DYNAMIC NETWORK MICRO-ASSIGNMENT WITH HETEROGENEOUS USERS

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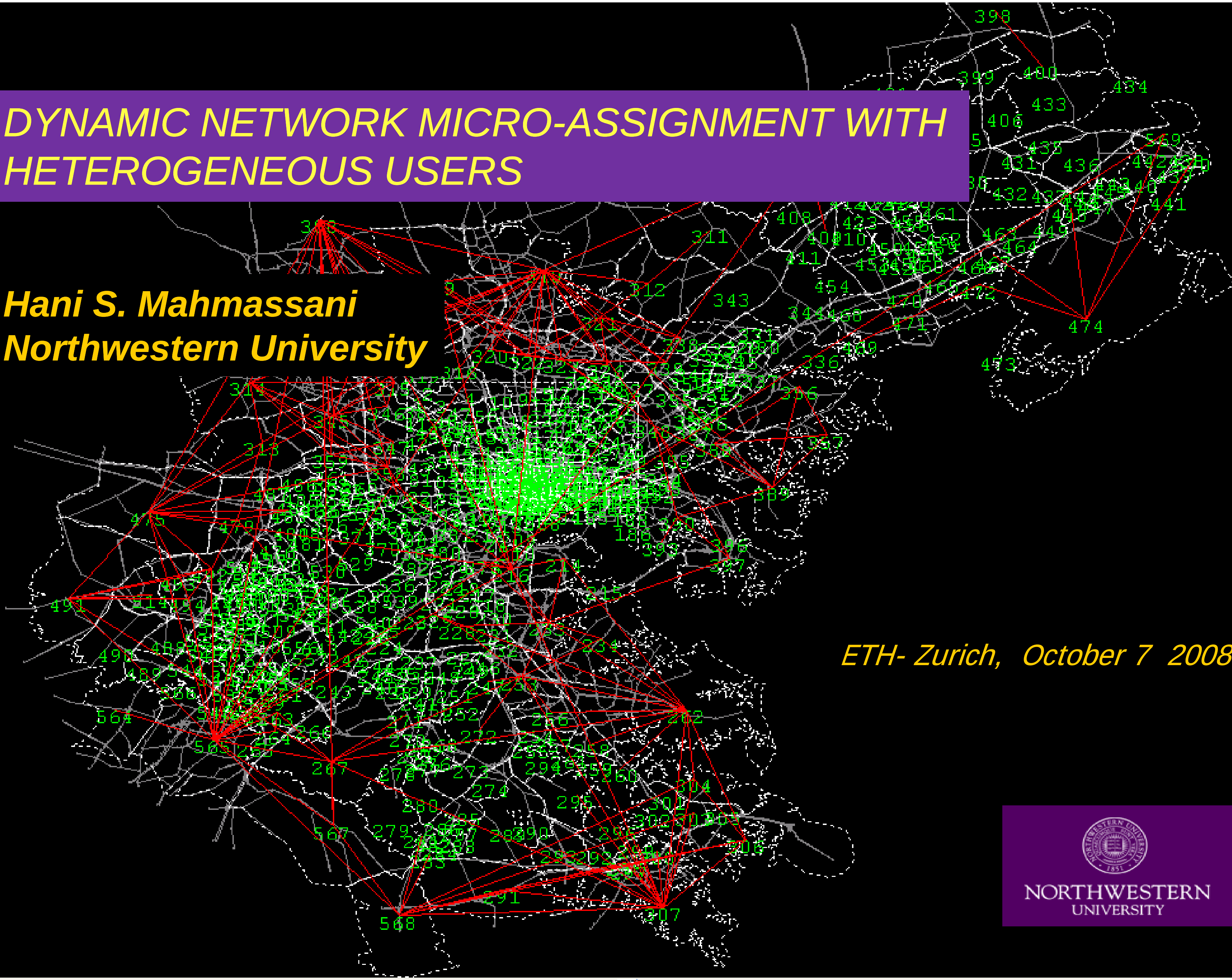

ETH- Zurich,   October 7 2008

NORTHWESTERN UNIVERSITY

INTEGRATING DEMAND AND SUPPLY

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“GIVE ME SUPPLY MODEL THAT IS RICH ENOUGH FOR MY DEMAND MODEL”

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"GIVE ME DEMAND MODELS THAT ARE PARSIMONIOUS ENOUGH TO FIT MY PLATFORM"

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INTEGRATING DEMAND AND SUPPLY

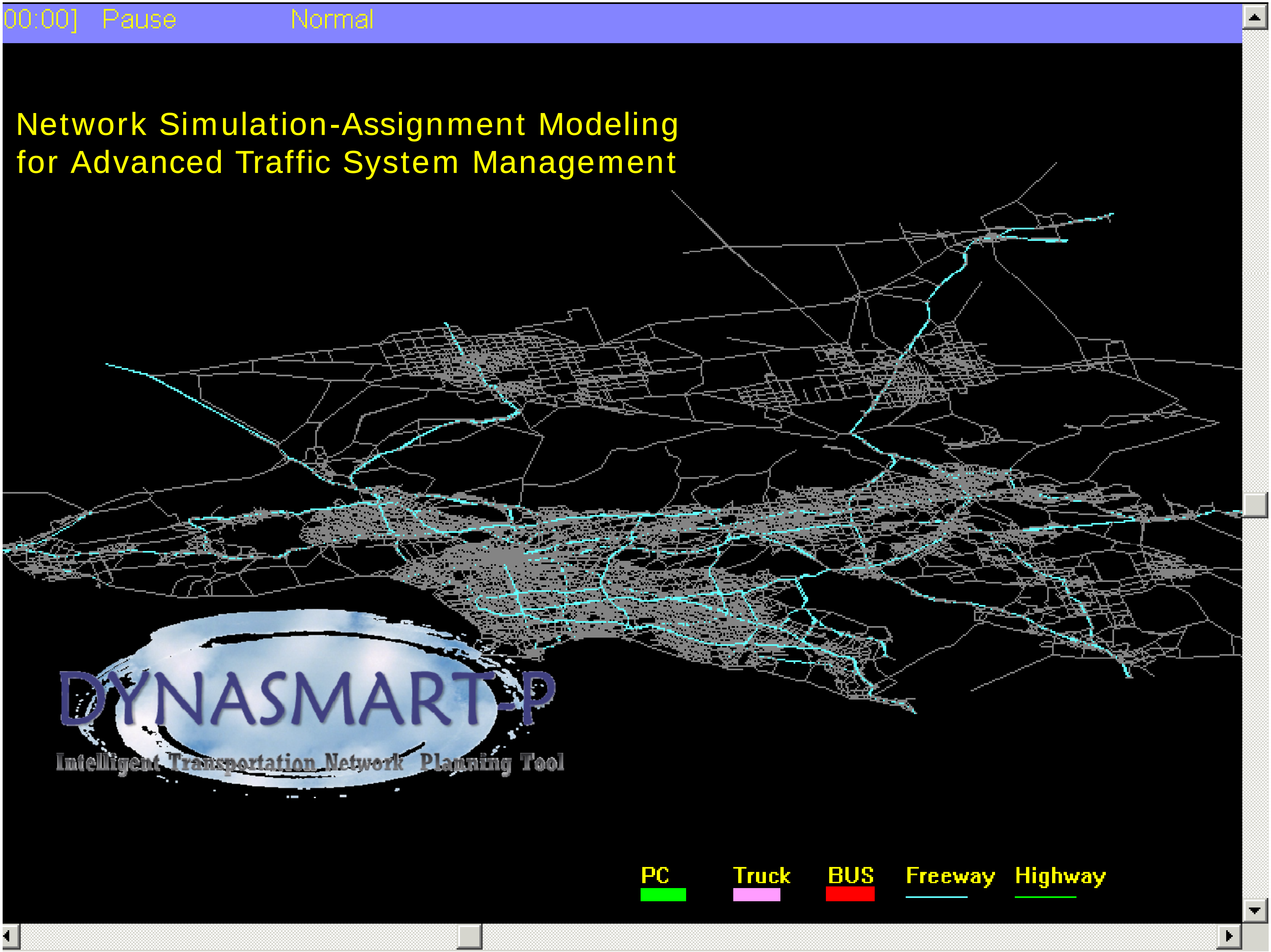
DISINTEGRATING DEMAND AND SUPPLY

DISINTEGRATING DEMAND AND SUPPLY

THE KEY IS THE PLATFORM:
SIMULATION-BASED DTA

CRITICAL LINK 1:
LOADING INDIVIDUAL TRIP CHAINS

CRITICAL LINK 2:
MODELING AND ASSIGNING HETEROGENEOUS USERS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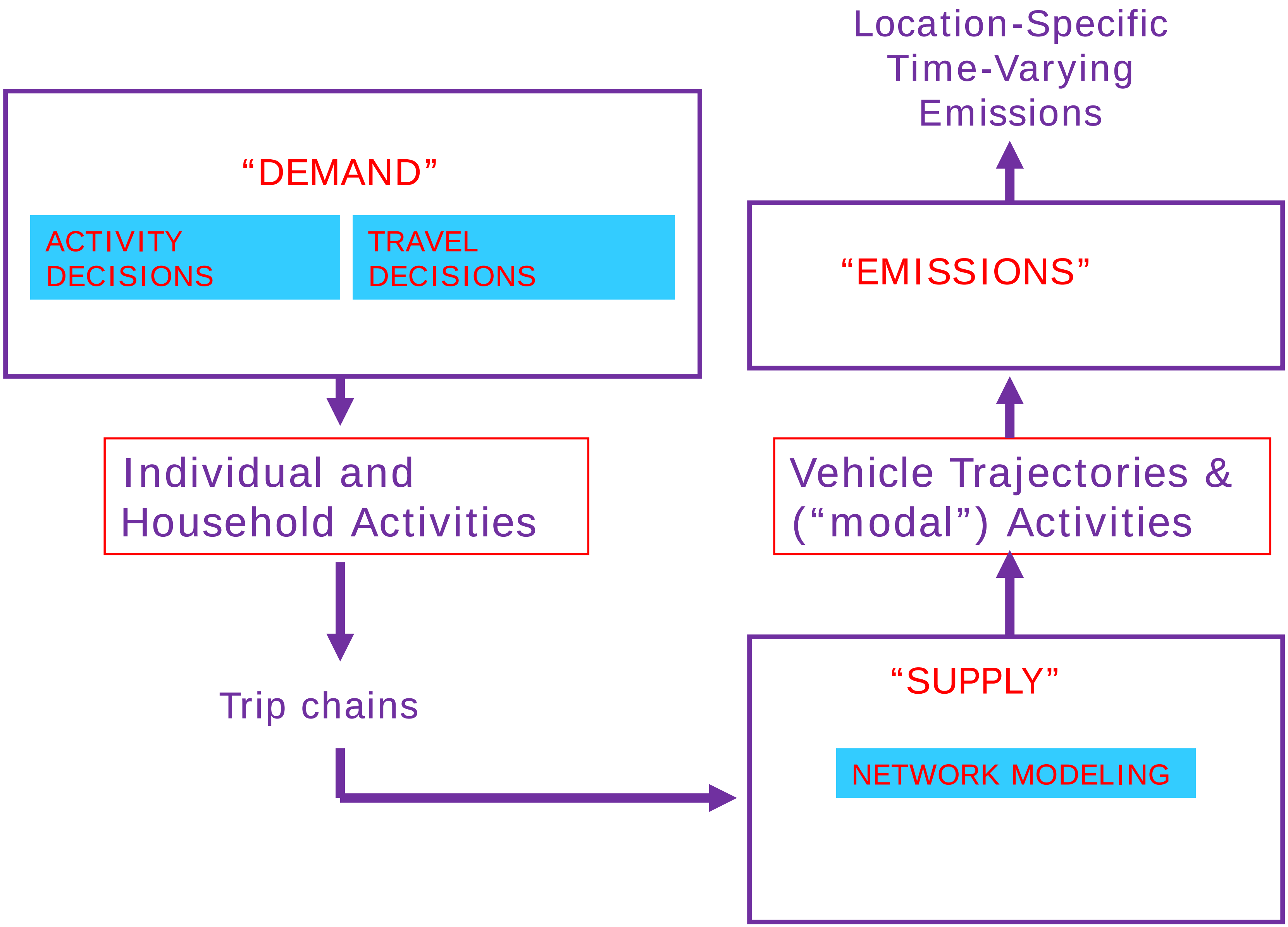
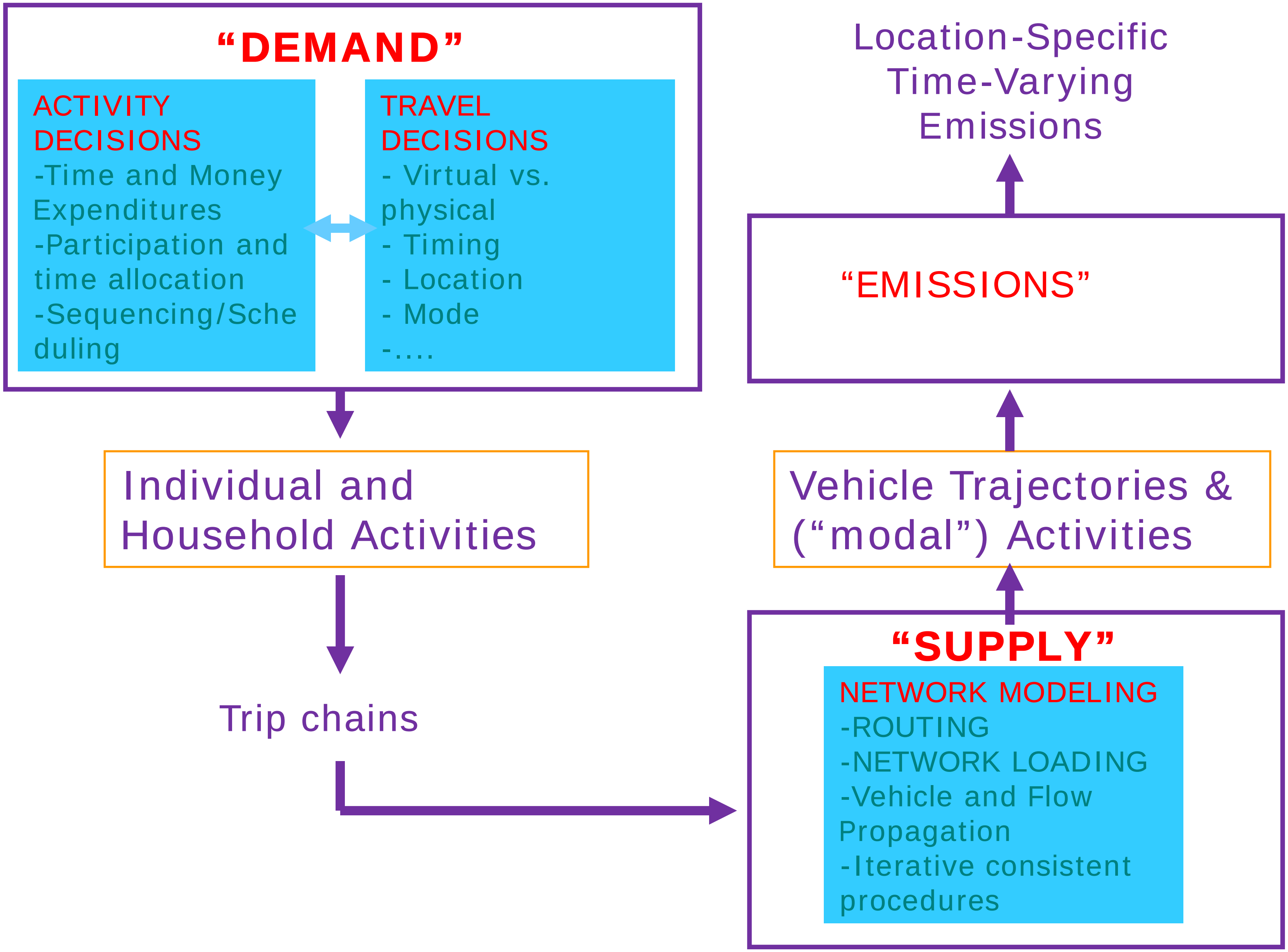
Network Simulation-Assignment Modeling
for Advanced Traffic System Management
DYNASMART-P
Intelligent Transportation Network Planning Tool
PC
Truck
BUS
Freeway
Highway

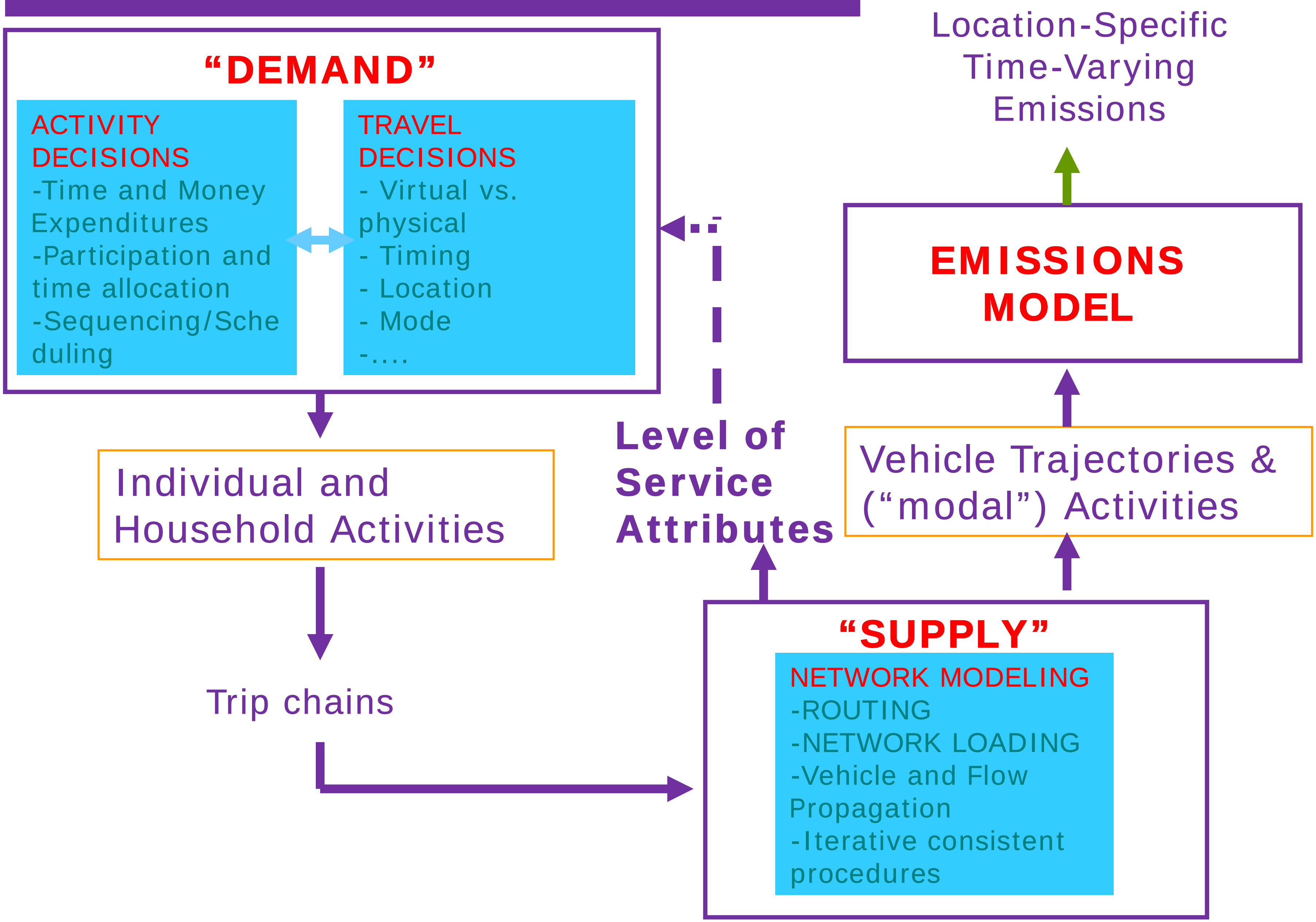
CONCEPTUAL FRAMEWORK



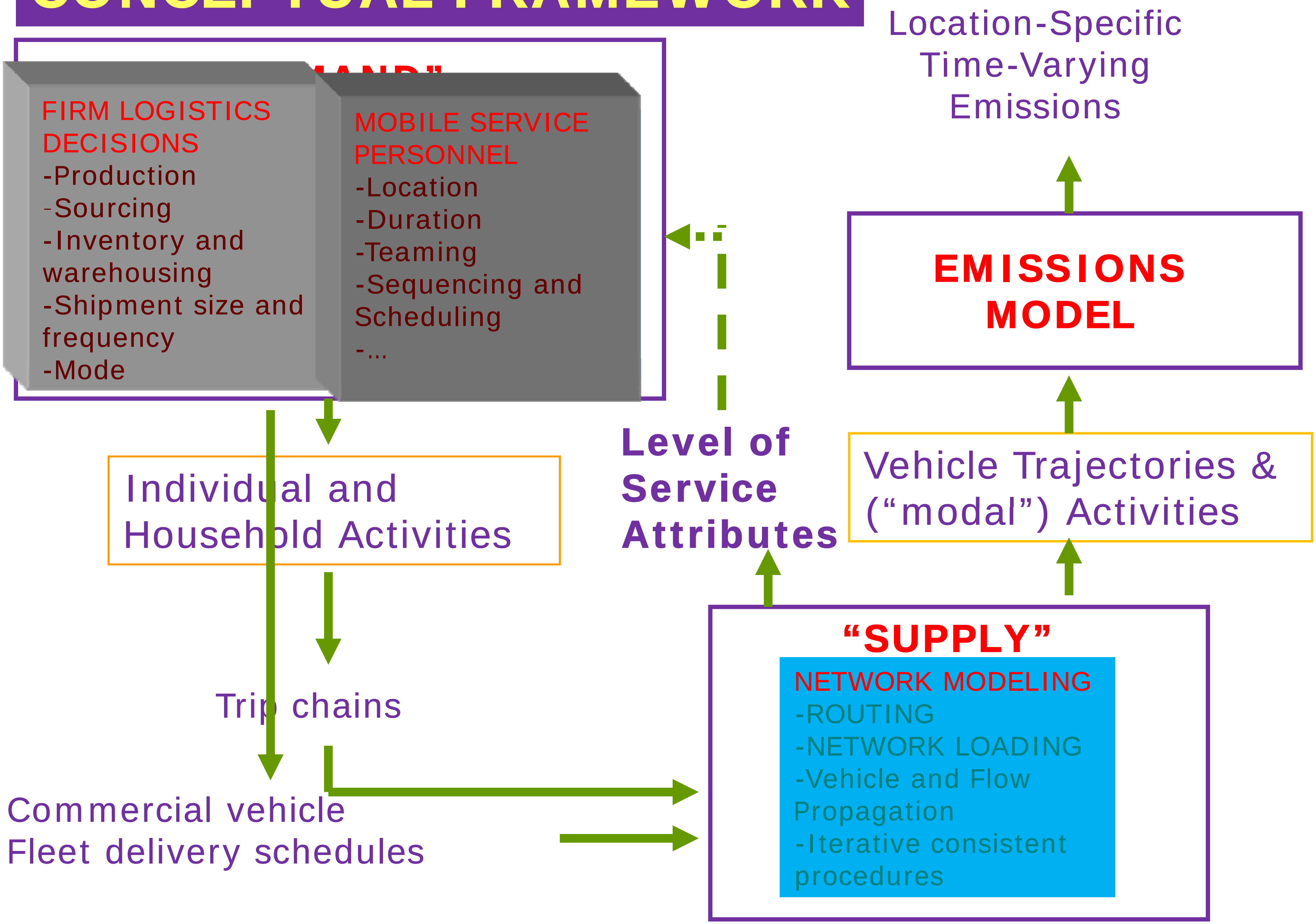
CONCEPTUAL FRAMEWORK

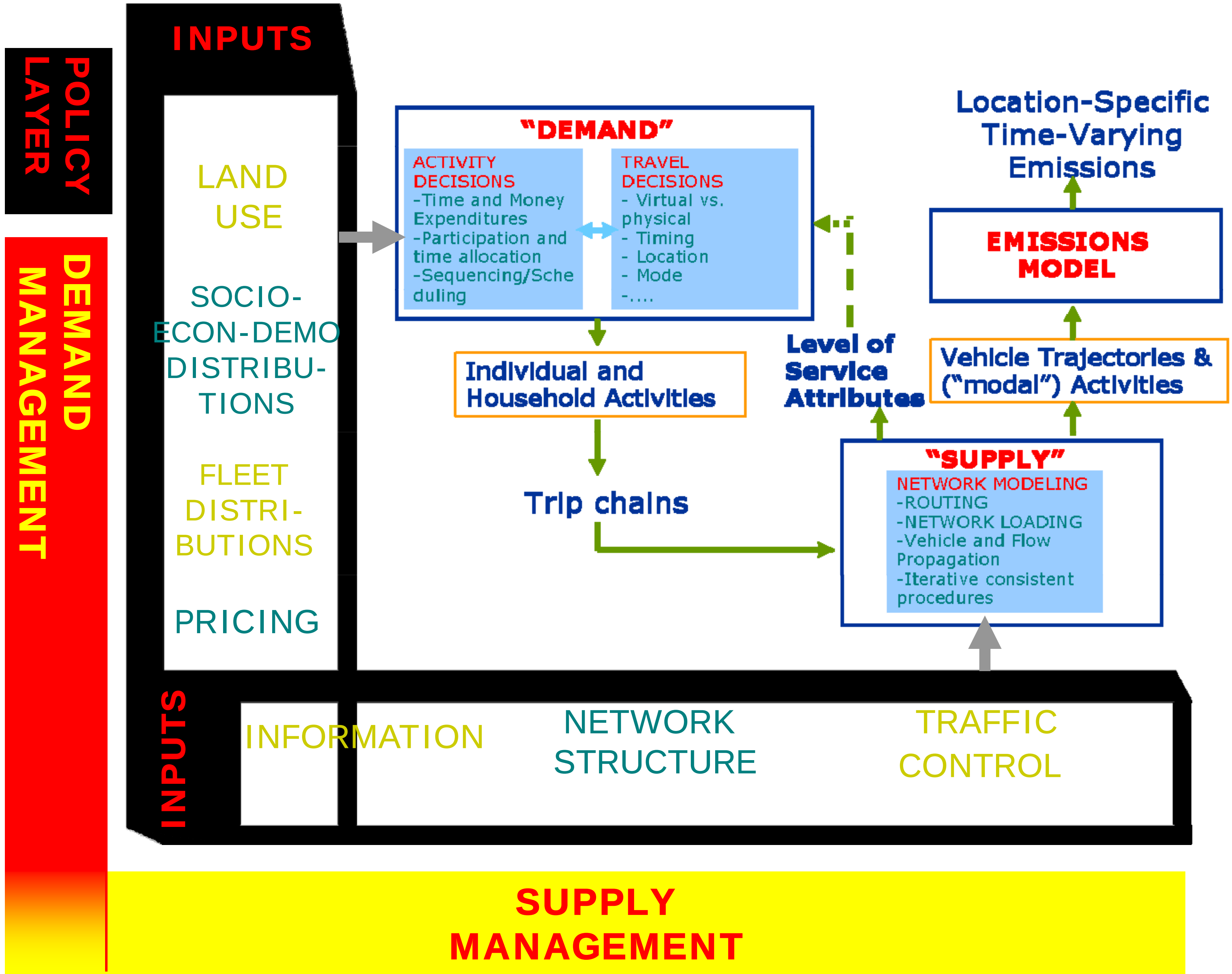


CONCEPTUAL FRAMEWORK



CONCEPTUAL FRAMEWORK




POLICY LAYER
DEMAND MANAGEMENT
INPUTS
LAND USE
SOCIO-ECON-DEMO DISTRIBU-TIONS
FLEET DISTRI-BUTIONS
PRICING
"DEMAND"
ACTIVITY DECISIONS
-Time and Money Expenditures
-Participation and time allocation
-Sequencing/Scheduling
TRAVEL DECISIONS
- Virtual vs. physical
- Timing
- Location
- Mode
-....
Individual and Household Activities
Trip chains
Level of Service Attributes
Location-Specific Time-Varying Emissions
EMISSIONS MODEL
Vehicle Trajectories & ("modal") Activities
"SUPPLY"
NETWORK MODELING
-ROUTING
-NETWORK LOADING
-Vehicle and Flow Propagation
-Iterative consistent procedures
INPUTS
INFORMATION
NETWORK STRUCTURE
TRAFFIC CONTROL
SUPPLY MANAGEMENT

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 beginning to break out of University research into actual application– market still small, fragmented, with many competing claims and absence of standards:

   - existing static players adding dynamic simulation-based capabilities, e.g. INRO (DYNAMEQ); Caliper (Transcad); CUBE (Voyager)

   - existing traffic microsimulation tools adding assignment (route choice) capability, e.g. AIMSUN-NG; VISSIM/VISUM

   - standalone simulation-based DTA tools, e.g. DYNASMART-P (distributed by FHWA); VISTA (tie in w. PTV-VISSIM)

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

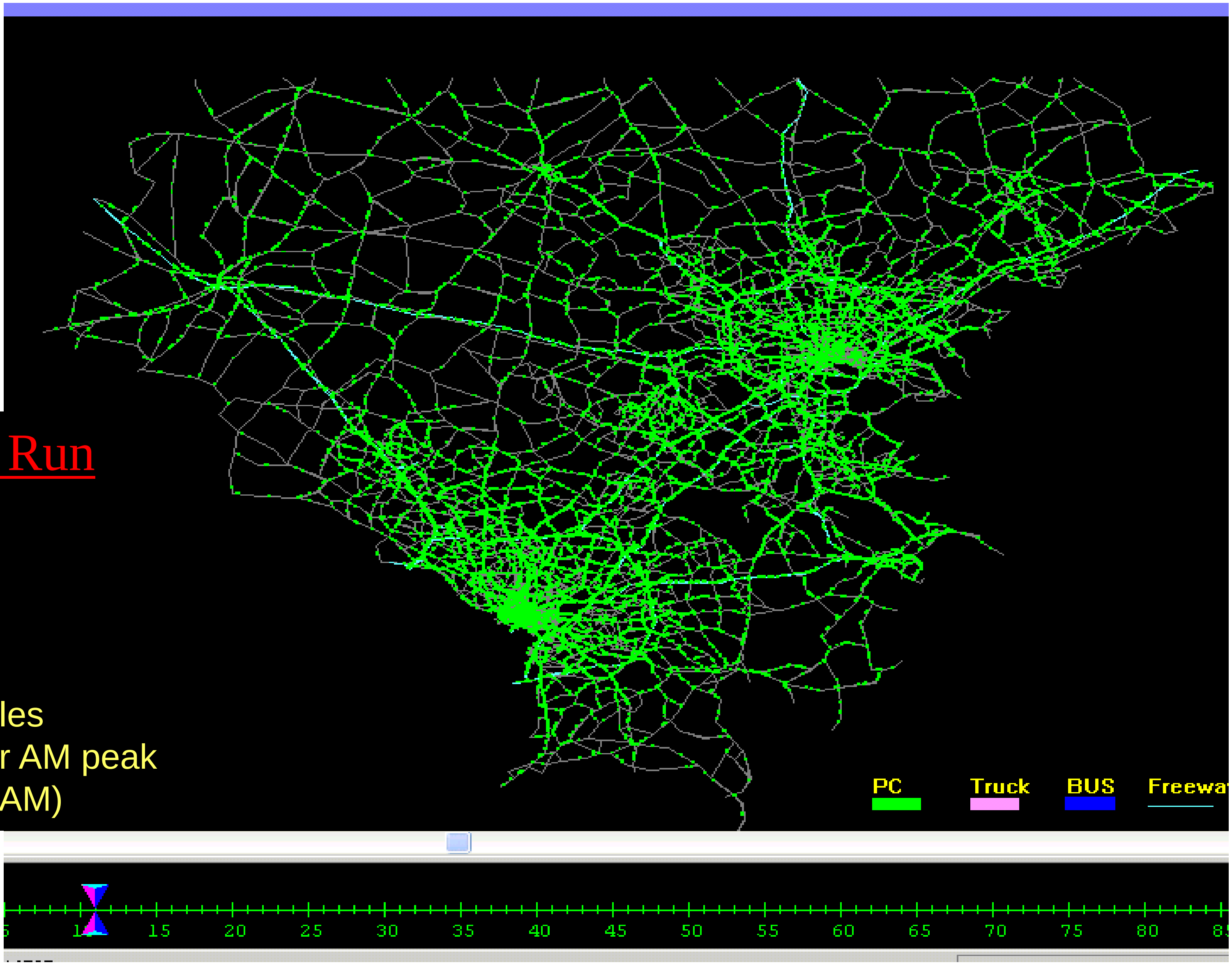
5. Existing commercial software differs widely in capabilities, reliability and features; not well tested.

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

7. 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 entitities, but according to traffic flow relations among averages (macroscopic speed-density relations): faster execution, easier calibration
- Ability to load trip chains (only tool with this capability, essential to integrate with activity-based models)

APPLICATION TO BALTIMORE REGIONAL NETWORK



DTA Model Run

25,375 links

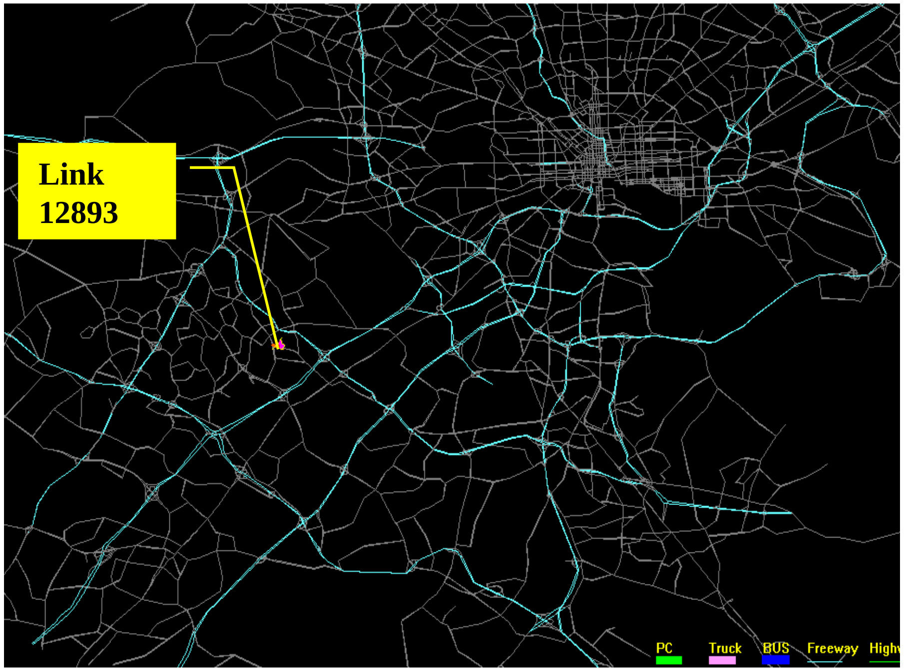
11,170 nodes

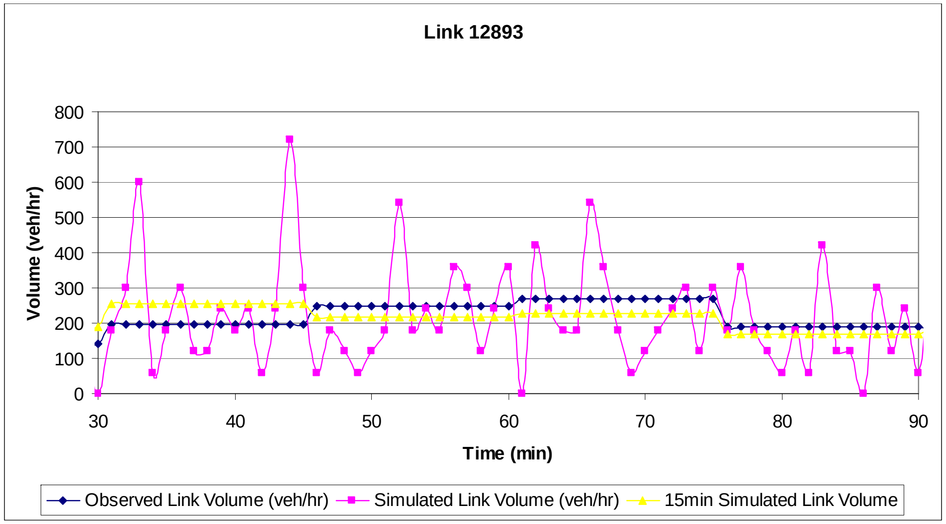
1,463 TAZs

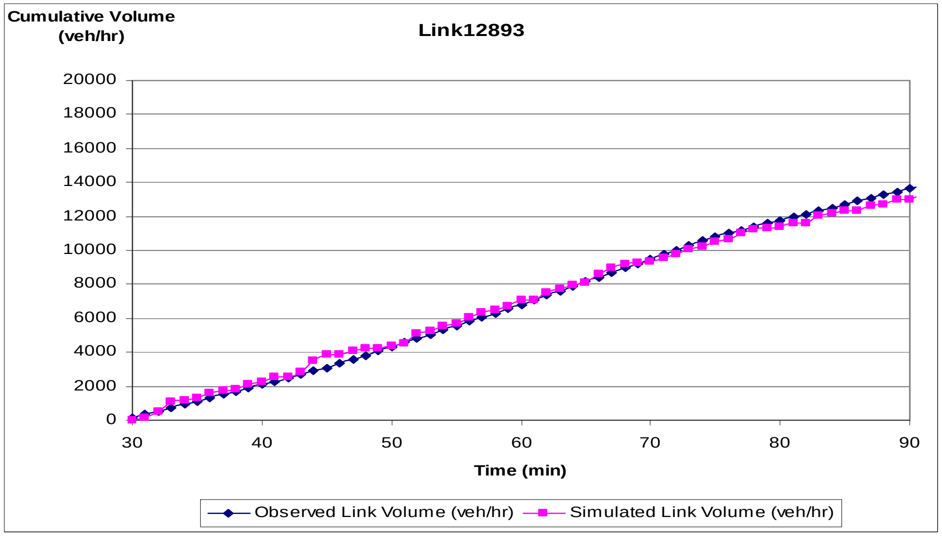
1,901,000 vehicles generated for AM peak period (6-10 AM)

OD Estimation performance on selected links

Estimation performance for link 12893 (MD 108 at Old Stockbridge Dr/Golden Bell Way)

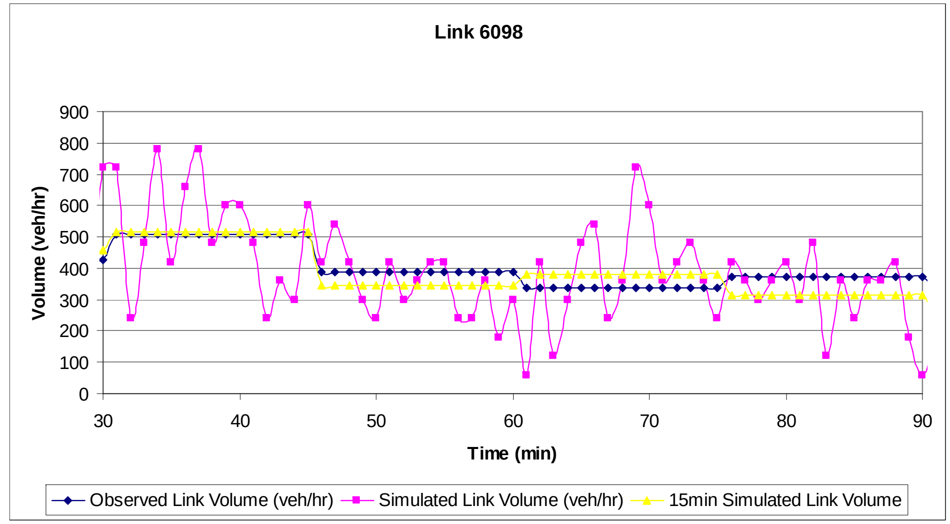


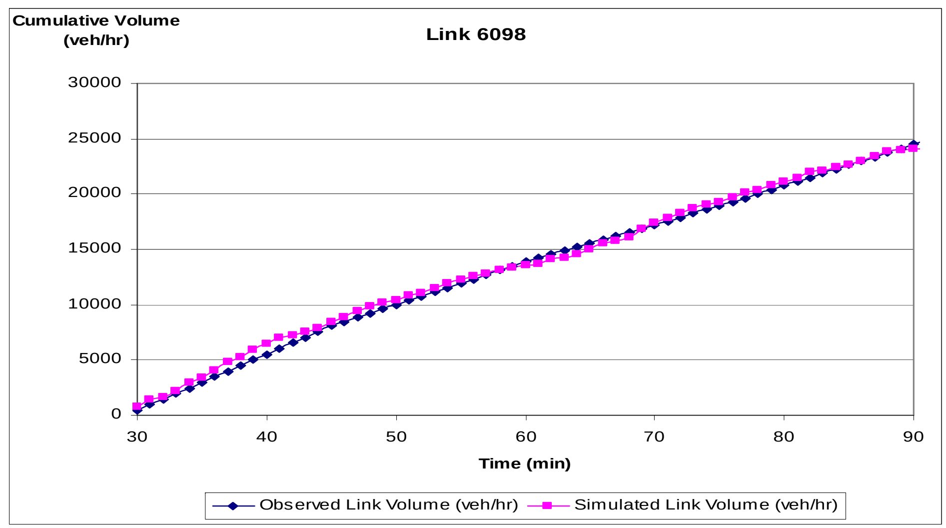




OD Estimation performance on selected links (ctd.)

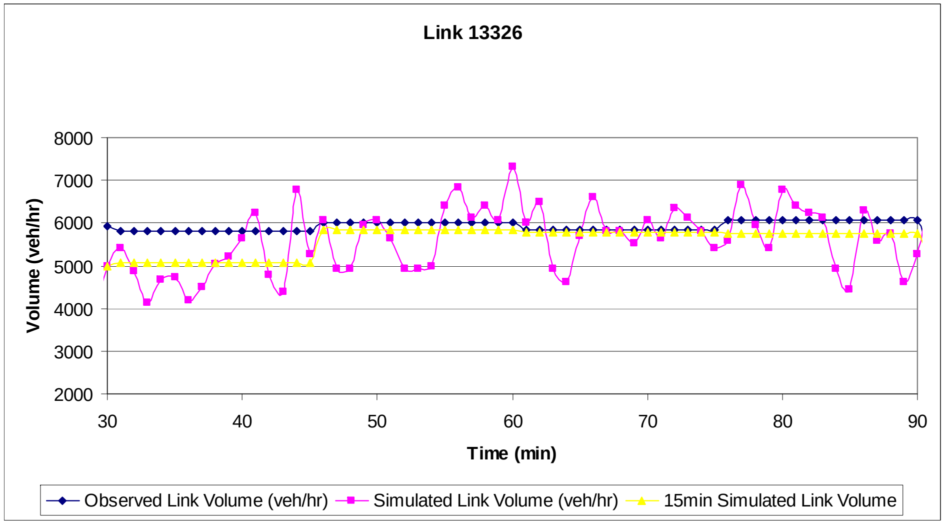
Estimation performance for link 6098
(Hospital Dr at Oakwood Rd)

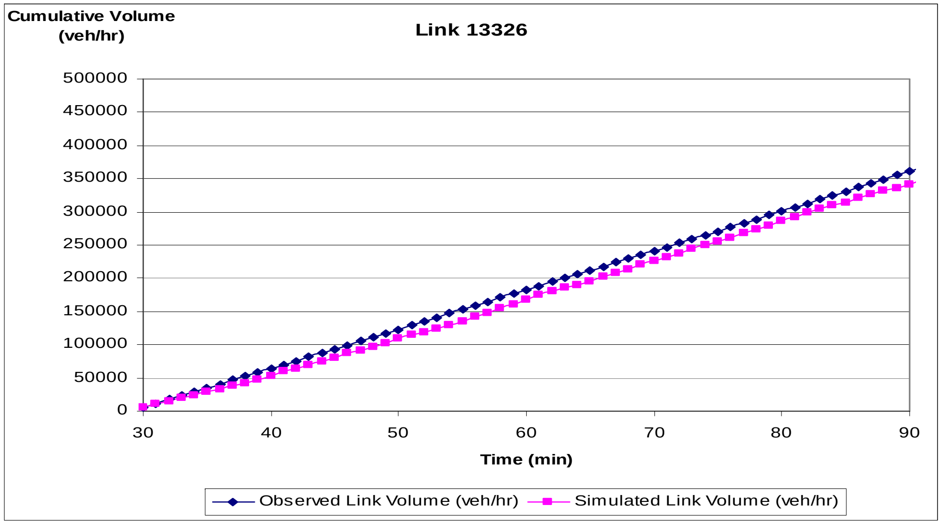




OD Estimation performance on selected links

Estimation performance for Link 13326 (I-95 NB @ MD Welcome Center North)





DISINTEGRATING DEMAND AND SUPPLY

THE KEY IS THE PLATFORM:

SIMULATION-BASED DTA

CRITICAL LINK 1:

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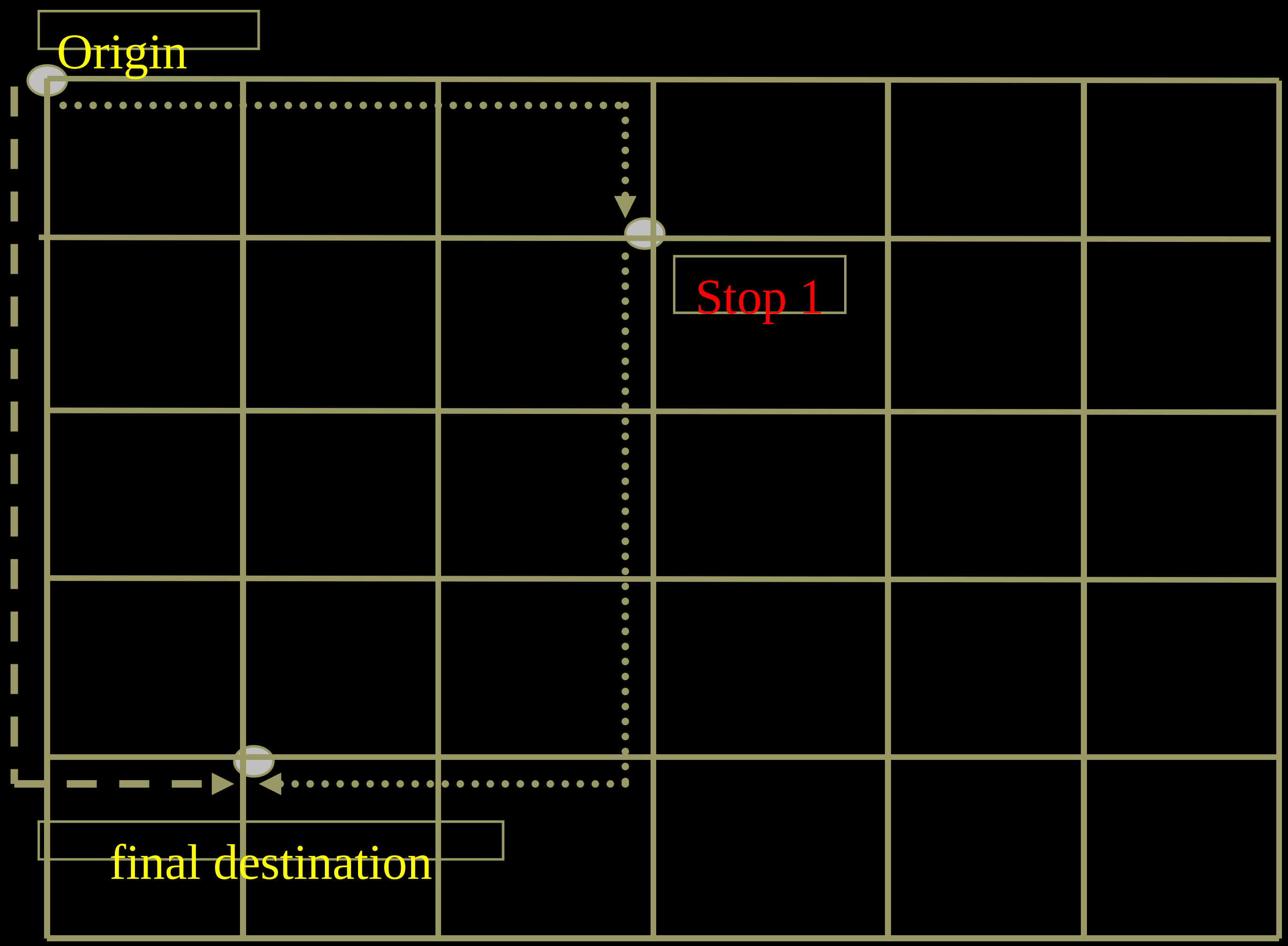
A critical missing link: modeling activity/trip chains in network assignment models



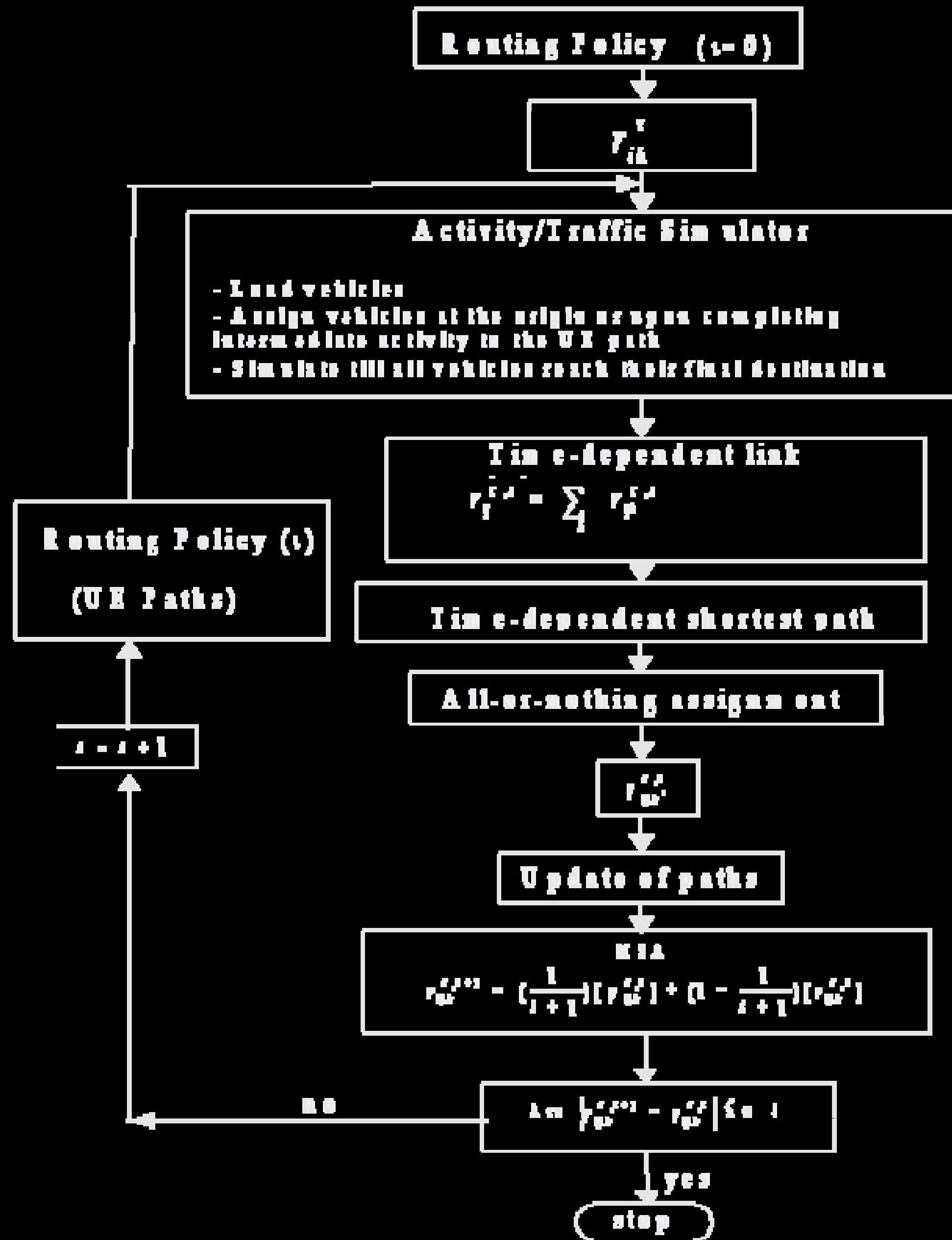
Dynamic Micro-Assignment of Travel Demand with Activity/Trip Chains

based on work with Ahmed Abdelghany,
PhD Dissertation at UT-Austin

Capabilities/Operational Modes

Choice Dimension		Path Choice Based on Prevailing Conditions	UE Path Choice	Joint Choice of Departure Time and Path	Joint Choice of Departure Time, Path, and Sequence of Activities
Spatial Assignment	Model 1	X			
	Model 2		X		
Temporal-Spatial Assignment	Model 1			X	
	Model 2				X

Stochastic Temporal-Spatial Micro-Assignment of Travel Demand with Activity/Trip Chains


Routing Policy (s=0)
Activity/Traffic Simulator
- Load vehicles
- Assign vehicles at the origin or upon completing intermediate activity to the UE path
- Simulate till all vehicles reach their final destination
Time-dependent link
Routing Policy (s)
(UE Paths)
Time-dependent shortest path
All-or-nothing assignment
Update of paths
MSA
no
yes
stop

Critical Link 2:

Modeling and assigning heterogeneous users--

exercising user preferences for path-based attributes

Essential Aspect of User Response Not Considered in Existing Network Modeling Methods

User Heterogeneity

- Critical limitation of existing dynamic traffic assignment tools
  - Each trip-maker chooses a path that minimizes the two major path travel criteria: travel time and out-of-pocket cost (path generalized cost).
  - 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

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.

3. Some recent developments with DYNASMART-P:

   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 equilibrium framework

Recent Methodological Development

- Develop Multi-Criterion Simultaneous Route and Departure Time User Equilibrium (MSRDUE) models and algorithms
  - Address the heterogeneous user preference of path and/or departure time choices in response to time-varying toll charges.
  - Capture traffic flow dynamics and spatial and temporal vehicular interactions (simulation-based approach).
  - Adhere to the time-dependent generalization of Wardrop's UE principle (gap function measures the deviation from equilibrium).
  - Be deployable on road traffic networks of practical sizes (vehicle-based implementation technique).

Problem Statement

- Assumptions:
  - G(*N*, *A*), discretized planning horizon, and time-dependent link tolls.
  - Define schedule delay as the difference between actual and preferred arrival times (PAT).
    - Every trip-maker has his/her own PAT interval θ
    - Early schedule delay (ESD) and late schedule delay (LSD)
    - Value of ESD (VOESD β) and value of LSD (VOLSD λ)
  - The experienced trip cost perceived by a trip-maker with θ, α, β, and λ

$$G_{odp}^{\tau}(\theta,\alpha,\beta,\lambda) = \underbrace{TC_{odp}^{\tau} + \alpha \times TT_{odp}^{\tau}}_{\text{Path generalized cost}} + \underbrace{\beta \times ESD_{odp}^{\tau}(\theta) + \lambda \times LSD_{odp}^{\tau}(\theta)}_{\text{Schedule delay cost}}$$

where $ESD_{odp}^{\tau}(\theta) = \max\{0, \theta^{lb} - \tau^{mid}\}$ $\quad LSD_{odp}^{\tau}(\theta) = \max\{0, \tau^{mid} - \theta^{ub}\}$

  - VOT α, VOESD β, and VOLSD λ are continuously distributed across trip-makers with given probability density functions and feasible ranges.

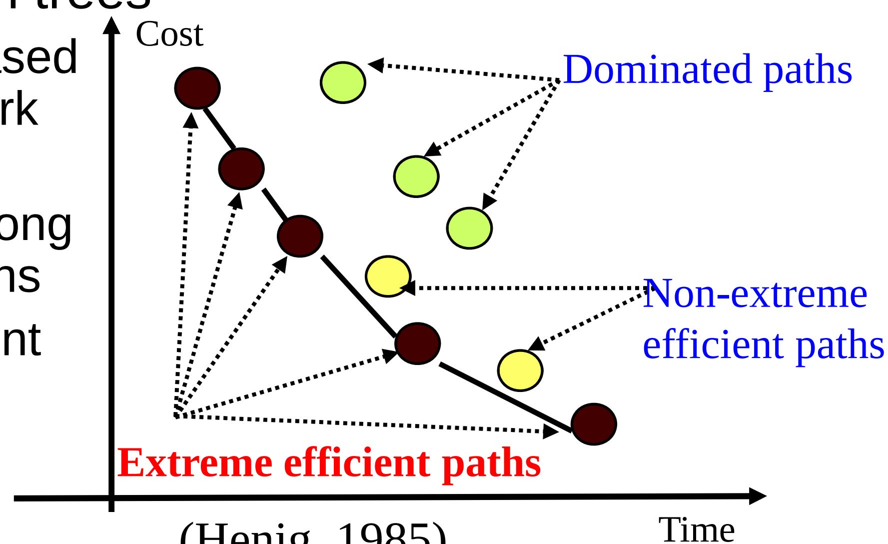
Problem Statement (ctd.)

- Departure time and path choice behavioral assumption:
  - Each trip-maker chooses the alternative that minimizes the experienced trip cost with respect to his/her PAT, VOT, VOESD, and VOLSD.
  - An alternative is a combination of arrival time interval and the corresponding least generalized cost path (that arrives the destination at that arrival time interval).
- Multi-criterion simultaneous route and departure time UE (MSRDUE)
  - For each OD pair, cannot decrease the experienced trip cost (given user's particular VOT, VOESD, VOLSD, and PAT interval) by unilaterally changing departure time and/or path.
    - Each trip-maker is assigned to the alternative that has the least trip cost with respect to his/her own PAT, VOT, VOESD, and VOLSD.
- MSRDUE problem:

  Under a given time-dependent road pricing scenario, solve for the departure time and path flow patterns satisfying the MSRDUE conditions.

Why is this problem difficult?

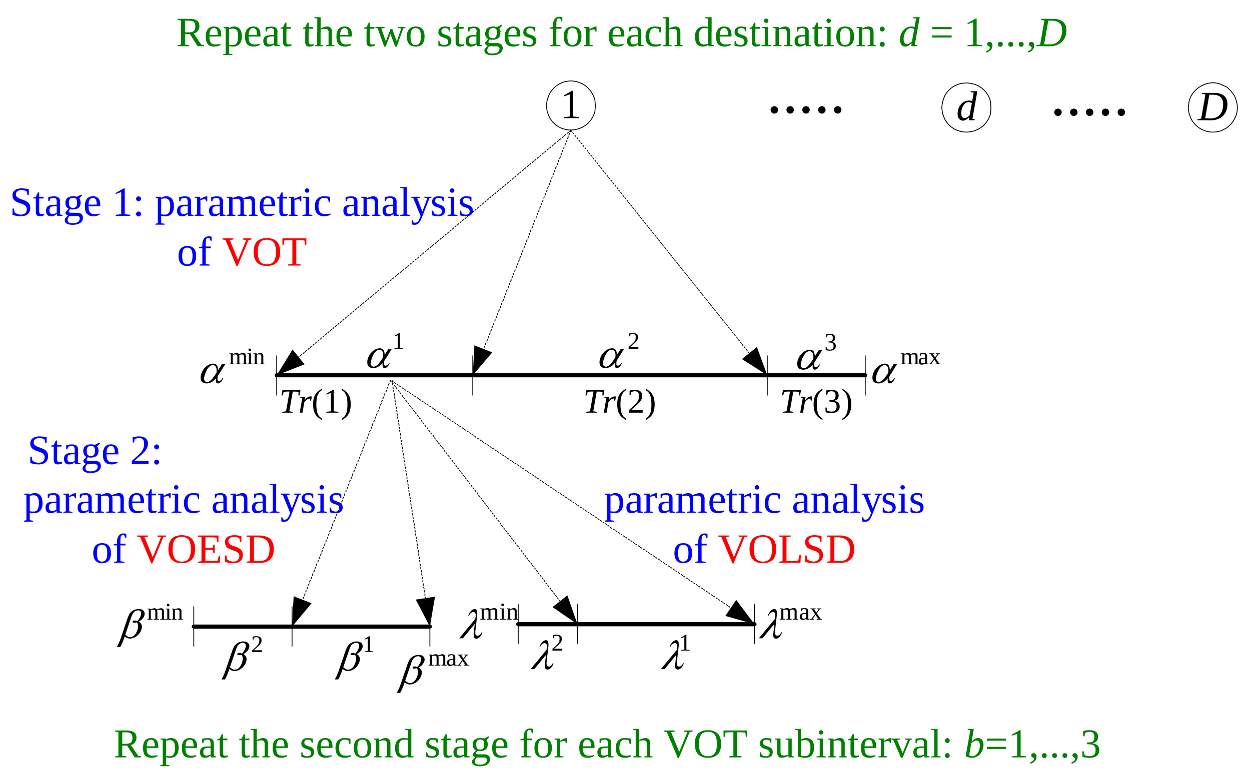
- Relaxation of VOT from constant to continuous random variable
  - Find an equilibrium state resulting from the interactions of (possibly infinite) many classes of trips, each of which corresponds to a class-specific VOT.
    - Computing and storing such a grand path set is computationally intractable and memory intensive in (road) network applications of practical sizes
  - Parametric Analysis Method (PAM) to find the set of extreme efficient (or non-dominated) path trees
    - In the disutility minimization-based path choice modeling framework with convex disutility functions
    - All trips would choose only among the set of extreme efficient paths
    - Applications in static assignment (Dial, 1996; Marcotte, 1997)



(Henig, 1985)

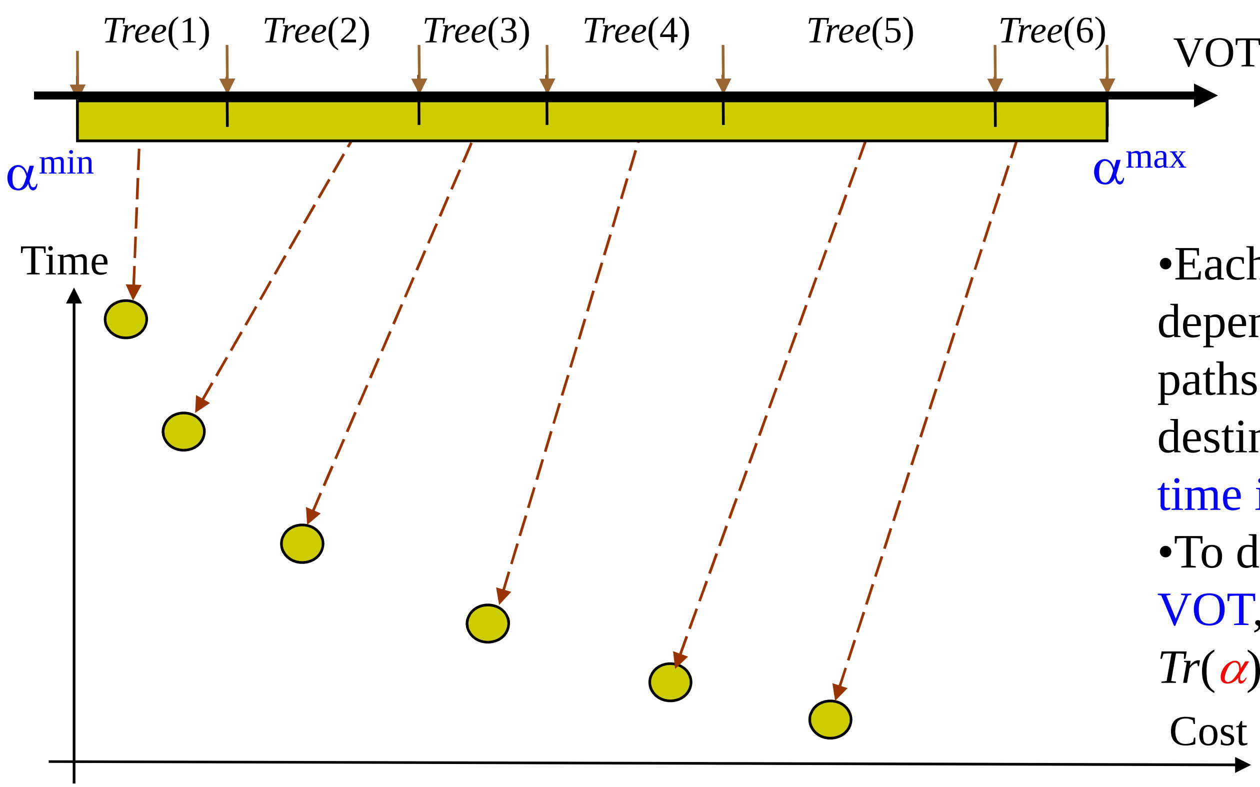
Sequential Parametric Analysis Method (SPAM)

- Determine VOT, VOESD, and VOLSD breakpoints that define multi-user classes, and find the least trip cost (extreme non-dominated) alternative for each user class



Parametric Analysis of VOT – stage 1 of the SPAM

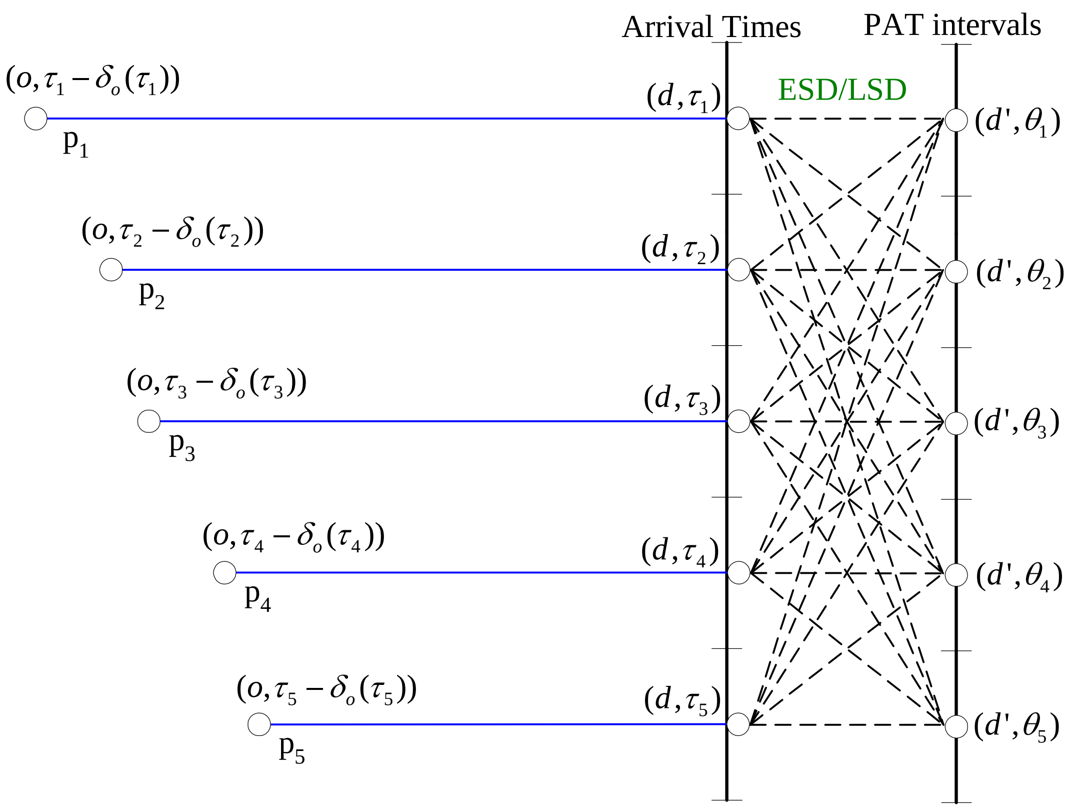
Determine the breakpoints that partition the feasible VOT range and define the master user classes, and find time-dependent least generalized cost path tree for each user class.



- Each tree consists of time-dependent least generalized cost paths from all origin nodes to a destination node, for all arrival time intervals.
- To determine the subinterval of VOT, in which the current tree *Tr*(α) is optimal.

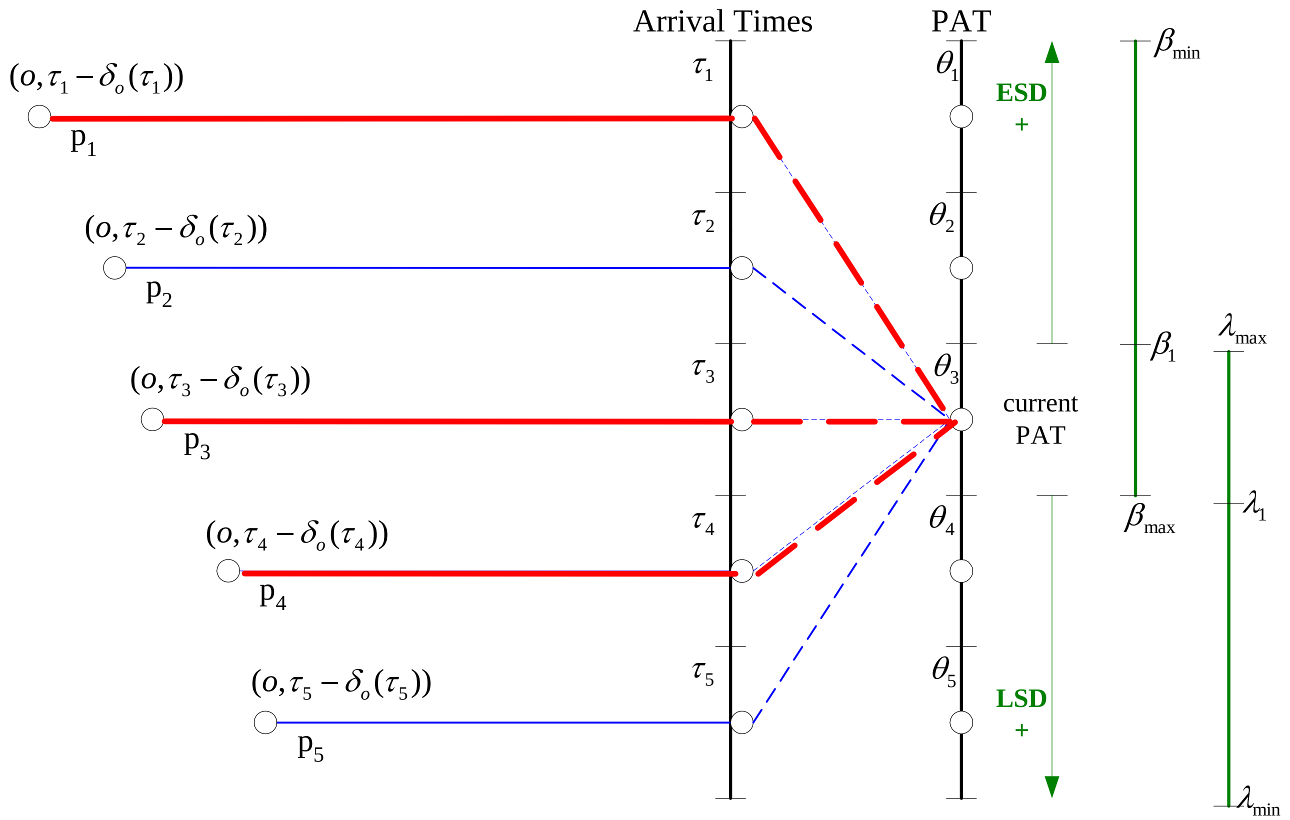
Parametric Analysis of VOESD and VOLSD for a VOT subinterval – stage 2 of the SPAM

- Given a time-dependent extreme efficient path tree *Tr*(*b*) corresponding to the VOT subinterval [α^{b-1}, α^{b}), the parametric analyses of VOESD and VOLSD are conducted in an expanded network.



Parametric Analysis of VOESD and VOLSD for a VOT subinterval

- An example



Parametric Analysis of VOESD and VOLSD for a VOT subinterval

- Output of the SPAM
  - VOESD breakpoints that define the subintervals, and the least trip cost alternative for each subinterval. $\forall b$, $\forall \theta$,

$$\beta(b,\theta) = \{\beta^0, \beta^1, ..., \beta^{M(b,\theta)} \mid \beta^{\max} = \beta^0 > \beta^1 > ... > \beta^m > ... > \beta^{M(b,\theta)} = \beta^{\min}\}$$

$$[\beta^{m-1}, \beta^m)_{b,\theta},\ (\tau^*, p^*)_{b,\theta,m},\quad m = 1,..., M(b,\theta)$$

  - VOLSD breakpoints that define the subintervals, and the least trip cost alternative for each subinterval. $\forall b$, $\forall \theta$,

$$\lambda(b,\theta) = \{\lambda^0, \lambda^1, ..., \lambda^{N(b,\theta)} \mid \lambda^{\max} = \lambda^0 > \lambda^1 > ... > \lambda^n > ... > \lambda^{N(b,\theta)} = \lambda^{\min}\}$$

$$[\lambda^{n-1}, \lambda^n)_{b,\theta},\ (\tau^*, p^*)_{b,\theta,n},\quad n = 1,..., N(b,\theta)$$

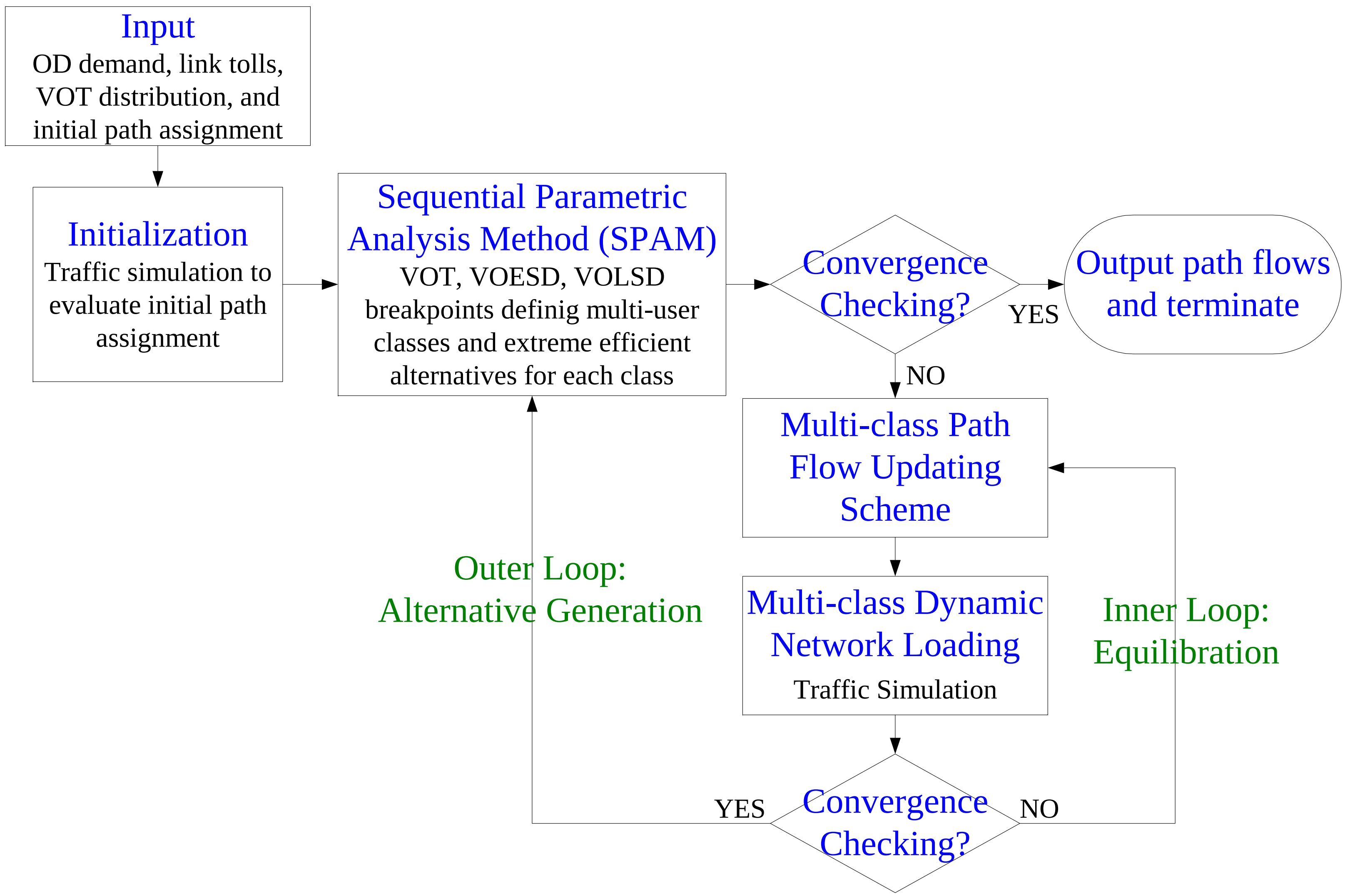
- Multiple user classes: for each VOT subinterval b and PAT θ,

$$u(b,\theta, m_{\beta(b,\theta)}, n_{\lambda(b,\theta)}),\ m = 1,..., M(b,\theta),\ n = 1,..., N(b,\theta)$$

  - Simplified as $u(b, \theta, m, n)$
  - The corresponding set of least trip cost alternatives

$$alt_{od}(b,\theta,m,n) = alt_{od}(b,\theta,m_{b,\theta}) \cup alt_{od}(b,\theta,n_{b,\theta})$$

Column Generation-based MSRDUE algorithm



Multi-Class Flow Updating and Convergence Checking

- Multi-Class Alternative Flow Updating Scheme
  - Multiple user classes $u(b, \theta, m, n)$ are naturally determined by the SPAM.
  - Decomposes the problem into many (b,θ,m,n,o,d) sub-problems and solves each of them by adjusting OD flows between non-least trip cost alternatives and the least trip cost alternative.
  - Extension of the multi-class path flow updating scheme for the BDUE
- Convergence Checking
  - Gap

$$Gap(r^l) = \sum_{u(b,\theta,m,n)} \sum_{o} \sum_{d} \sum_{(\tau,p)\in alt_{od}(b,\theta,m,n)} r_{odp}^{\tau,l}(b,\theta,m,n) \times \Delta_{odp}^{\tau,l}(b,\theta,m,n)$$

  - Average Gap

$$AGap(r) = \frac{\sum_{u(b,\theta,m,n)} \sum_{o} \sum_{d} \sum_{(\tau,p)\in alt_{od}(b,\theta,m,n)} r_{odp}^{\tau,l}(b,\theta,m,n) \times \Delta_{odp}^{\tau,l}(b,\theta,m,n)}{\sum_{u(b,\theta,m,n)} \sum_{o} \sum_{d} \sum_{(\tau,p)\in alt_{od}(b,\theta,m,n)} r_{odp}^{\tau,l}(b,\theta,m,n)}$$

Numerical Experiments and Results

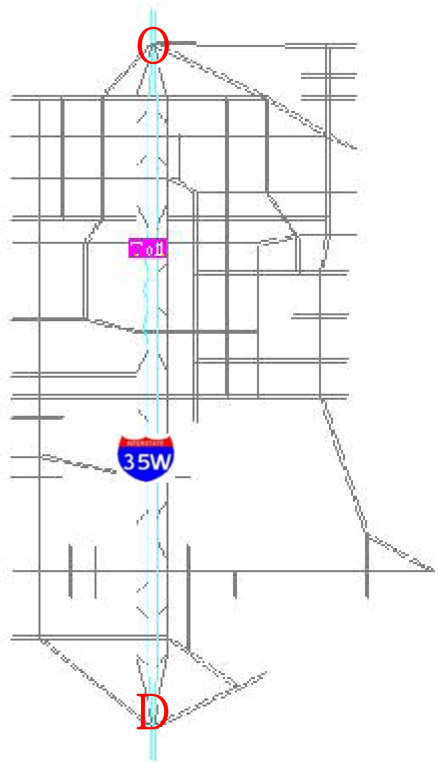
- Purpose
  - Examine the algorithmic convergence property and solution quality of the algorithm
  - Investigate how the random parameters would affect departure time and path flow patterns (or toll road usage) under different dynamic pricing scenarios (i.e. to compare the random and constant parameter models).
- Random parameters
  - VOT distribution: N($0.4/min, $0.2/min), $[\alpha^{min}, \alpha^{max}]$ = [0.01, 3.0]

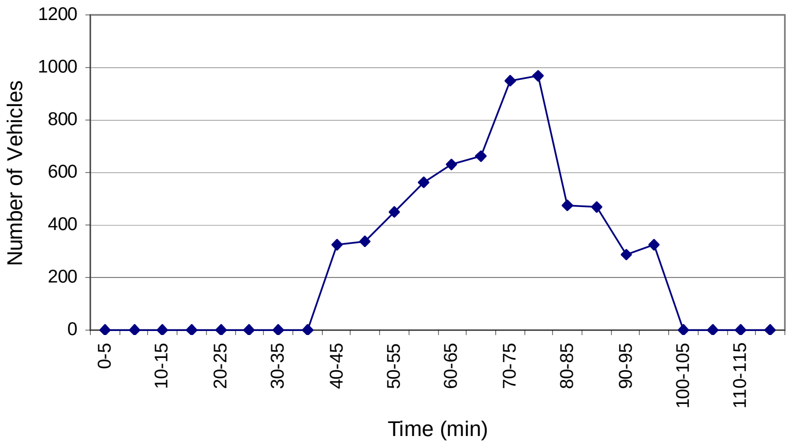
    (Lam and Small, 2001; Brownstone and Small, 2005; Southern CA)
  - VOESD distribution: N($0.3/min, $0.15/min), $[\beta^{min}, \beta^{max}]$ = [0.01, 2.0]
  - VOLSD distribution: N($1.8/min, $0.6/min), $[\lambda^{min}, \lambda^{max}]$ = [0.25, 4.0]

    (economic judgments based on the results reported in Small (1982))
- Arrival time and PAT intervals: 5 minutes.

Numerical Experiments and Results

- Experiment conducted on the Fort Worth network (TX)
  - Select a critical OD pair that accounts for 25% of total demand.





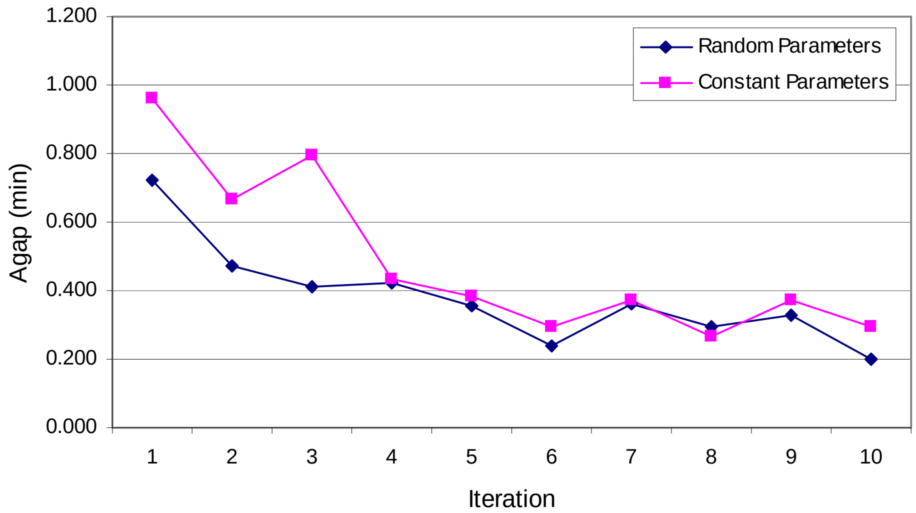
PAT pattern

Pricing Scenario	0-20 minutes	20-40 minutes	40-60 minutes	60-80 minutes	80-100 minutes	100-120 minutes	120-150 minutes
#1 (low)	$0.05	$0.20	$0.35	$0.50	$0.35	$0.20	$0.05
#2 (mid)	$0.25	$0.40	$0.55	$0.70	$0.55	$0.40	$0.25
#3 (high)	$0.45	$0.60	$0.75	$0.90	$0.75	$0.60	$0.45

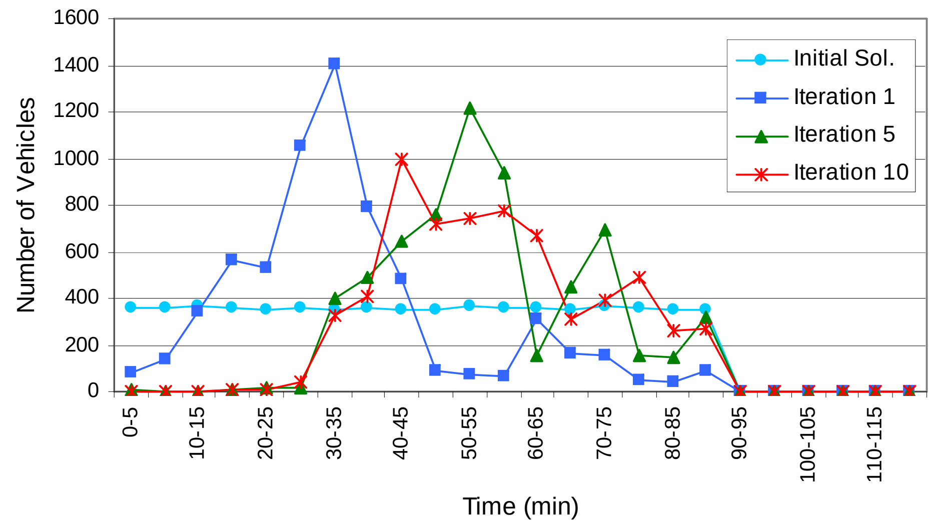
dynamic pricing scenarios

Numerical Experiments and Results

- Experiment conducted on the Fort Worth network (TX)
  - Convergence pattern and solution quality in terms of Average Gap.
  - Convergence pattern in terms of departure time distribution



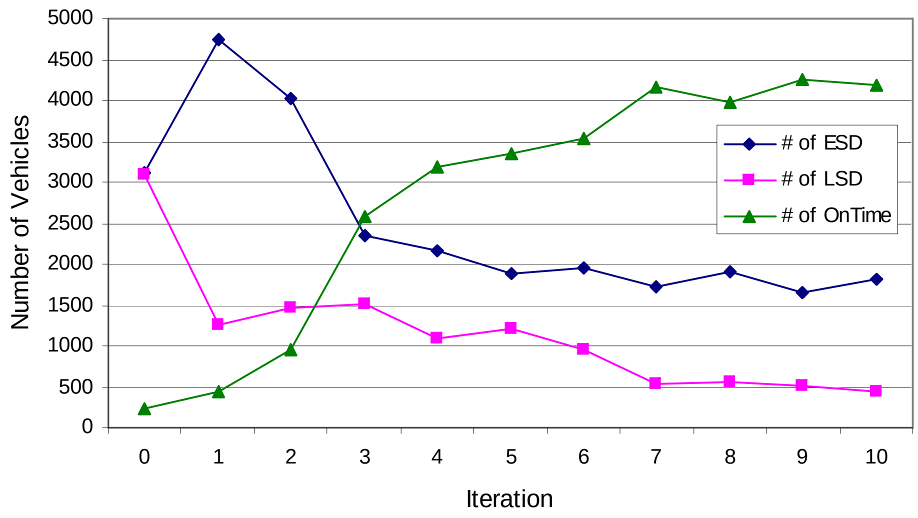
average gap



departure time distribution
(random parameter model)

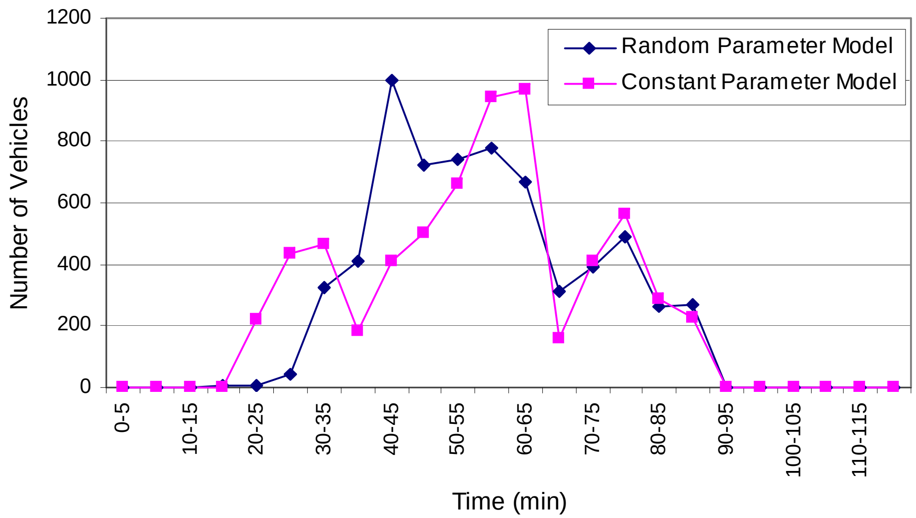
Numerical Experiments and Results

- Experiment conducted on Fort Worth network (TX)
  - Convergence pattern in terms of the number of schedule delay vehicles (i.e. early, late, and on-time vehicles) in the random parameter model

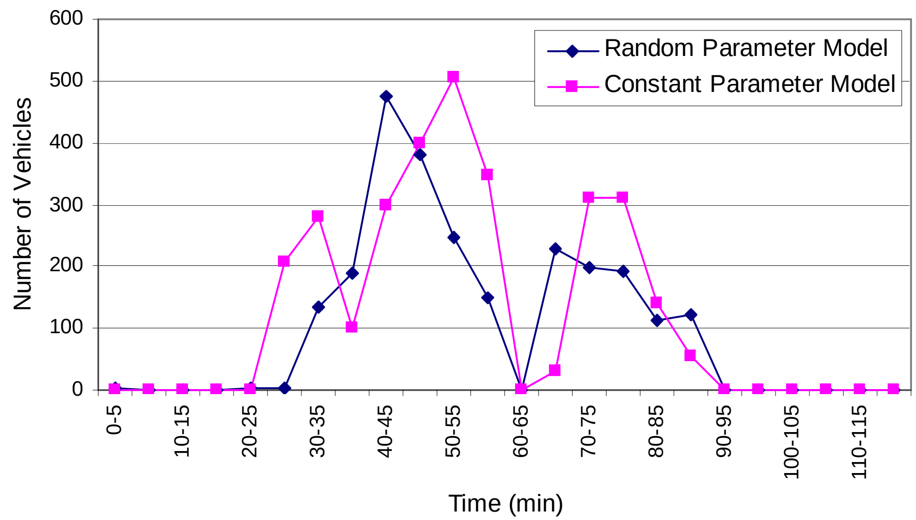


Numerical Experiments and Results

- Experiment conducted on the Fort Worth network (TX)
  - Compare the differences in departure time distribution and toll road usage between random and constant parameter models



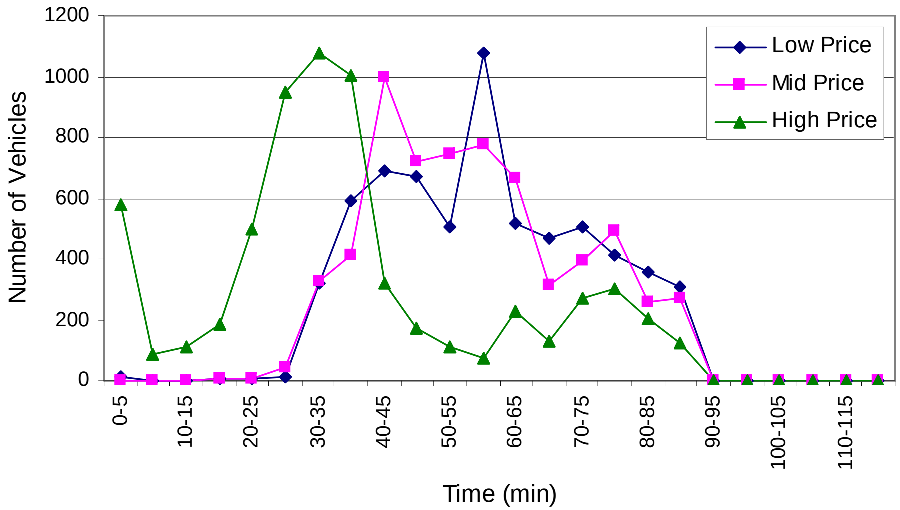
departure time distribution



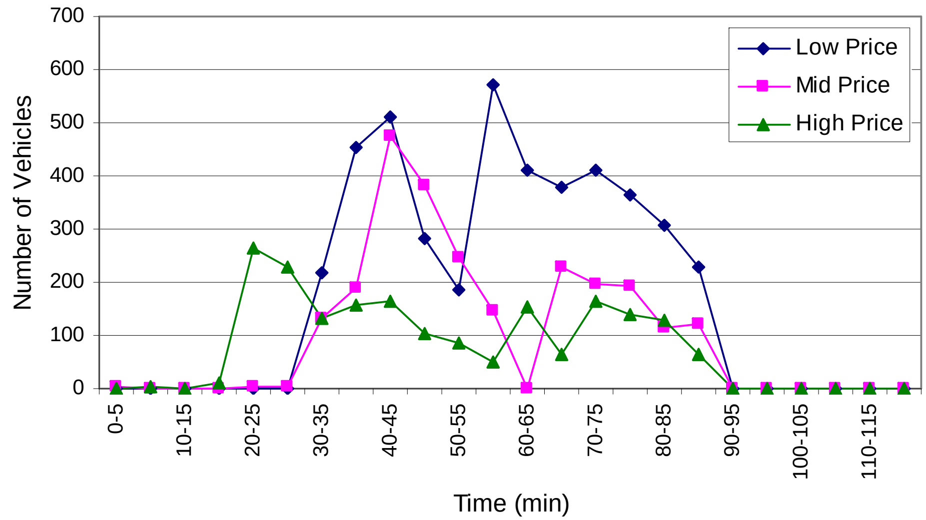
Time-varying toll road usage

Numerical Experiments and Results

- Experiment conducted on the Fort Worth network (TX)
  - Comparison of departure time distribution and toll road usage under different dynamic pricing scenarios



departure time distribution



Time-varying toll road usage

Concluding Remarks

- Integration of activity-based models and network models requires:
  - disaggregate micro-assignment platform; simulating traffic dynamics at meso scale allows application to large networks
  - Retaining activity/trip chains as basic assignment entity; do not break into individual trips
  - Capturing user heterogeneity while retaining computational tractability
  - Integration is more than mere "juxtaposition" or back and forth iteration between models designed for separate purposes
- DTA software can readily integrate today with rich activity-based micro-level software through "vehicle" and "path" files
- Equilibration with choice dimensions other than route choice, with general VOT distribution still in experimental software stage
- Rapid development in new algorithms and intelligent implementations of equilibration algorithms designed to operate with particle-based micro-assignment models
- Experience to date: procedures can find equilibrium (verified through gap function methods), but uniqueness not likely for the general case with heterogeneous users (known from static case)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