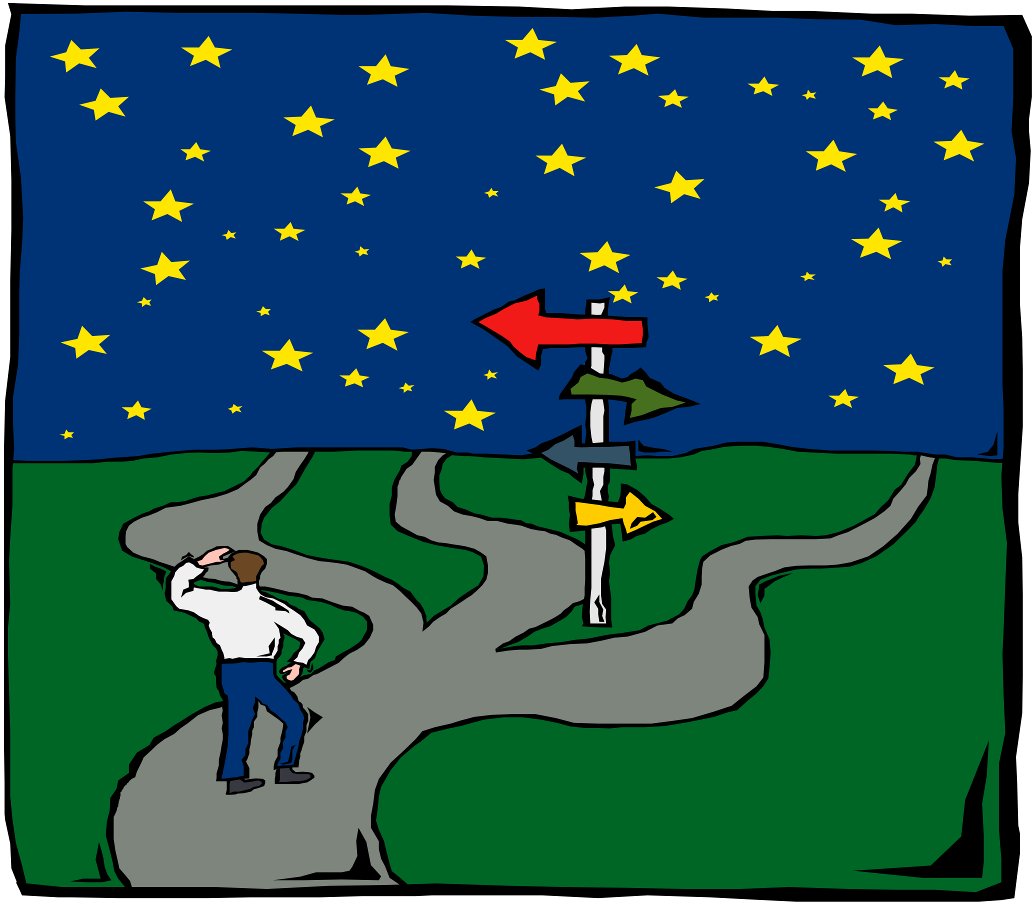
Integrated activity-based demand & network microsimulation

Process models of cognition and learning in networks

Demand forecasting for planning decisions

- Transportation planning has lacked a forecasting paradigm that recognizes the complex nature of the system and the limitations of available tools
- Behavioral models more for deriving insights and understanding behavior than to serve as crystal ball
- Greater uncertainty in the input (future technology, economy, spatial patterns, lifestyles) than in the tripmaking behavior of users *given* these inputs

Towards new forecasting paradigm...



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