McCormick

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Network Micro-simulation Extension to Activity-Based Travel Model

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Outline

- **Integration of ABM and DTA Framework**
- **Mode Choice Application**

  (MODELING AND FORECASTING OF TOLL REVENUES)
- **Departure Time Choice Application**

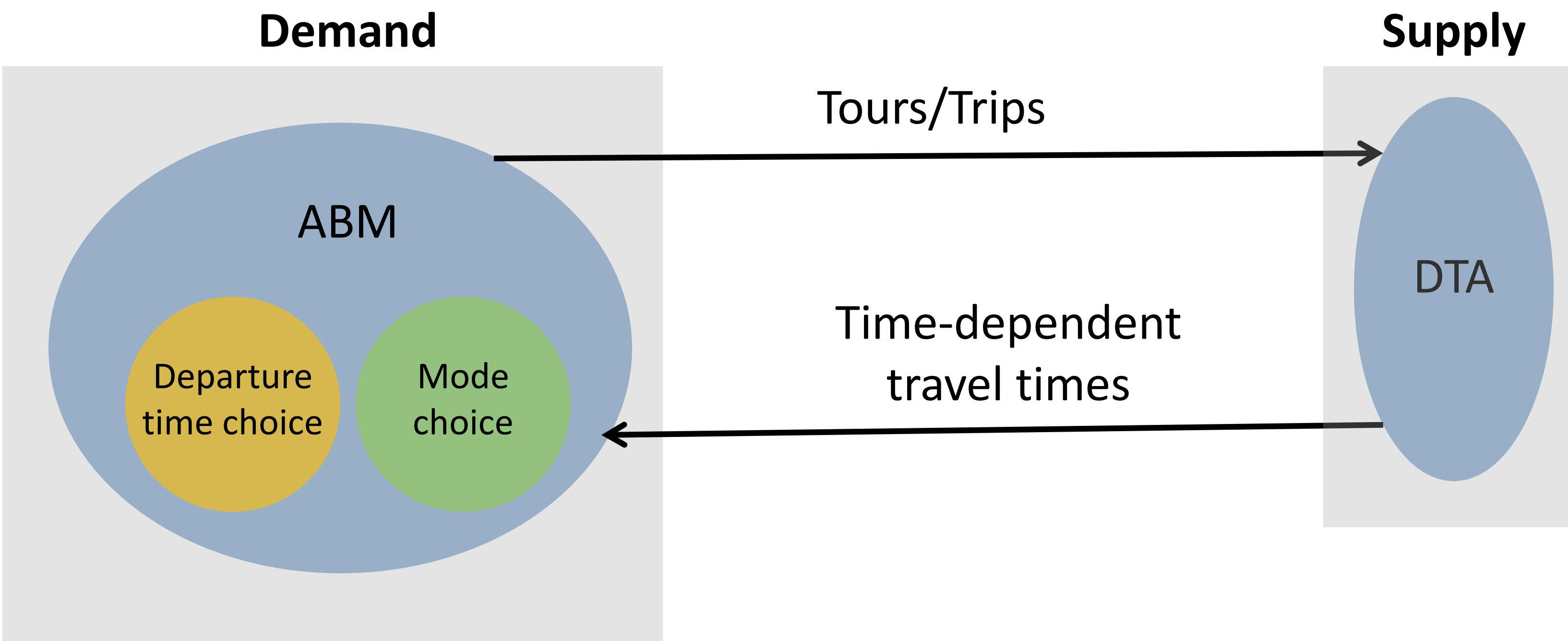
  (Evaluating Traveler Information and Demand Management for Weather-related Events)
- **Equilibrium Concept**
- **Real-Time Activity Adjustment and Rescheduling**

Introduction

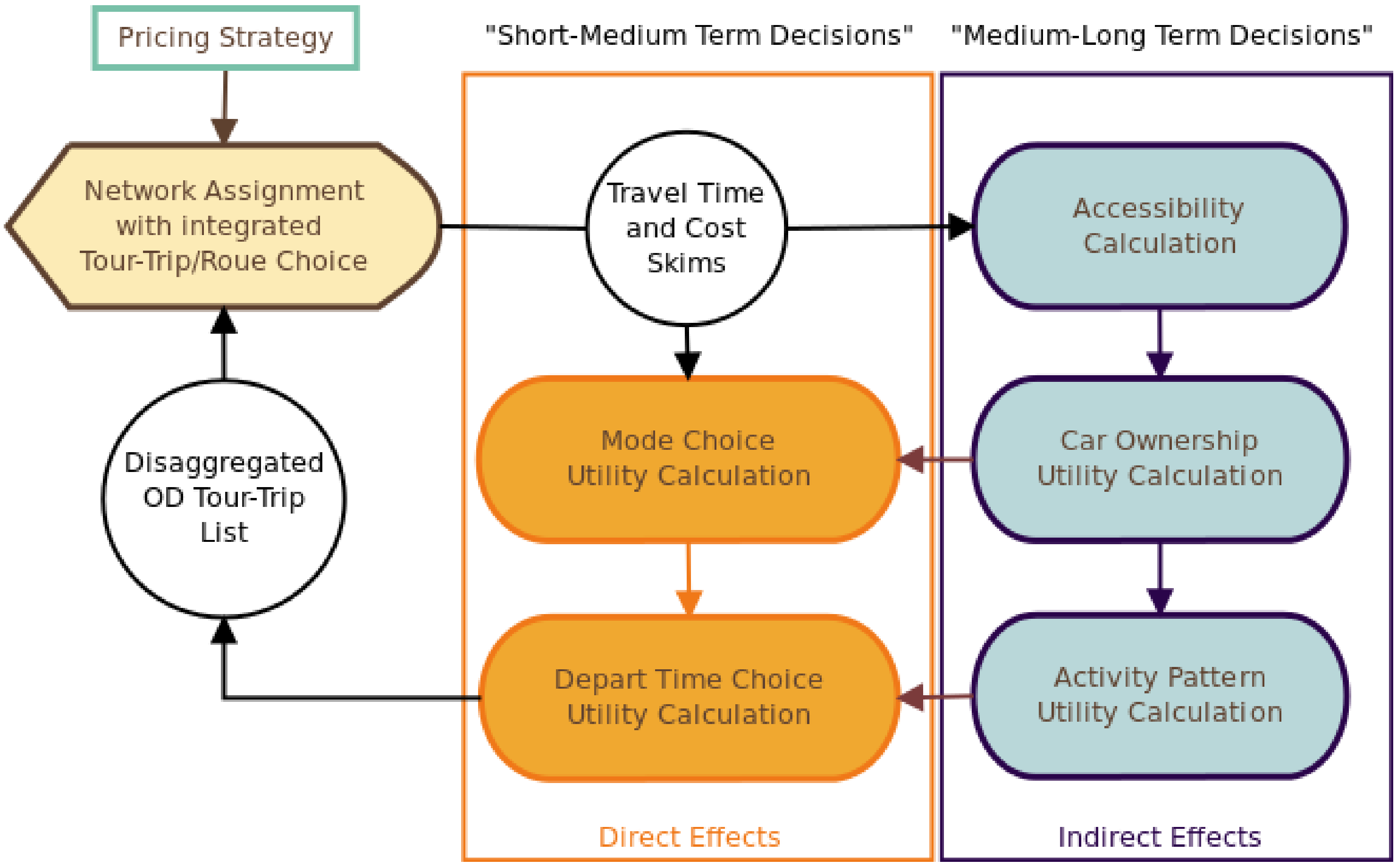
- Individual activity choices of users determine temporal and spatial patterns of demand and flow; ABM's require time-varying times and costs.
- Dynamic Traffic Assignment (DTA) tools can be applied as the route choice model considering time-dependent travel times in the network. A DTA tool models the evolution of traffic flows in a traffic network resulting from the decisions of individual travelers seeking to fulfill a chain of activities at different locations considering the collective effects of users' decisions (route choice).
- Interrelation between activity choices (given by ABM) and network performance measures (given by DTA) calls for an integrated framework consisting of these two models.
- The transit network should also be incorporated in a multimodal DTA model to consider time-dependent travel times by all modes.
- Equilibrium concepts in this integrated framework need to be revisited.

Integration of ABM and DTA Framework

Supply-Demand Model Integration



ABM-DTA Integration



ABM output

- ABM provides detailed records of estimated individual and joint tours and trips.
- The individual trip table includes all the estimated trips for the synthesized population.
- The joint trip table includes all the estimated trips made by any party of more than one person from the same household.

Trip table

Household ID	Person ID	Tour Purpose	Org. Purpose	Dest. Purpose	Org. TAZ	Dest. TAZ	Departure Time Period	Trip Mode	Tour Mode
1841355	6382830	work	Home	Escort	1	48	4	1	3
1841355	6382830	work	Escort	Escort	48	367	5	2	3
1841355	6382830	work	Escort	Escort	367	391	8	3	3
1841355	6382830	work	Escort	work	391	340	11	3	3
1841355	6382830	work	work	Eating Out	340	1440	35	3	3
1841355	6382830	work	Eating Out	Maintenance	1440	602	36	3	3
1841355	6382830	work	Maintenance	Home	602	1	39	3	3

DTA input

DTA input

- There are two methods for preparing vehicle generation in DYNASMART-P.

1. Specify Origin-Destination (O-D) matrices among origin-destination zones at different time intervals.

2. Specify the itineraries (origin and destination) of all vehicles with or without their corresponding travel plans. In this format, a trip plan (chain) for each traveler can be specified.

This provides maximum flexibility to interface with micro-simulation activity-based travel demand forecasting models.

DTA input

Demand table

Household ID	Origin TAZ	Destination TAZ	Departure Time (minute)	Value of Time ($/hour)
1806500	1906	1905	1.54	28.09
1903000	951	956	7.77	4.82
1266800	1927	1941	12.43	15.31
2071900	1903	1903	55.21	15.50
3544972	206	691	66.21	21.23

user heterogeneity

- ABM assigns a specific value of time to each household based on its income.
- It is assumed that all the members of a household have the same value of time regardless of the individual attributes and trip purposes.
- Therefore, each estimated trip (auto or non-auto) has a value of time assigned to it.

DTA output

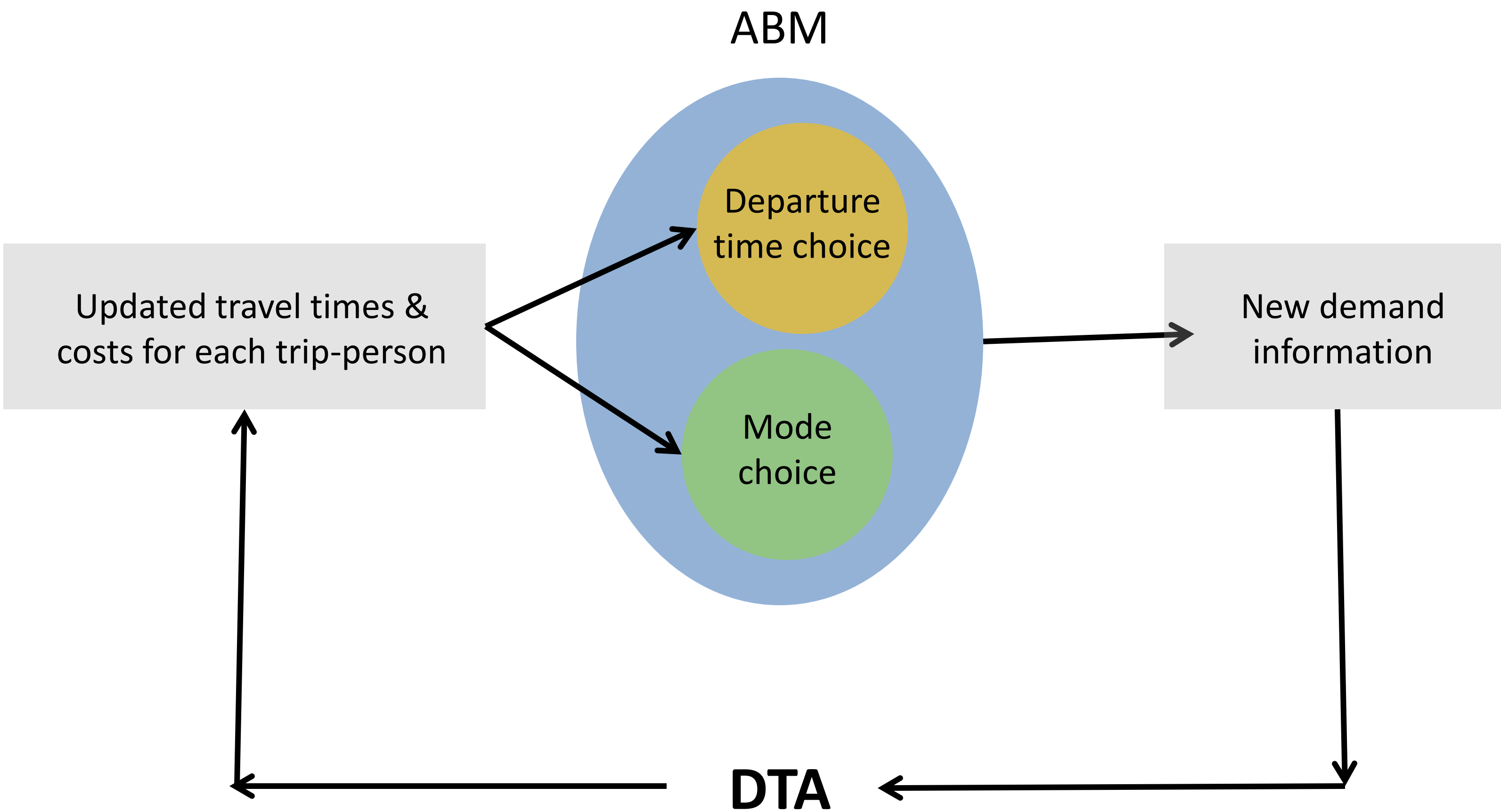
Vehicle Trajectory

- DYNASMART-P outputs trajectory of each simulated vehicle. This file describes the traffic information and itinerary associated with each vehicle in the network.

Time-dependent O-D Travel Times & Costs

- From the vehicle trajectories, average travels time for each O-D can be obtained at different time intervals.
- Accordingly, travel costs can be estimated.

Iterative Process



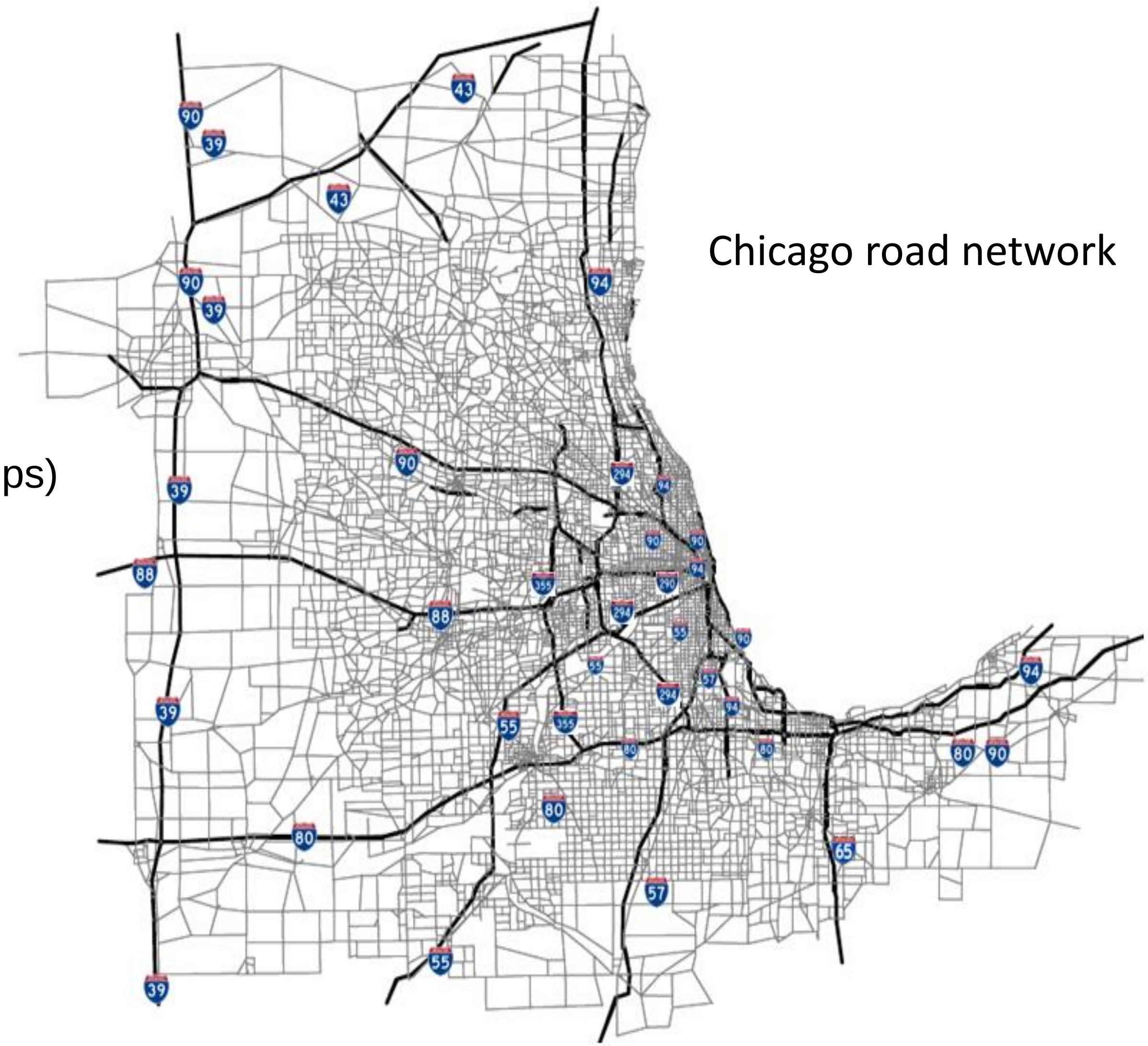
Mode Choice Application

(Modeling and Forecasting of Toll Revenues)

Simulation-based DTA

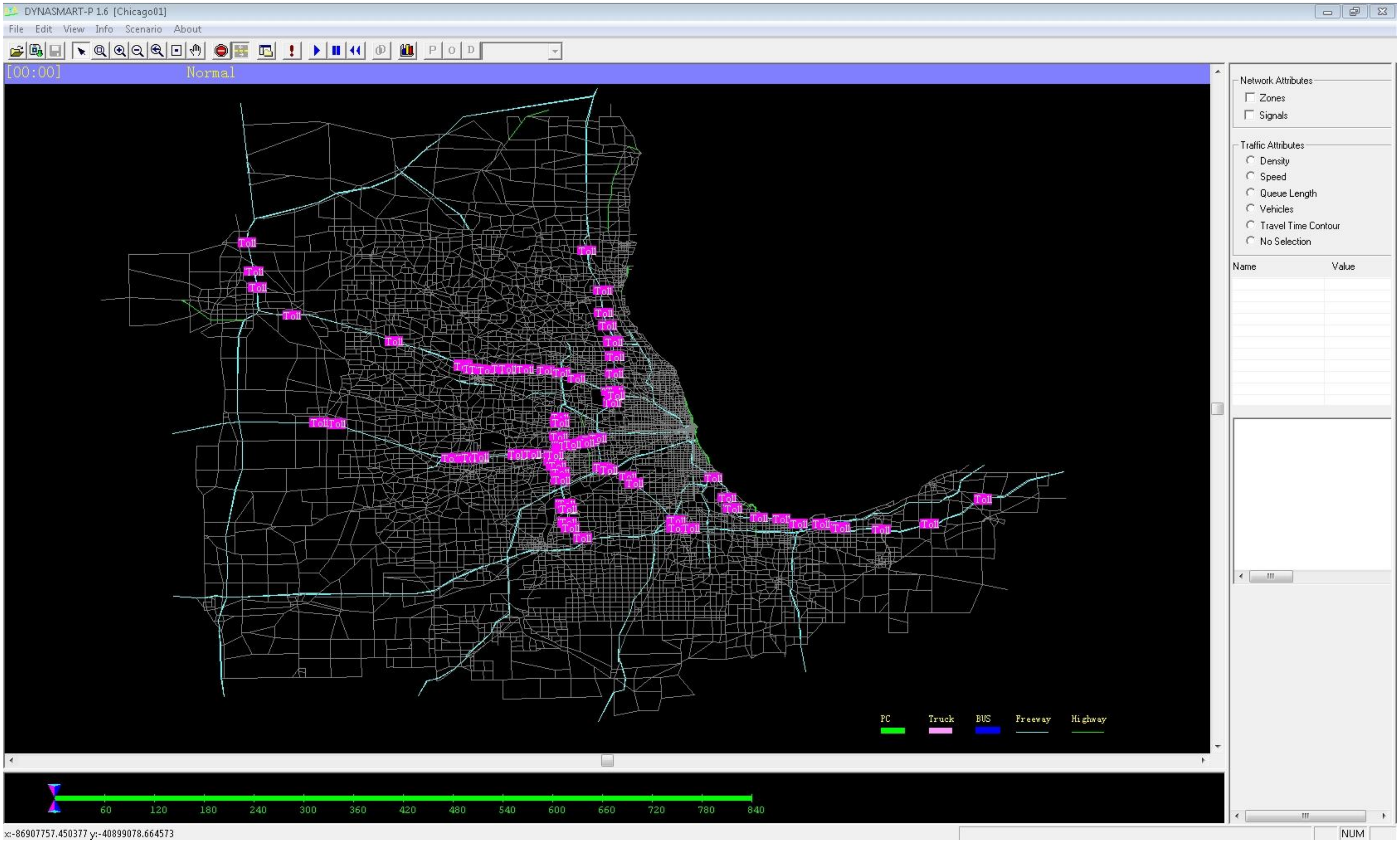
Network Specifications:

- 40,443 links
- 1,400 freeways
- 201 highways
- 2,120 ramps (96 metered ramps)
- 36,722 arterials
- 13,093 nodes
- 2,093 signalized intersections
- 1,961 zones
- 1,944 internal
- 17 external



Chicago road network

Simulation-based DTA Tool



Existing Toll Ways Shown by DYNASMART-P GUI

DTA Specifications for Considering Heterogeneity

Route Choice

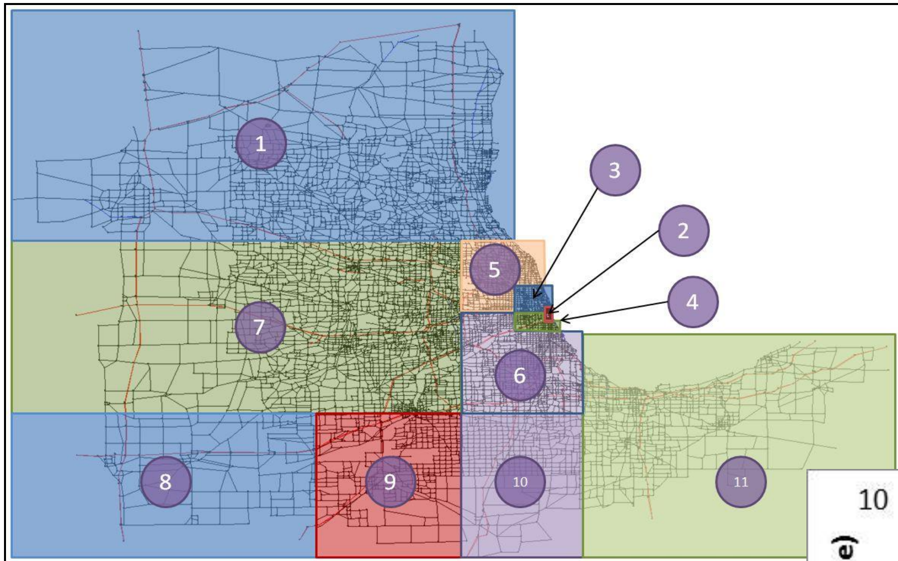
- Based on the general cost for heterogeneous users
- General cost includes Travel Time multiplied by VOT, Travel Cost (toll) and Travel Time Reliability

$$GC_{odp}^{\tau,m}(\alpha) = \begin{cases} \alpha \times TT_{odp}^{\tau,m} + \beta \times TTSD_{odp}^{\tau,m} & if\ \ non-tolled\ \ path \\ \gamma + TC_{odp}^{\tau,m} + \alpha \times TT_{odp}^{\tau,m} + \beta \times TTSD_{odp}^{\tau,m} & otherwise \end{cases}$$

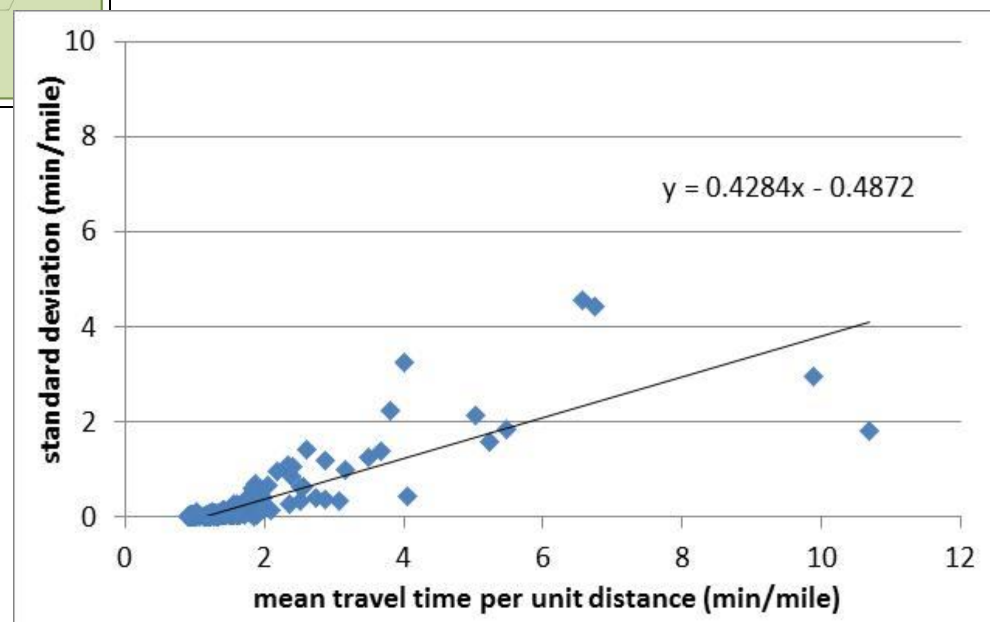
User Equilibrium Dynamic Traffic assignment

- 5 inner and outer UE iterations
- simulation horizon from 6:00 AM to 10:00 AM
- 6,332,185 generated vehicles with different values of time
- Three class of vehicles based on the occupancy
  (Single, Joint 2 and Joint 3)

Calibration of Reliability Measures



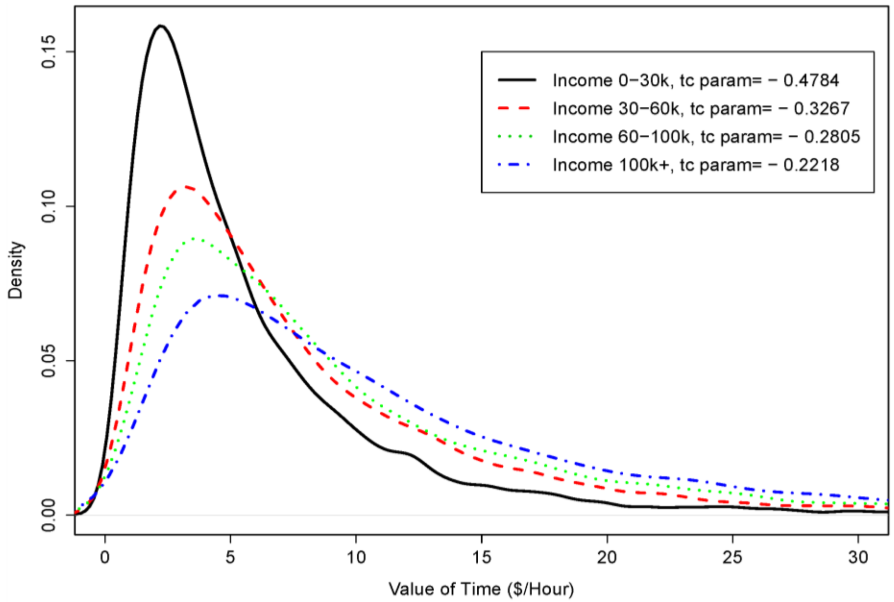
- **Eleven regions are defined to calibrate reliability factor.**
- **11 by 11 matrix is used based on the location of origin and destination of trips in these regions.**



Standard Deviation versus Mean Travel Time per Unit Distance from Area 1 to Area 7

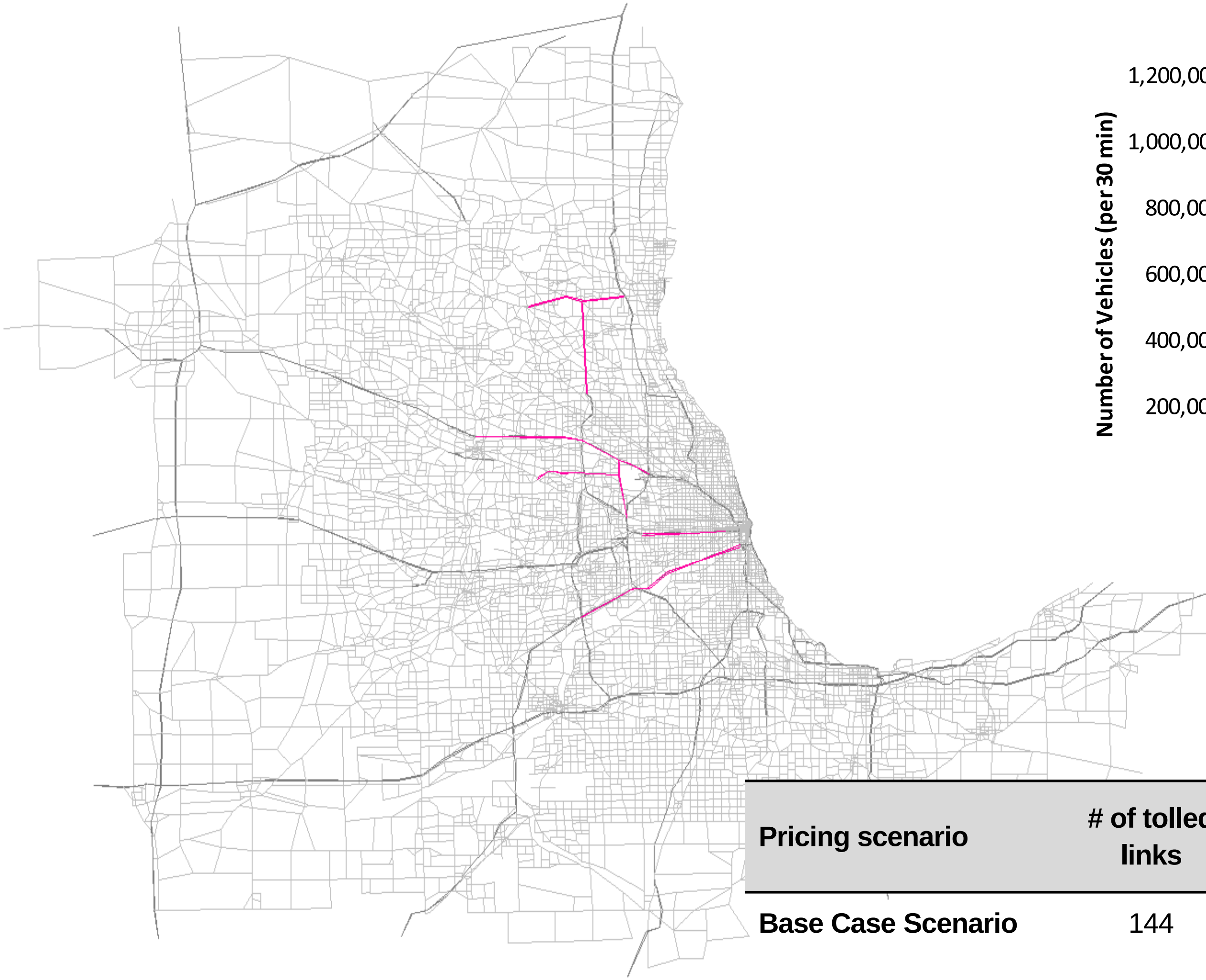
Heterogeneous Users with Different Value of Time

Four Different Continuous Value of Time Distributions for different groups of users based on the income level

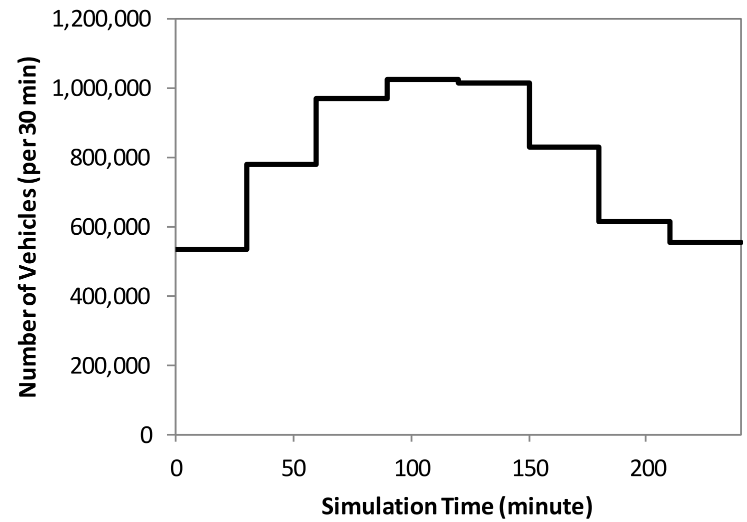


Household income group	N HH	Mean Person in HH	N Person	HH weights	Person weights
0-30,000 [$]	1,081,423	1.99	2,153,288	0.274	0.202
30,0001-60,000 [$]	1,189,229	2.65	3,156,618	0.302	0.296
60,001-100,000 [$]	988,625	3.15	3,119,355	0.251	0.292
100,001+ [$]	684,051	3.29	2,248,882	0.173	0.211
Total	3,943,328	2.77	10,678,143	1	1
	0-30K	30-60K	60-100K	100K+	Aggregated
VOT	6.01	8.81	10.44	12.86	9.68
VOTTollConst	2.18	3.20	3.79	4.67	3.48
VOTTSD	0.80	1.17	1.39	1.71	1.27
***VOTTSD* w/o network ratio**	1.52	2.22	2.64	3.25	2.42

Future Network and Demand



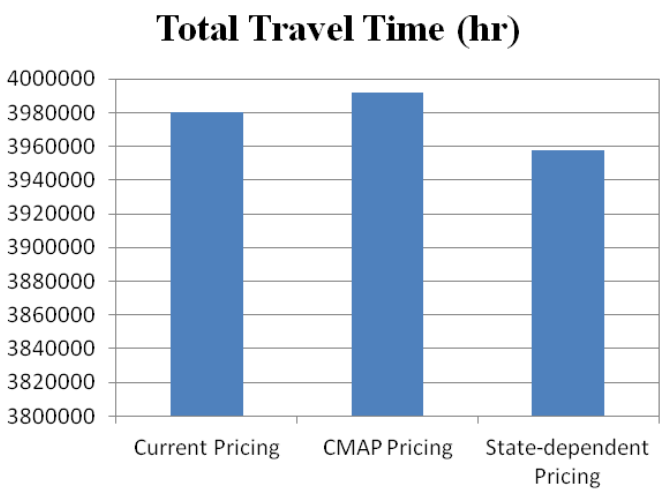
Chicago Future network with new additional priced lanes

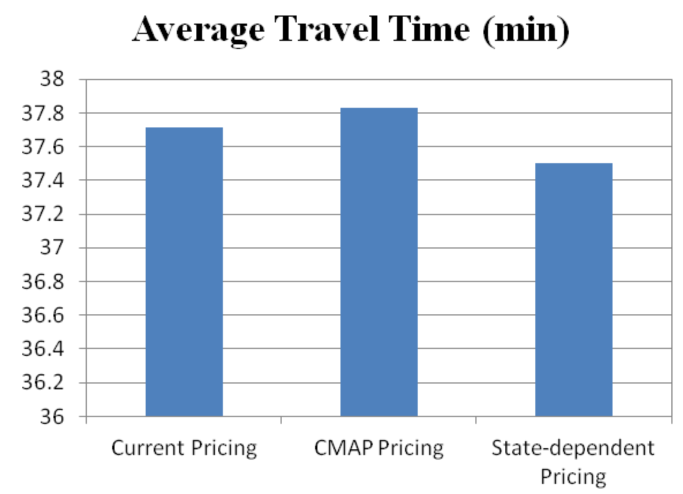


Chicago Future Morning Peak Demand Profile

Pricing scenario	# of tolled links	# of newly built tolled links	Toll Rate Design
Base Case Scenario	144	0	Fixed rate
CMAP Pricing	210	66	Fixed rate and schedule
State Dependent Pricing	210	66	Dynamically updated every 10-mininute based on the current traffic condition

Network-wide Performance Measures

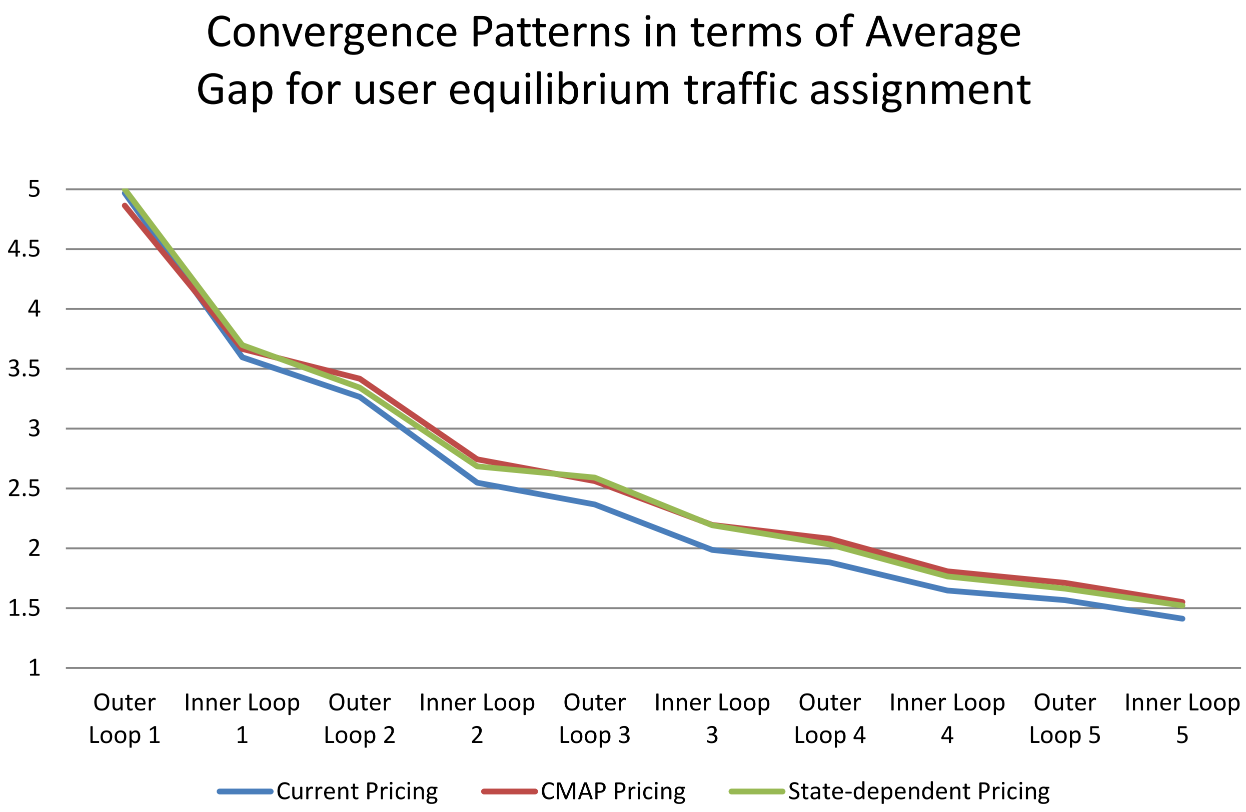




	Revenue Generated by Existing Links	Revenue Generated by New Links	Total Revenue
Base Case Scenario	$141,924.00	N/A	$141,924.00
CMAP Pricing	$139,651.00	$58,511.00	$198,162.00
State-dependent Pricing	$142,481.00	$63,176.40	$205,657.40

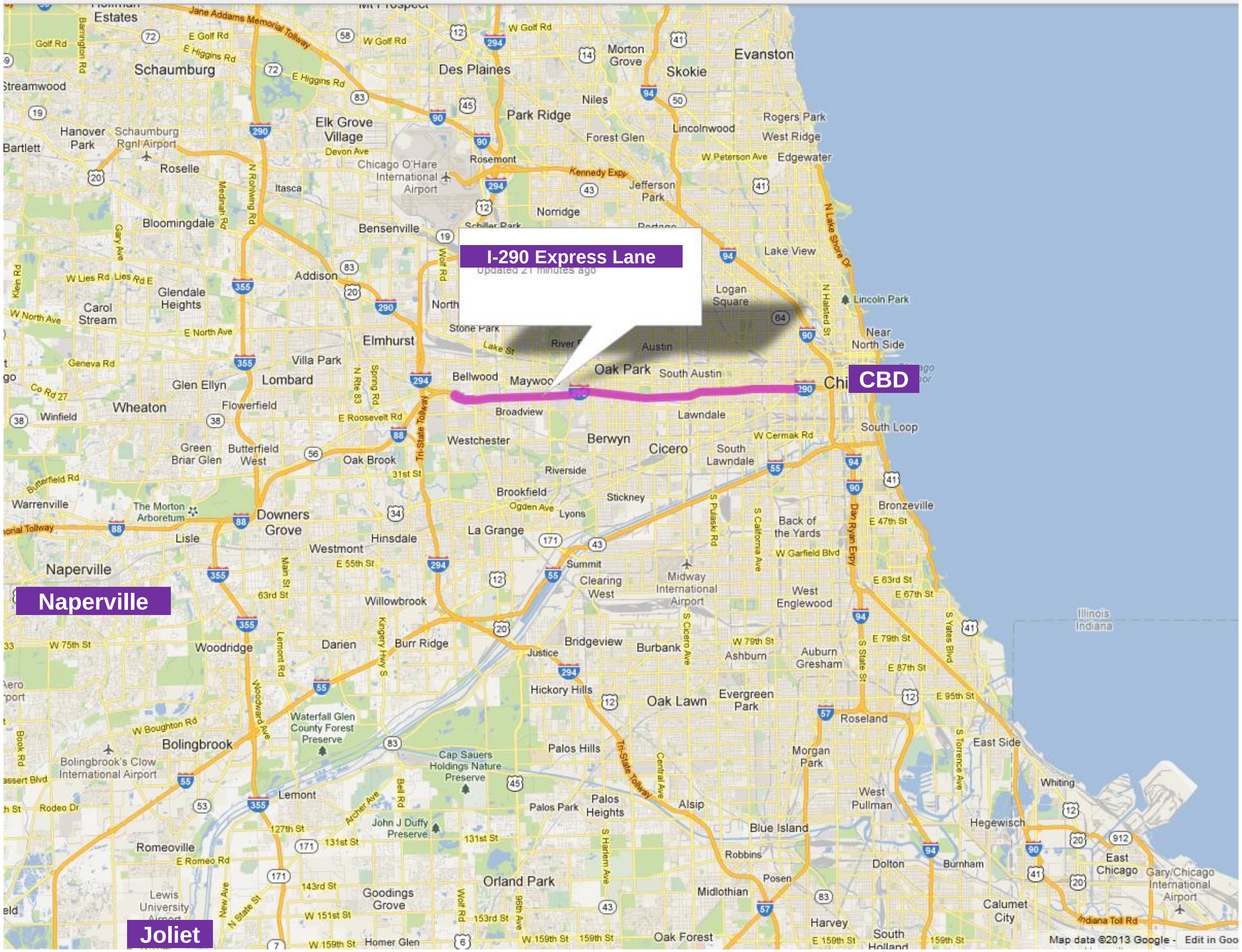
State-dependent pricing scheme slightly improves performance of the network

Network-wide Performance Measures



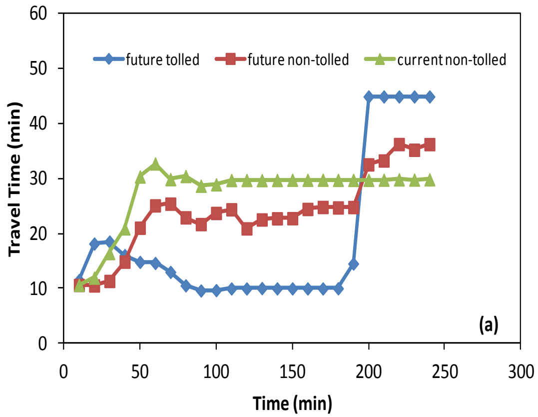
$$AGap(r) = \frac{\sum_{o \in O} \sum_{d \in D} \sum_{\tau=1}^{T} \sum_{m=1}^{2} \sum_{\alpha=\alpha^{\min}}^{\alpha=\alpha^{\max}} \sum_{p \in P^m(o,d,\tau)} r_{odp}^{\tau,m}(\alpha) \times \left| GC_{odp}^{\tau,m}(\alpha) - \pi_{od}^{\tau,m}(\alpha) \right|}{\sum_{o \in O} \sum_{d \in D} \sum_{\tau=1}^{T} \sum_{m=1}^{2} \sum_{\alpha=\alpha^{\min}}^{\alpha=\alpha^{\max}} \sum_{p \in P^m(o,d,\tau)} r_{odp}^{\tau,m}(\alpha)}$$

Selected Facility and Origin-Destination Pairs

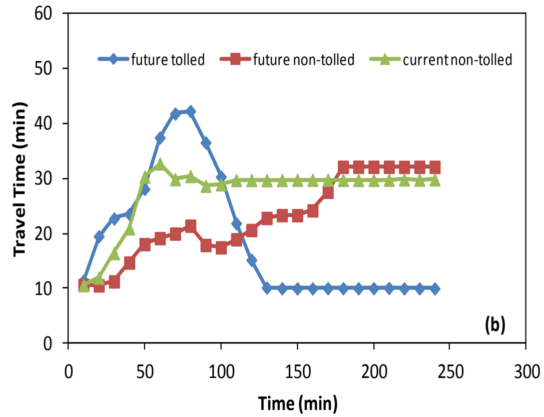


Facility-wide Performance Measures

I-290 Express Lane Westbound (Damen Ave to Mannheim)

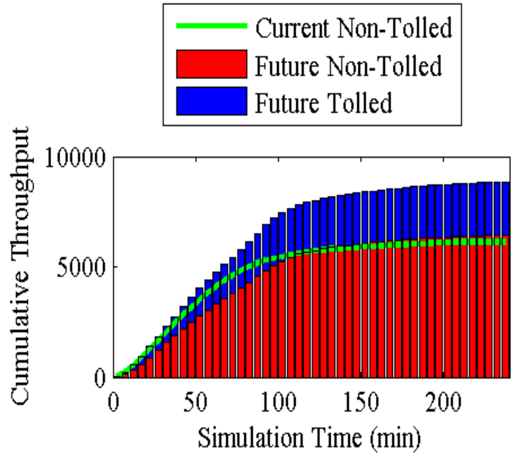


CMAP Pricing

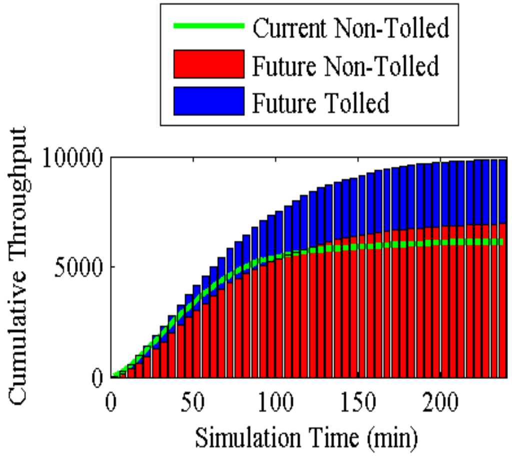


State-dependent Pricing

Travel Time



(a) CMAP Pricing

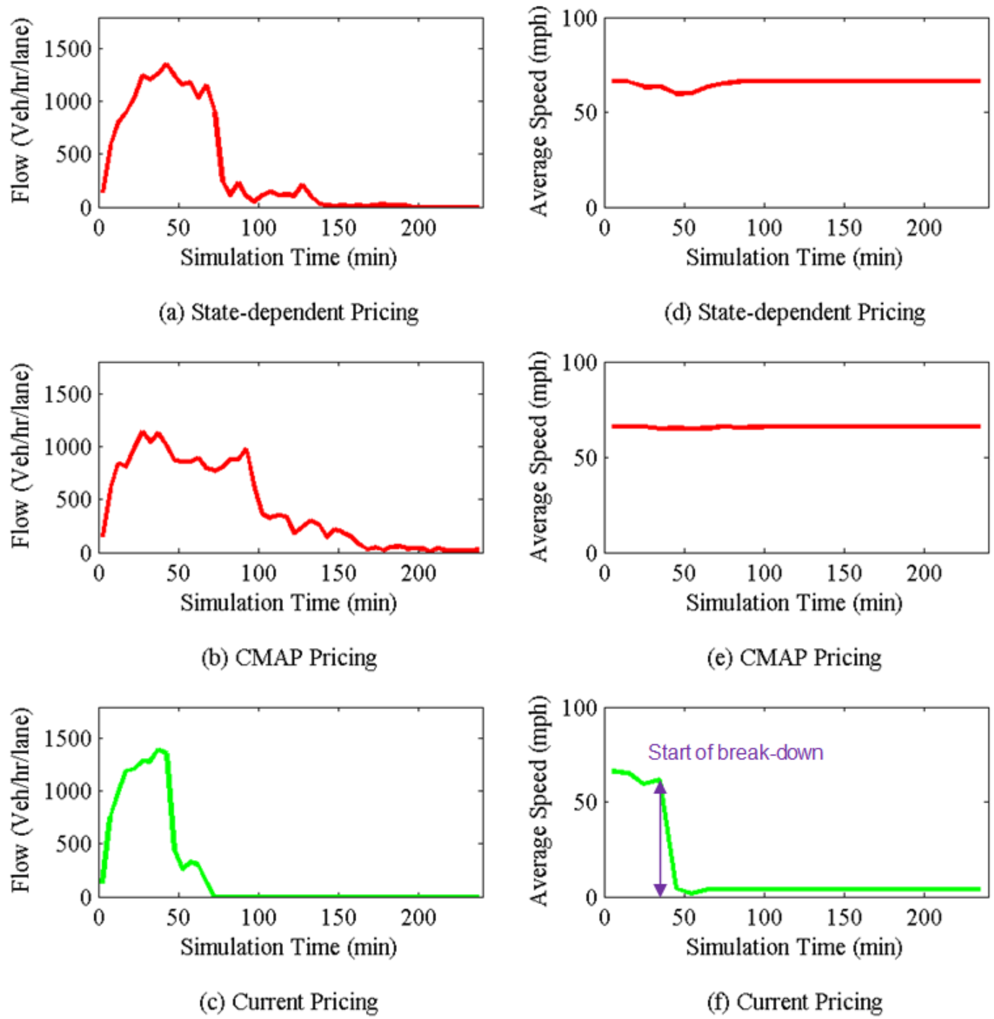


(b) State-dependent Pricing

Throughput

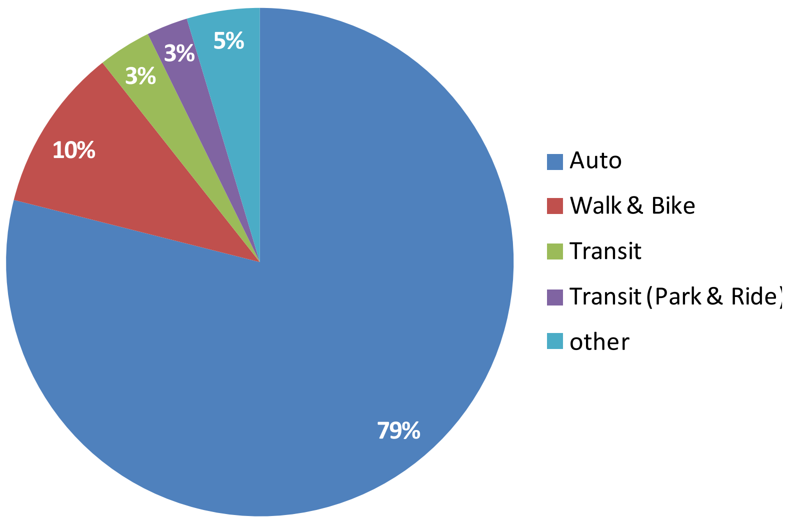
Facility-wide Performance Measures

I-290 Express Lane Westbound (Damen Ave to Mannheim)

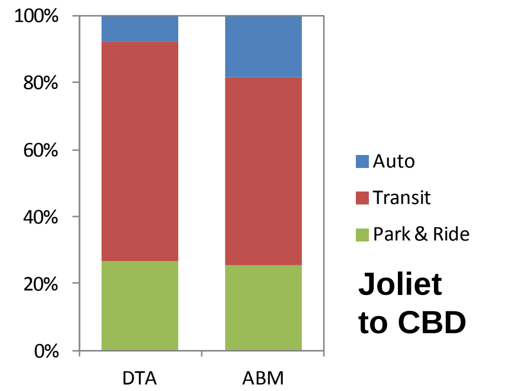


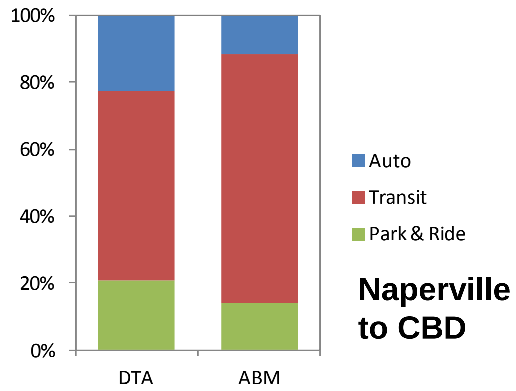
Flow **Speed**

Mode Choice Results



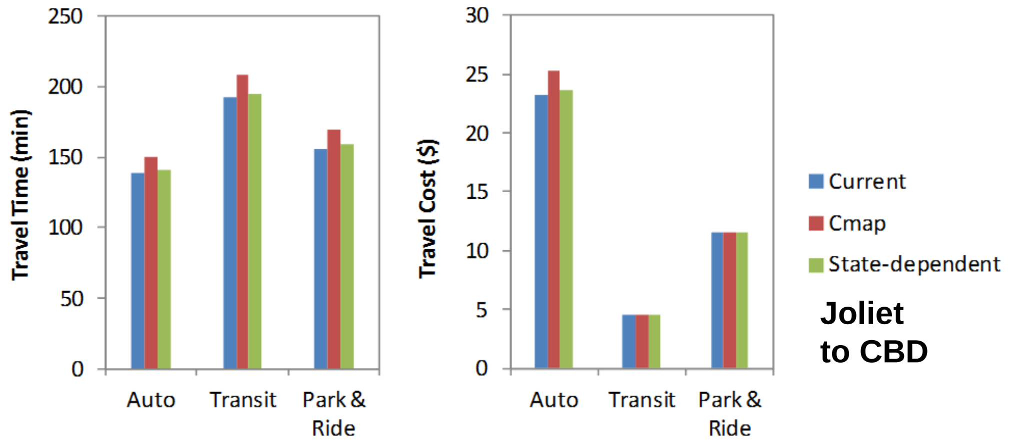
ABM Mode Share

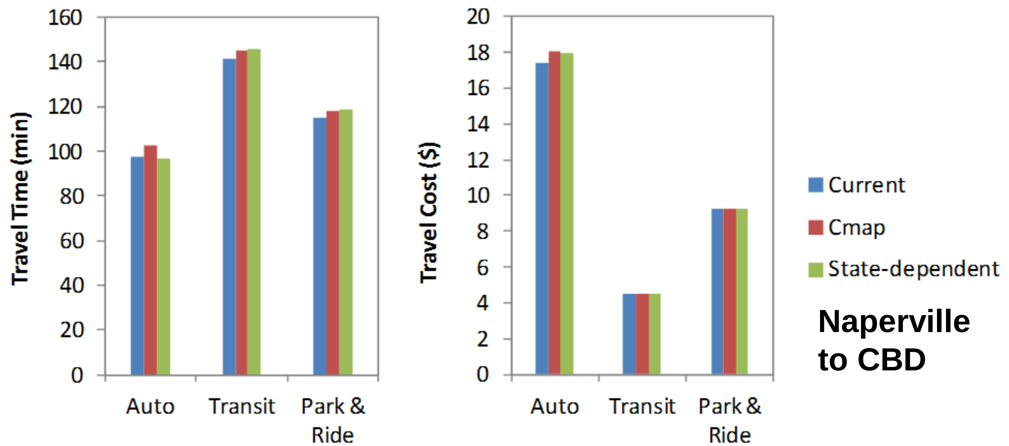




Mode Choice Results

OD Specific Comparison of Travel Times and Costs for Different Modes



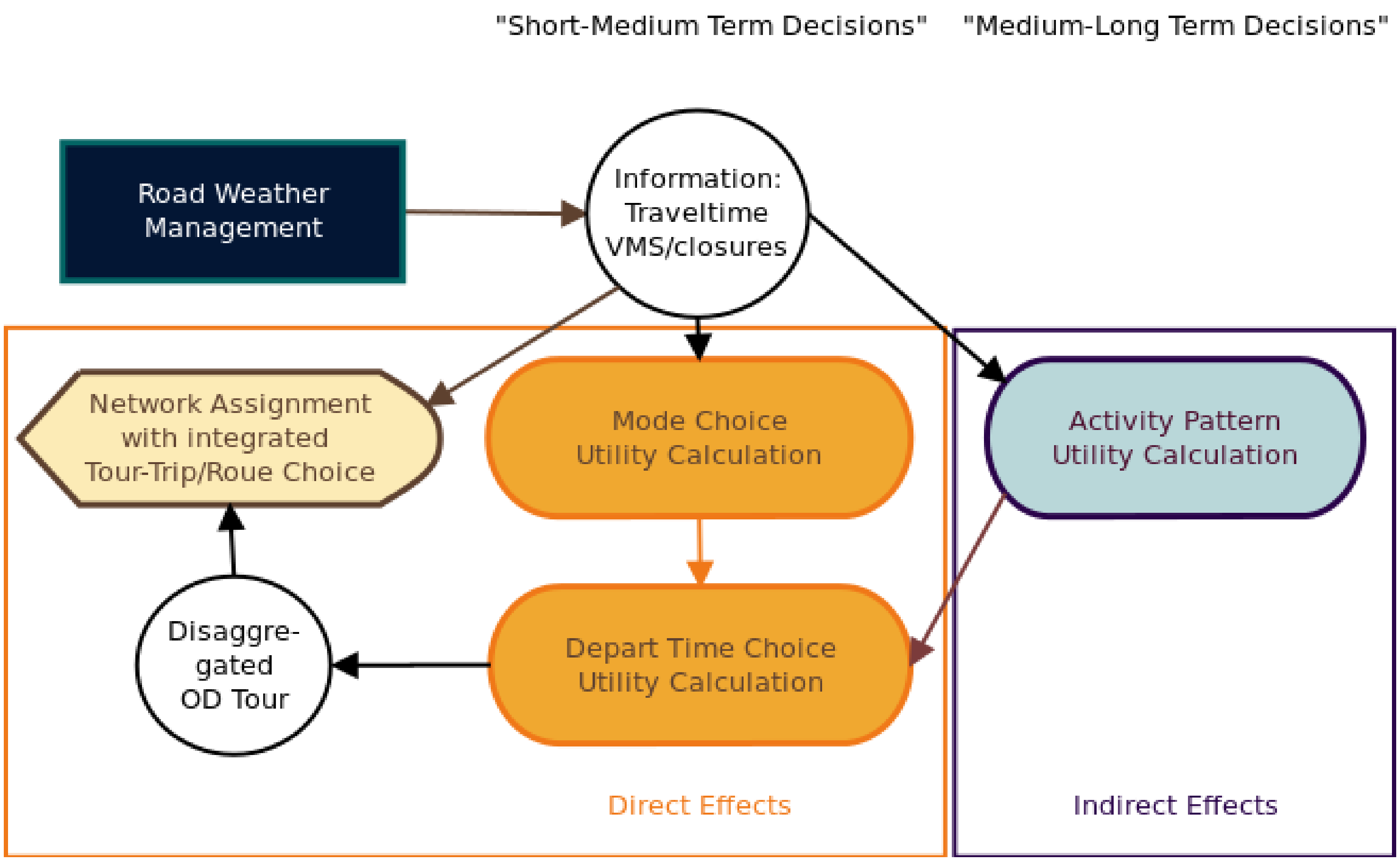


Departure Time Choice Application

(Evaluating Traveler Information and Demand Management for Weather-related Events)

- **DynaSmart integration so far:**
  - All en-route choices (route choice) on the platform
  - daily, pre-trip decisions as an outer layer.

- **Example: Intervention of Road Weather Management Strategies:**
  - VMS/Closure: En-route information
  - Pre-trip travel time information targeting Mode Choice and Departure Time Choice
  - Policy Intervention: School activity pattern changes

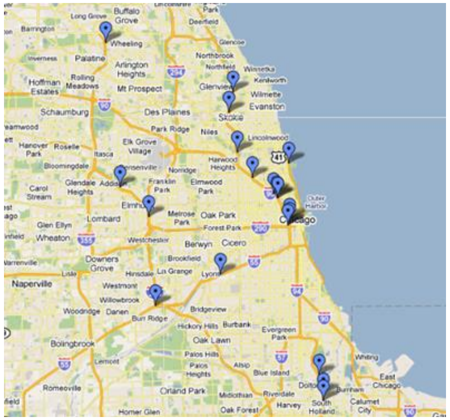


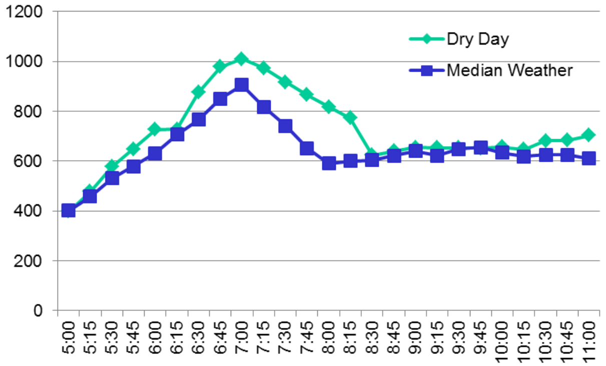
RWTM: Data available and used

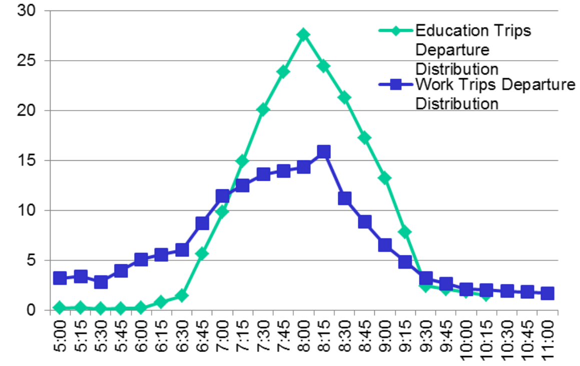
- Chicago Sub-Network
- Weather Station Information
- Traffic Data from Detectors

    5 am to 11 am

- Chicago HH Travel Survey Data
- Dynamic Travel times



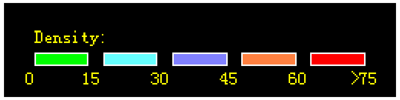


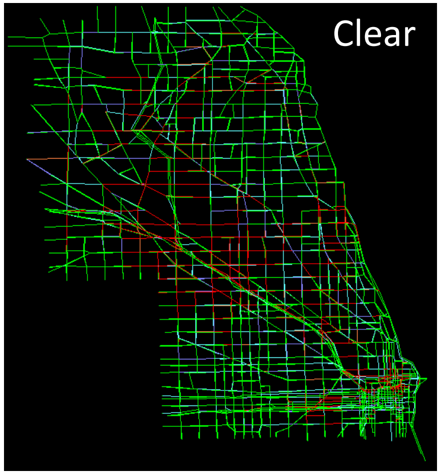


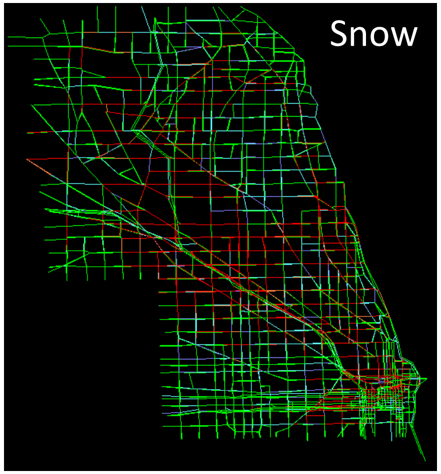
RWTM: Simulation Results

Effects of Natural Reduction, Information, Mode Choice and Departure Time Choice

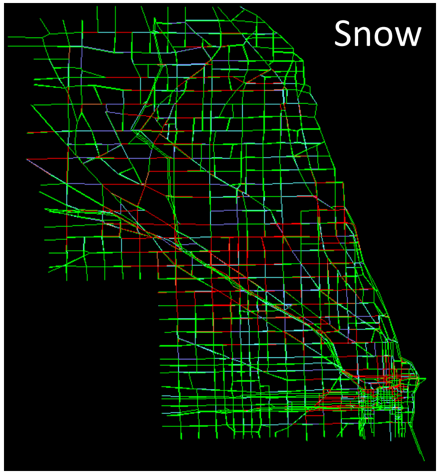
9:30 am Density:



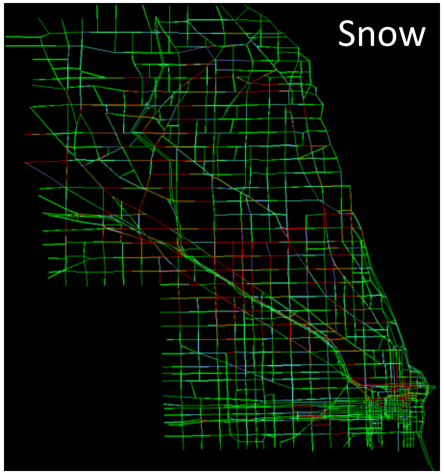




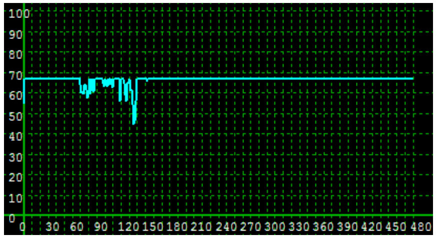
No Intervention

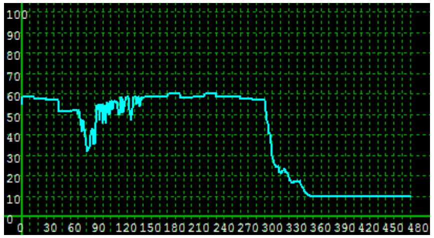


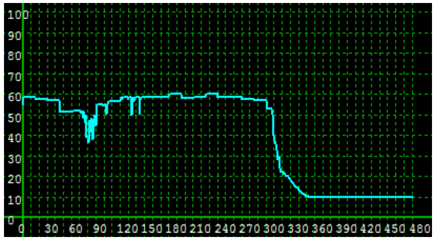
Cancelation + Teleworking

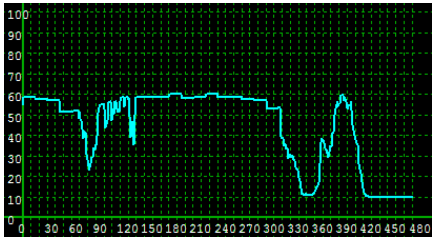


Cancelation + Teleworking + Mode/Dep.-T. C. 100% Info.



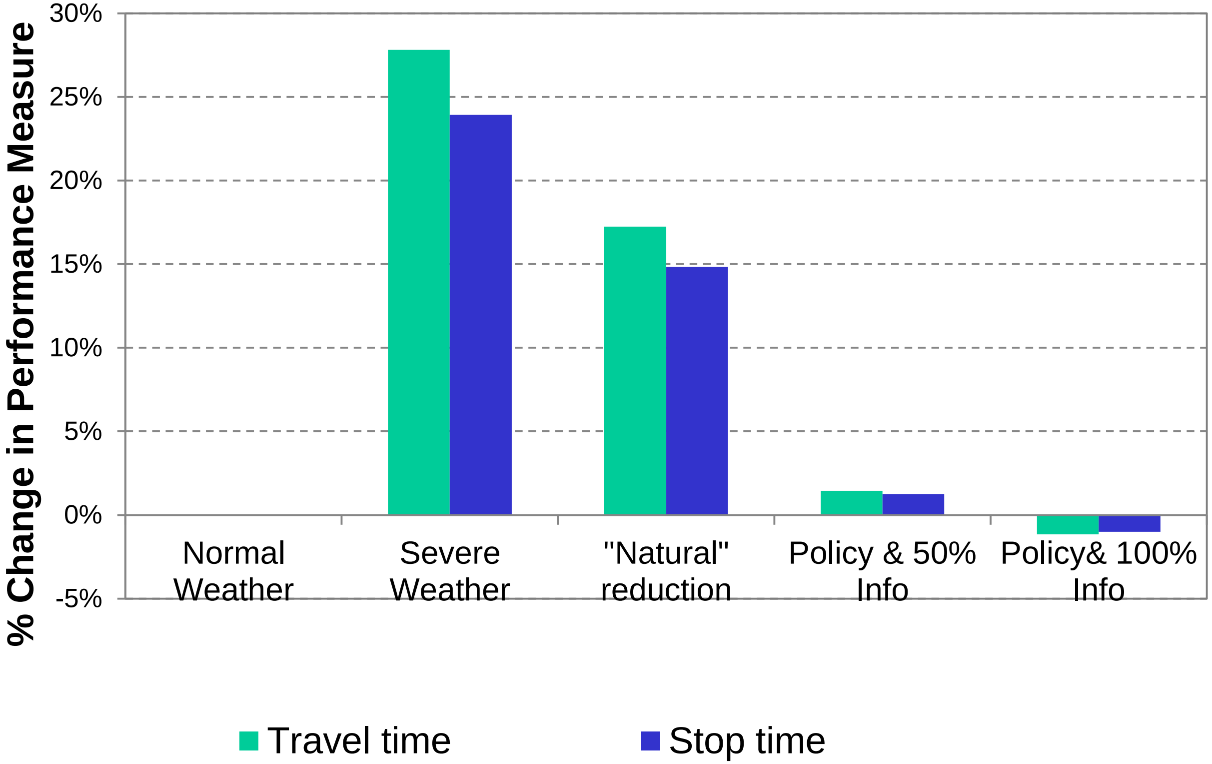






Kennedy Expy between Pulaski Rd and N Cicero Ave (west bound) (Speed)

- Chicago Network performance drops around 20 to 25 percent
- To retain a similar LOS as observed in clear weather conditions, en-route WRTM strategies need to be combined with policy strategies to reach a demand reduction between 15-20%



Limitations

- Except for route choices, all choices are on a outer loop
- Transit travel times are fixed (also bus travel time!) and not affected by the traffic condition, and no constraints on transit capacity is used
- Inter-modal trips (car part) is simulated with fixed transit travel times
- No full blown ABM model to incorporate indirect effects
- No equilibrium solution between DTA and a demand model

Integration

- Transit assignment integrated with DTA (dynamic bus travel times)
- ABM-DTA equilibrium

Equilibrium Concept for ABM and DTA Integration

Definition of Equilibrated State

- Individual travelers cannot increase their utility by unilaterally changing their activity chain (activities, durations, schedule).

- An activity chain is defined by a sequence of activities with departure time and duration for each of activity in the chain.

Definition of Variables

- CT-RAMP outputs individual trip chain with activity chain, departure time, and activity durations:

$$a_i = [a_i^1, a_i^2, \ldots, a_i^M]$$

$$\tau_i^{ABM} = [\tau_i^{1,ABM}, \tau_i^{2,ABM}, \ldots, \tau_i^{M,ABM}]$$

$$d_i = [d_i^1, d_i^2, \ldots, d_i^M]$$

- DTA load individual trip chain and outputs experienced travel time and/or generalized travel cost:

$$a_i = [a_i^1, a_i^2, \ldots, a_i^M]$$

$$\tau_i^{DTA} = [\tau_i^{1,DTA}, \tau_i^{2,DTA}, \ldots, \tau_i^{M,DTA}]$$

$$d_i = [d_i^1, d_i^2, \ldots, d_i^M]$$

Fixed Point Formulation

$$U(a,\tau,d) = S(P(A(U(a,\tau,d))))$$

Experienced Utility or Generalized Cost

Fixed Point Formulation

$$U(a,\tau,d) = S(P(A(U(a,\tau,d))))$$

Activity Chain from ABM

Fixed Point Formulation

$$U(a,\tau,d) = S(P(A(U(a,\tau,d))))$$

User path (trajectory) from assigning activity schedules

Fixed Point Formulation

$$U(a,\tau,d) = \boxed{S(P(A(U(a,\tau,d))))}$$

Utility obtained from simulating user path (trajectory) $P(A(U(a,\tau,d)))$

Possible Convergence Criteria

- **<u>Traditional measures:</u>** change in direct quantities (Trip table, travel time or cost) between successive iterations (k: iteration index; N: total population):

  – Trip table convergence (ABM)

  Average Difference of Trip (%) = $\frac{1}{N}\sum_{od\tau}\frac{|f_{od\tau}^{k,ABM}-f_{od\tau}^{k,DTA}|}{f_{od\tau}^{k,ABM}}\times 100$

  – Travel time convergence (DTA)

  Average Difference of Travel Time (%) = $\frac{1}{N}\sum_{od\tau}\frac{|TT_{od\tau}^{k-1}-TT_{od\tau}^{k}|}{TT_{od\tau}^{k}}\times 100$

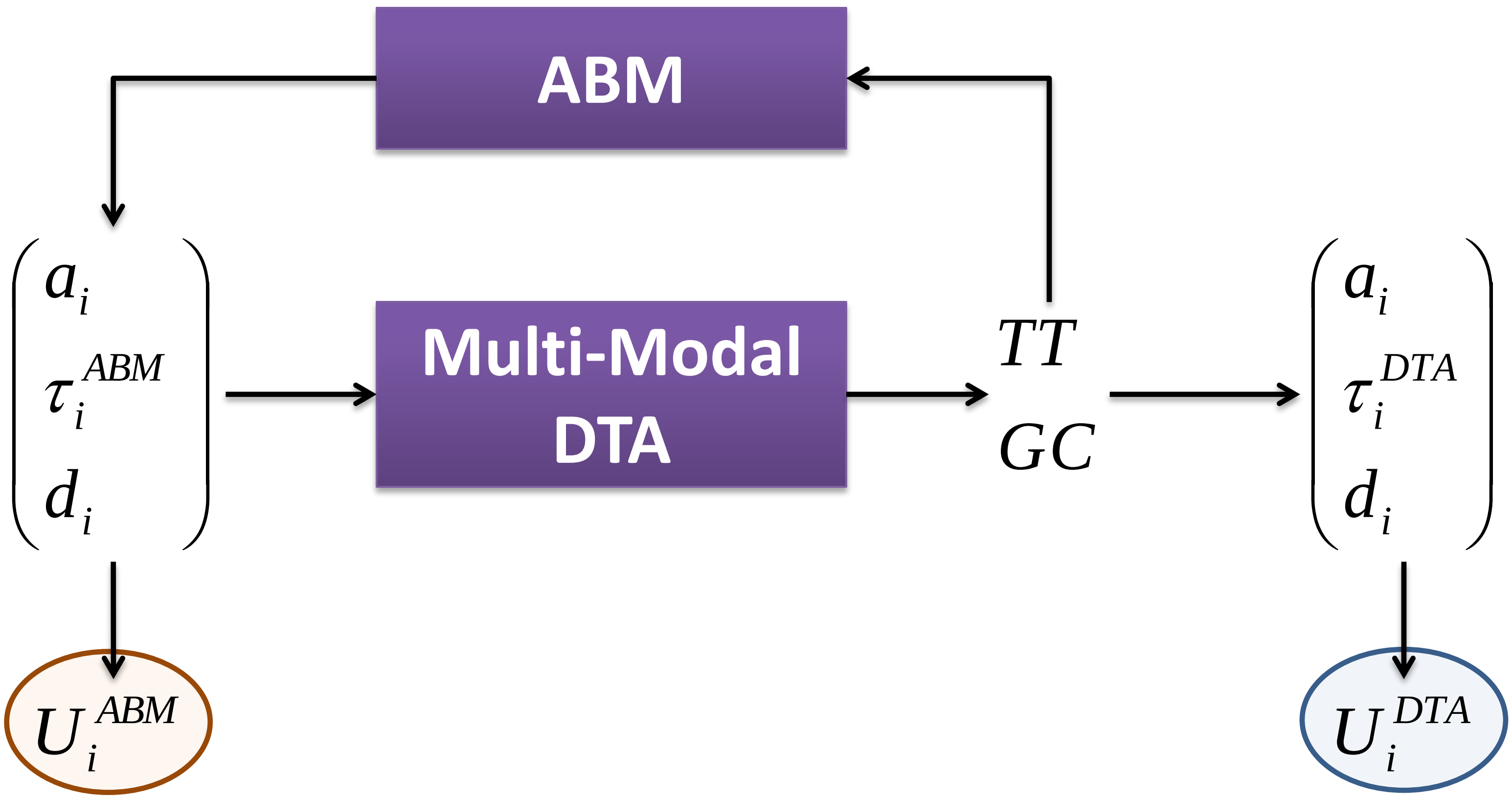
  Note that trip tables here are generated from chain of daily activities before and after DTA run.

  These measures might lead to convergence and consistency but not necessarily to equilibrium

Possible Convergence Criteria

- **Gap-based measures:** difference between individual experienced times or utilities and corresponding minimum values.
  - More directly related to equilibrium state properties
  - Provide consistent (reproducible) basis for comparing alternatives across different scenarios
  - Difficult to compute in certain cases

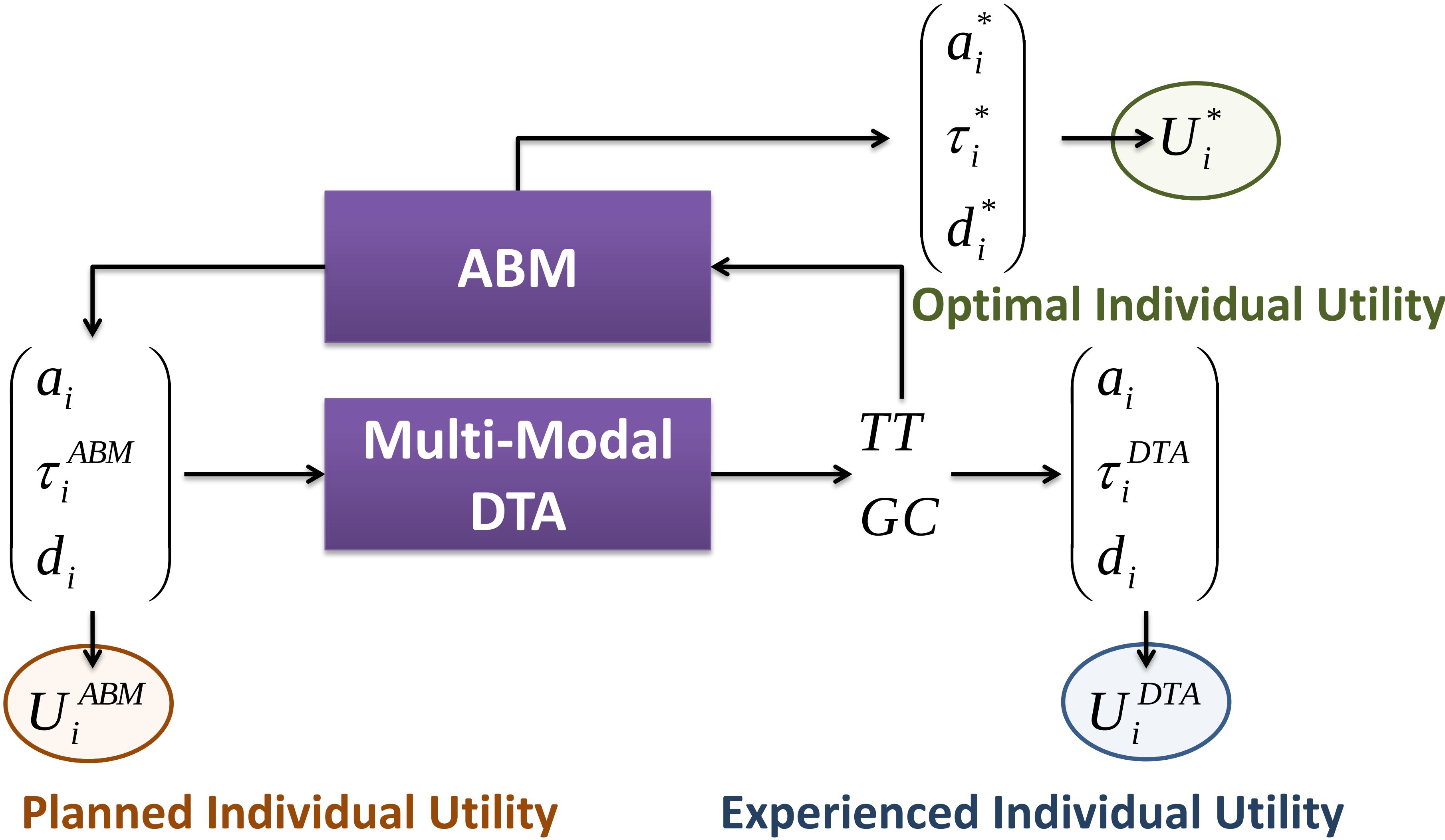
Linking the Variables



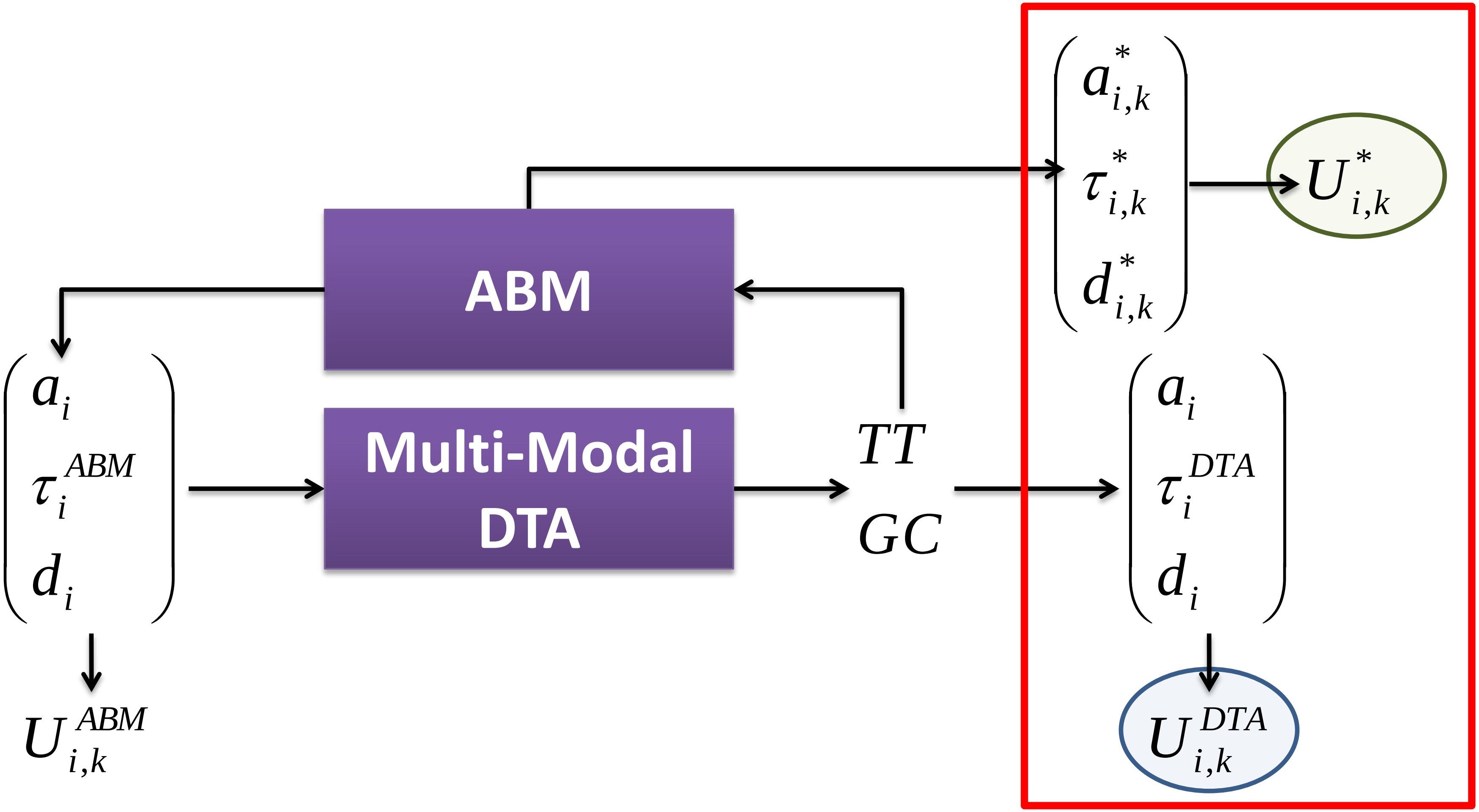
Planned Individual Utility

Experienced Individual Utility

Convergence Criteria: Gap Measure I



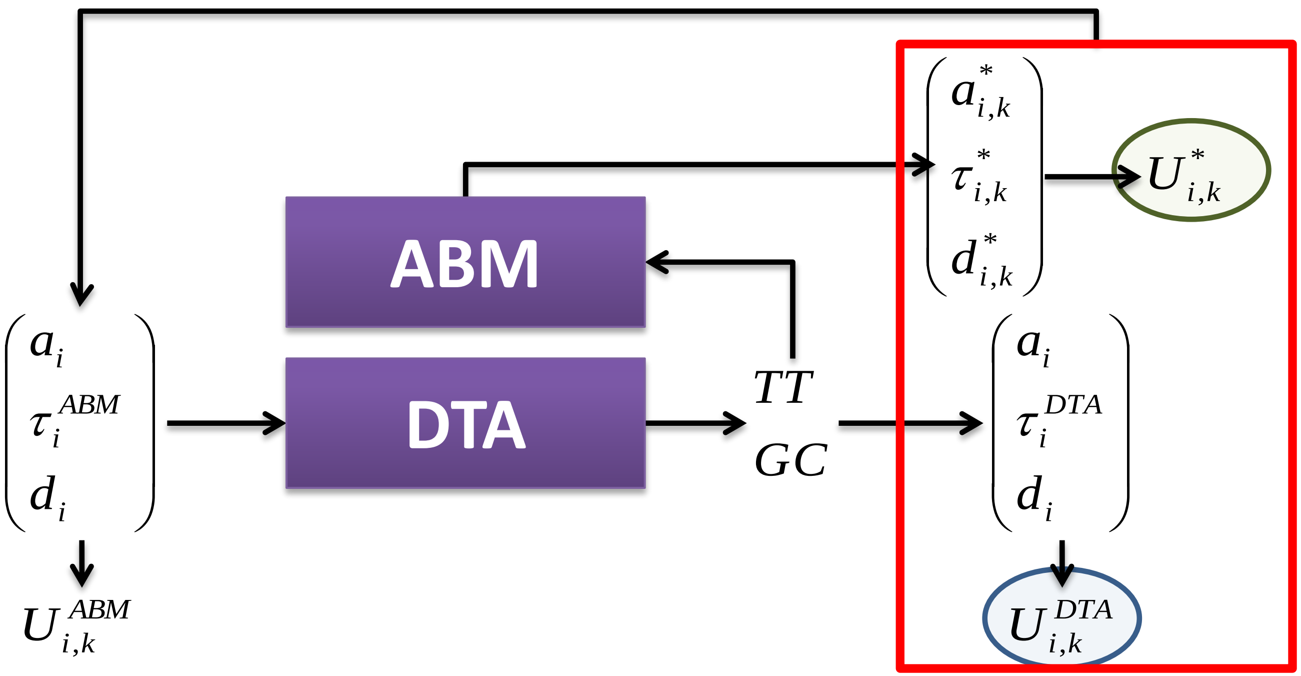
Convergence Criteria: Gap Measure II



At equilibrated state, we have: $U_{i,k}^{DTA} = U_{i,k}^*(a_k, \tau_k, d_k), \ \forall i \in N$

$$GAP = \frac{1}{N}\sum_i^N \left(\left|U_{i,k}^{DTA} - U_{i,k}^*(a_k, \tau_k, d_k)\right|\right)$$

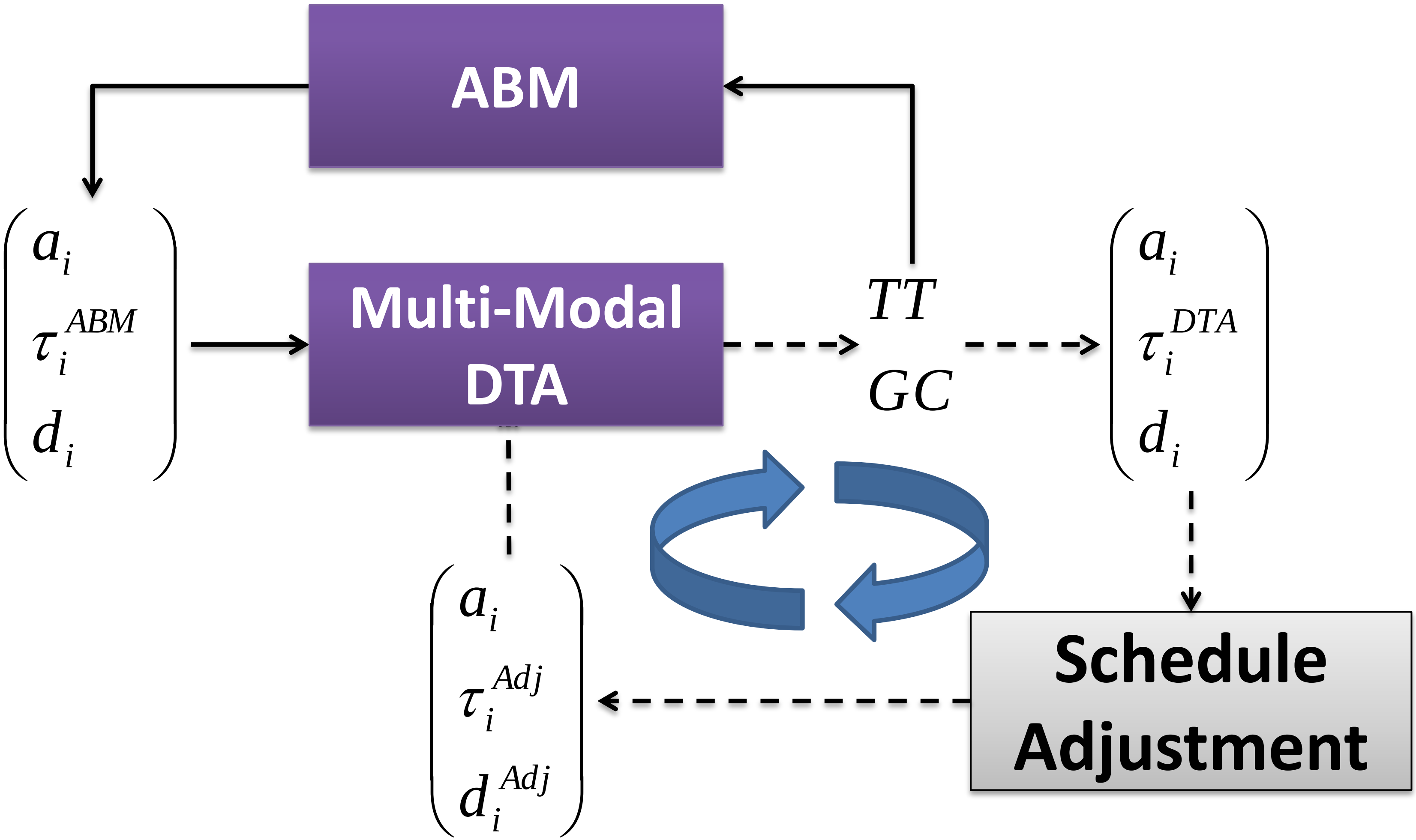
Solution Approach: Outer Loop



The planned activity chain for the next iteration is updated for a subset of travelers based on the magnitude of their gap measure (e.g. likelihood of selection for update proportional to experienced gap.

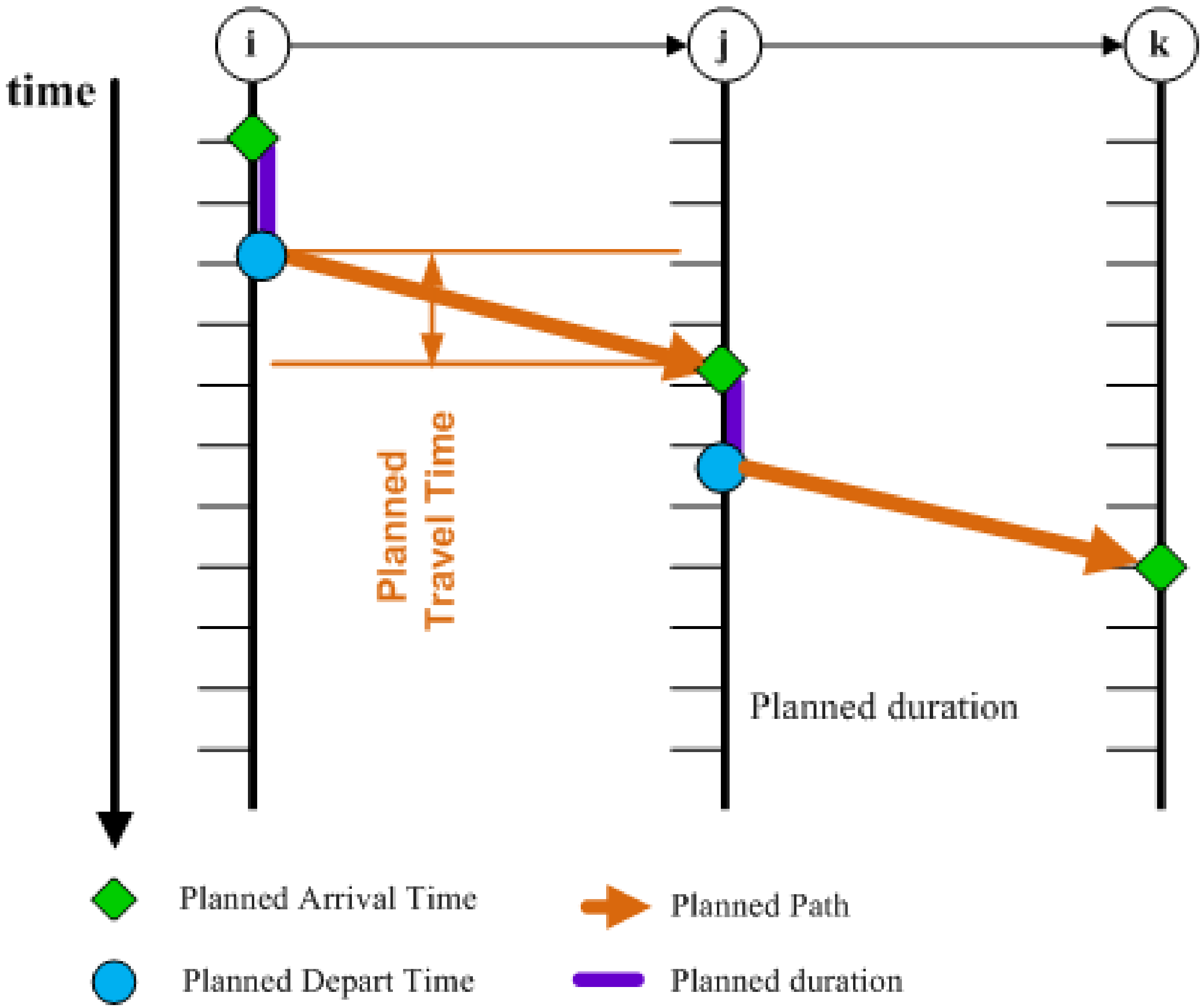
$$\begin{pmatrix} a_{i,k+1} \\ t^{ABM}_{i,k+1} \\ d_{i,k+1}\end{pmatrix} = \begin{pmatrix} a_{i,k}\\ t^{ABM}_{i,k} \\ d_{i,k}\end{pmatrix} + f(U^*_{i,k}, U^{DTA}_{i,k})\begin{pmatrix} a^*_{i,k}\\ t^*_{i,k}\\ d^*_{i,k}\end{pmatrix}$$

Solution Approach: inner loop

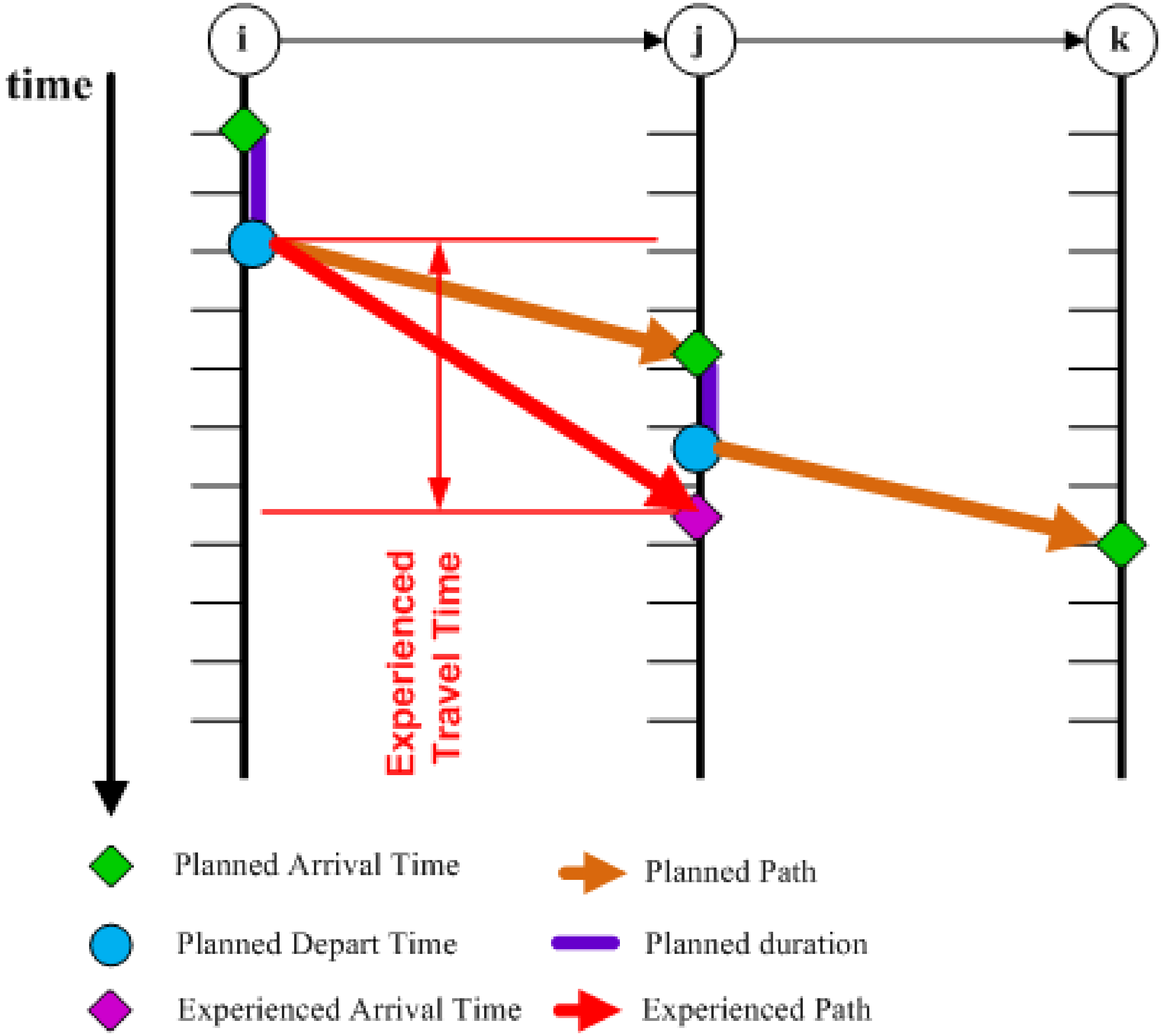


Objective: schedule consistency

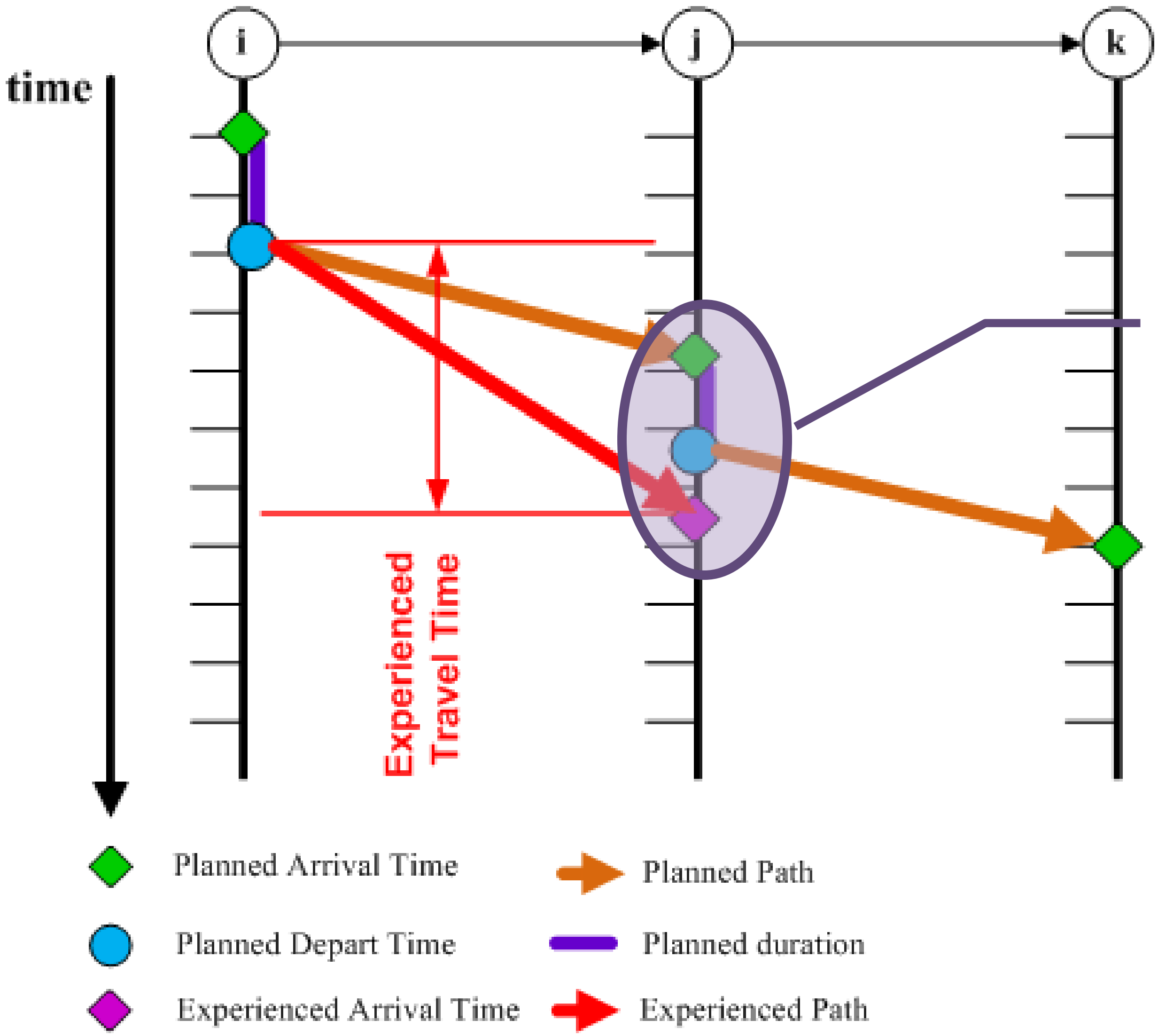
Schedule Consistency: Planned Activity Chain



Schedule Consistency: Experienced Activity Chain

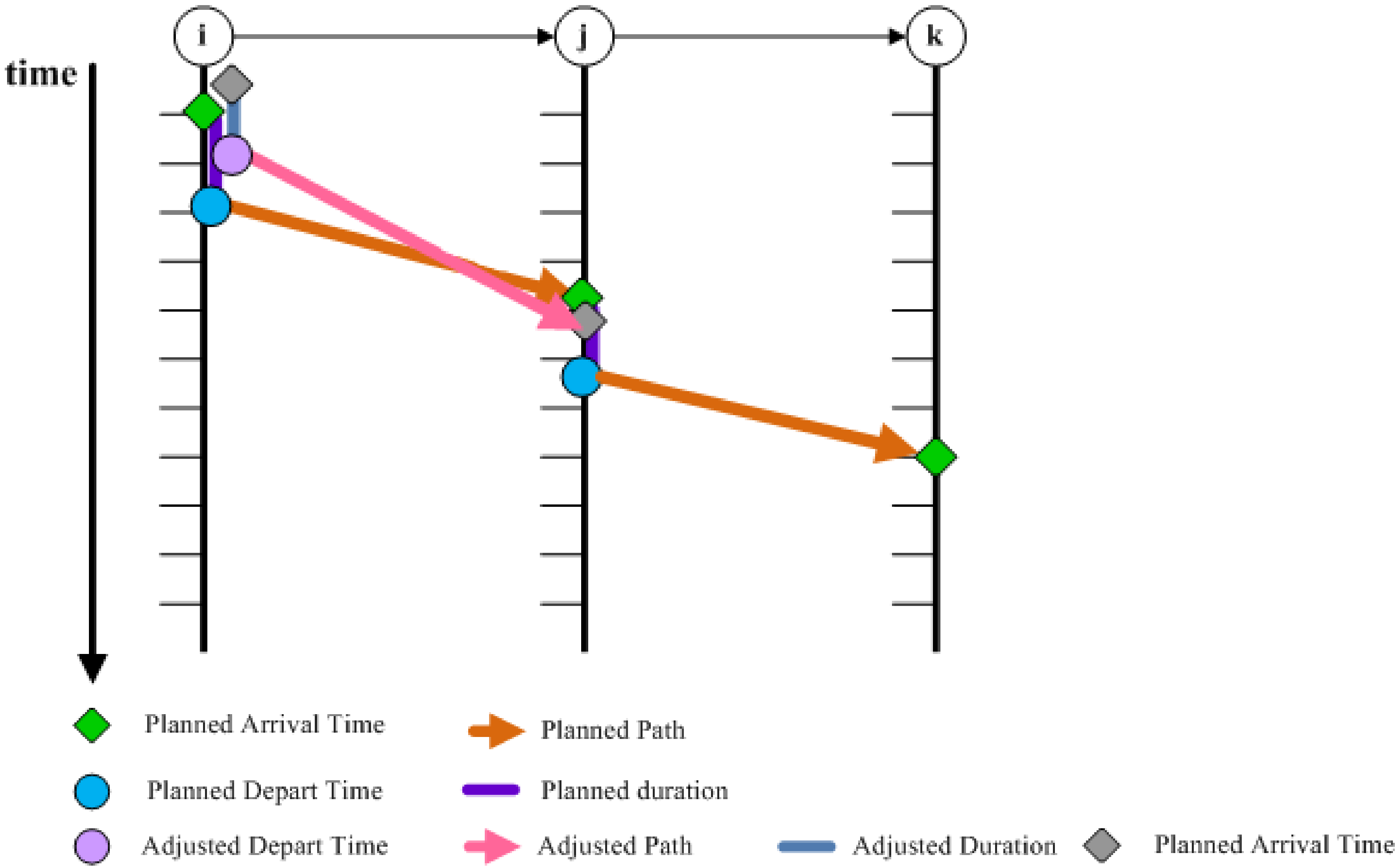


Schedule Consistency: Experienced Activity Chain

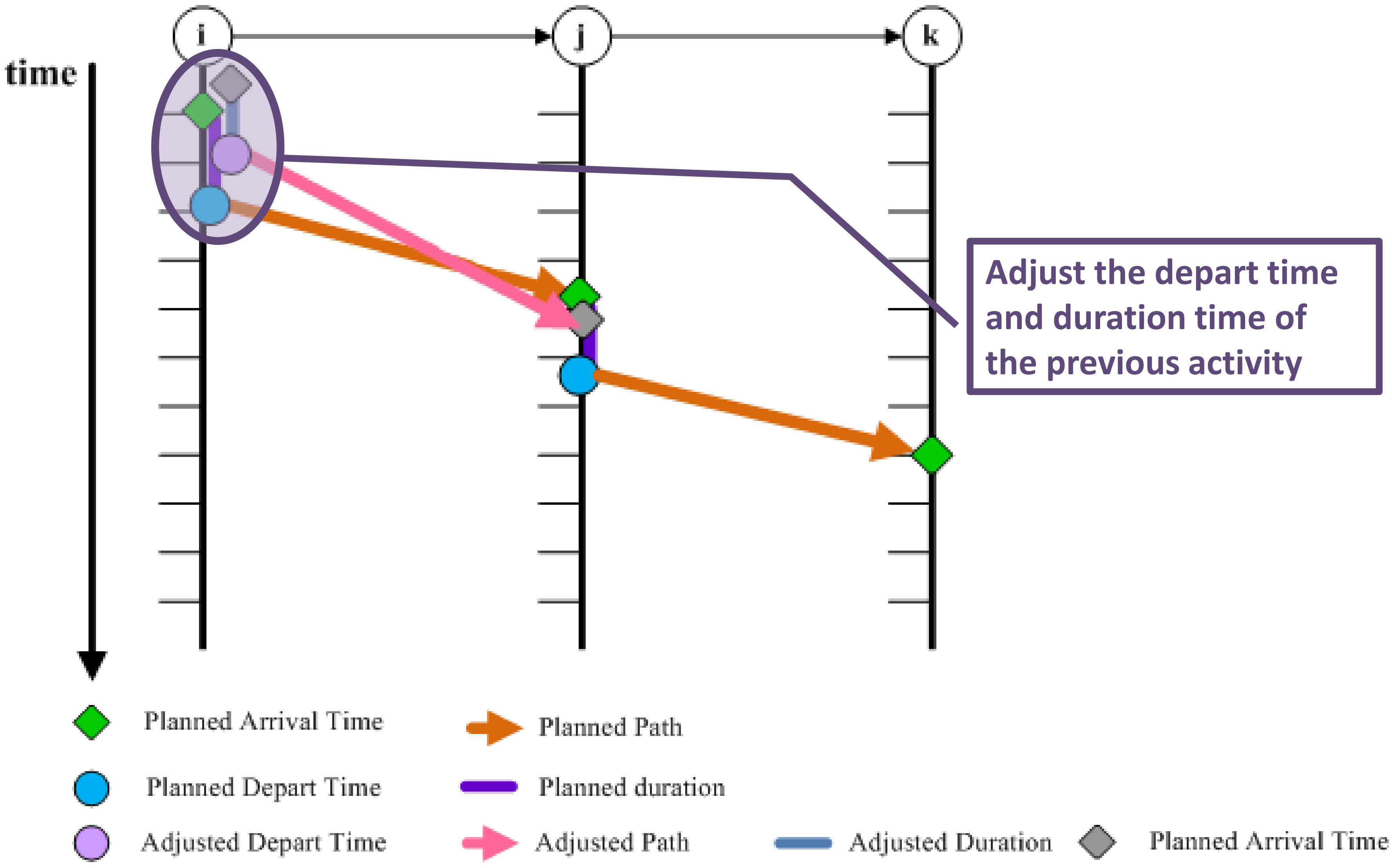


The experienced arrival time is later than the planned depart time

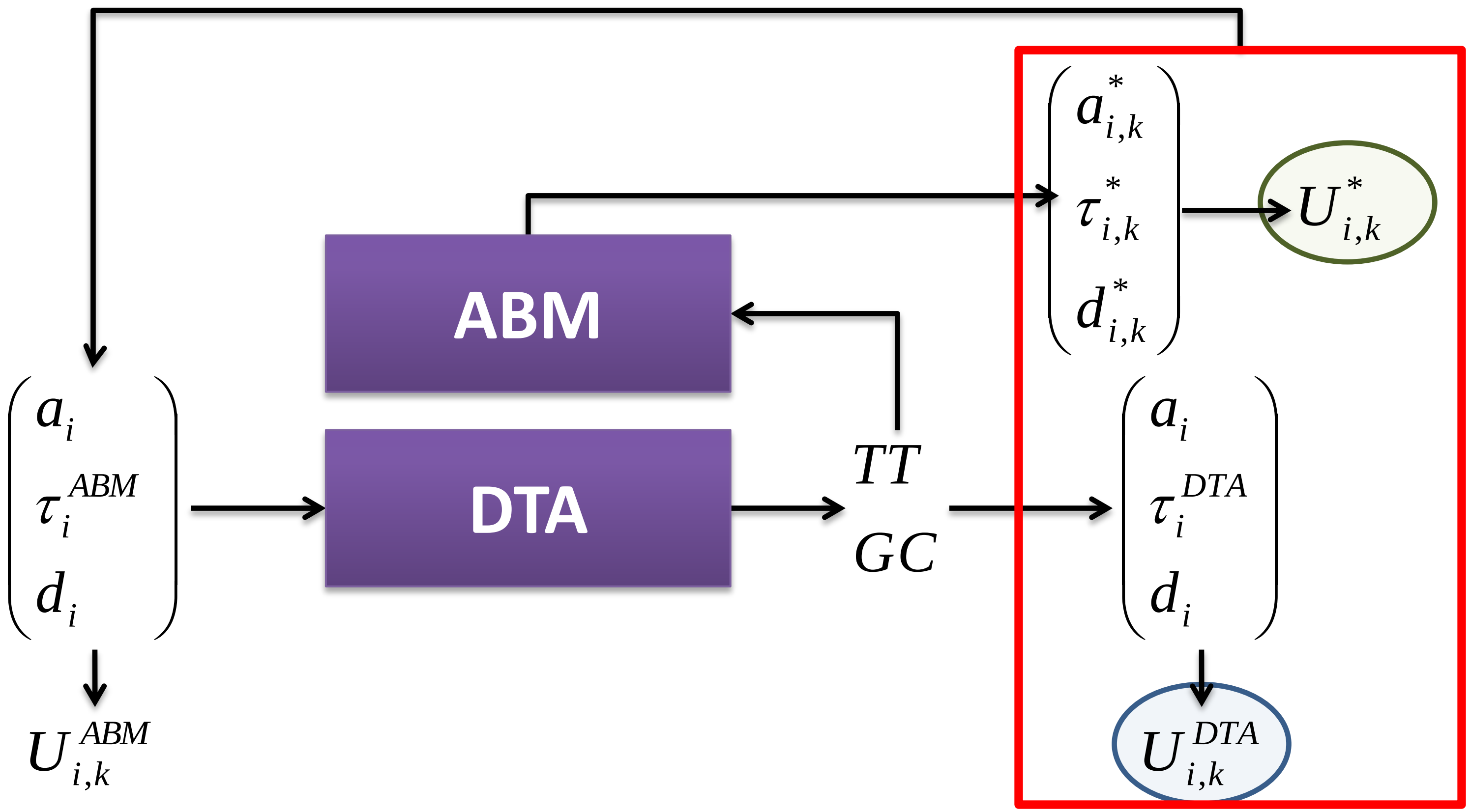
Schedule Consistency: Adjusted Activity Plan



Schedule Consistency: Adjusted Activity Plan

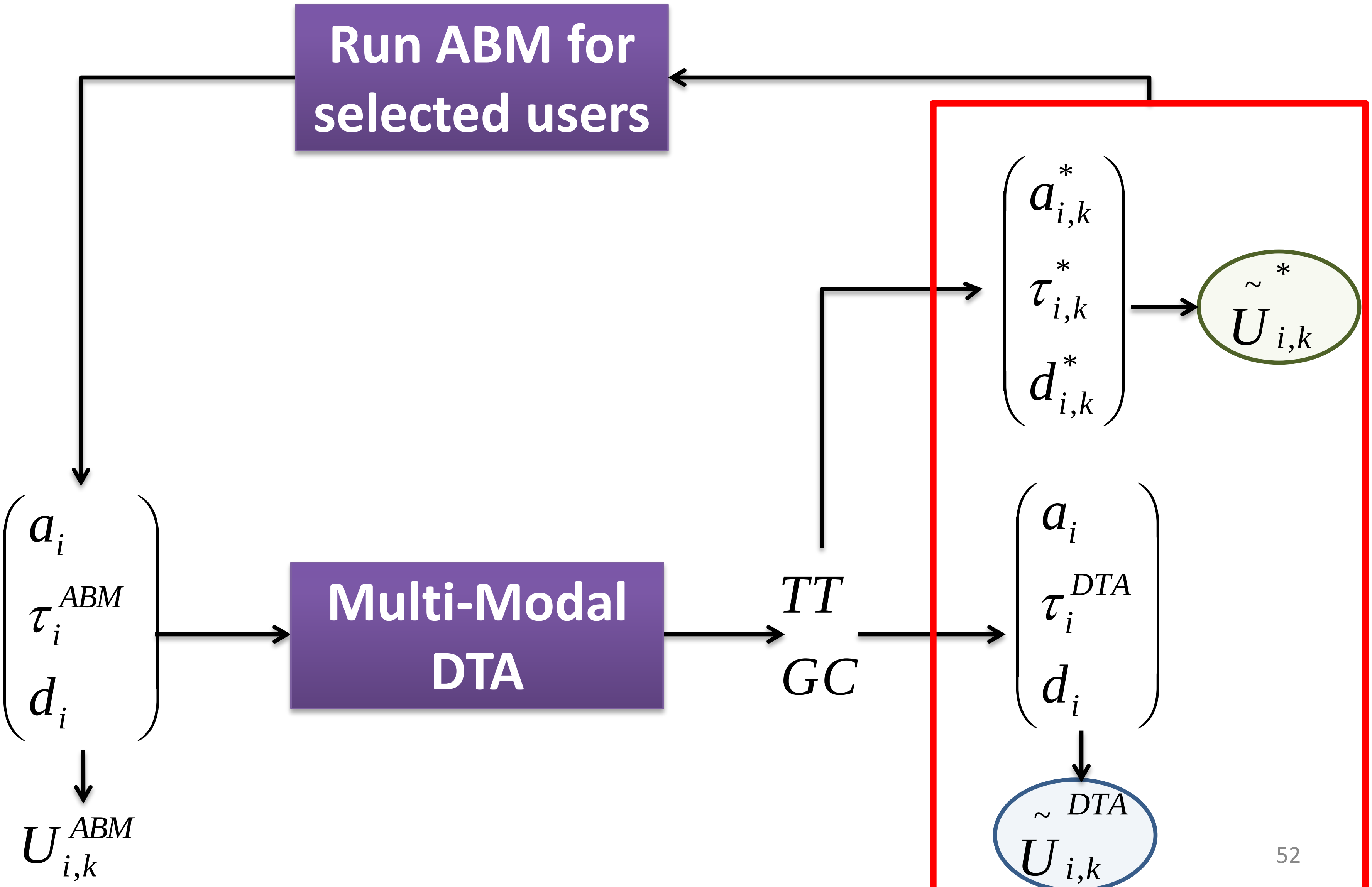


Solution Approach: Computational Considerations for Outer Loop



However calculating U^{DTA} and U^* requires full run of ABM which is computationally demanding; instead we propose defining "surrogate utilities" that do not require running the full ABM $\tilde{U}^{DTA}$ and $\tilde{U}^*$

Solution Approach: Computational Consideration for Outer Loop



Real-Time Activity Adjustment and Rescheduling

Trip-level and Real-time Integration

Assuming a given equilibrated day-level Integrated activity plans:

- In **Trip-level Integration**, an individual trip travel time is fed back to the **activity adjustment module** after completion of each particular trip that may result in rescheduling of the subsequent activities of the same person.
- The activity adjustment module can be defined **inside the either of ABM or DTA environment**.
- This approach has strong advantages for **analysis of short-term shocks**, accidents, special events, holidays, severe weather conditions, emergency evacuation, and other situations where the system is apparently not in an equilibrium state.
- It is also called for to study **day to day variability**, under different realizations or instances from the **“usual” pattern**.
- In **Real-time Integration**, the feedback from the network simulation model to the activity adjustment module is implemented even earlier than the end of the trip, i.e. in the *en-route* status of the traveler.

Trip-level Integration Algorithm

Set *n = 1*

At an iteration I:

For n = 1 to T/t

1- Route the list of trips in the current interval *nt* based on the current activity schedule.

2- Simulate the trips departing at *nt* and the incomplete trips already in the network

3- Examine all trips that can start in period *(n+1)t*

a) If the current trip of any activity chain has not been completed at the end of *(n+1)t* time interval:
Do not start the subsequent trips of that activity chain for DTA in the next period (Experience)

b) If the current trip of any activity chain has been completed at the end of *(n+1)t* time interval:

I. Route subsequent trips of the activity chain for period (n+1)t to obtain anticipated delays
II. Correlation between previous iteration and previous time periods to obtain anticipated delays

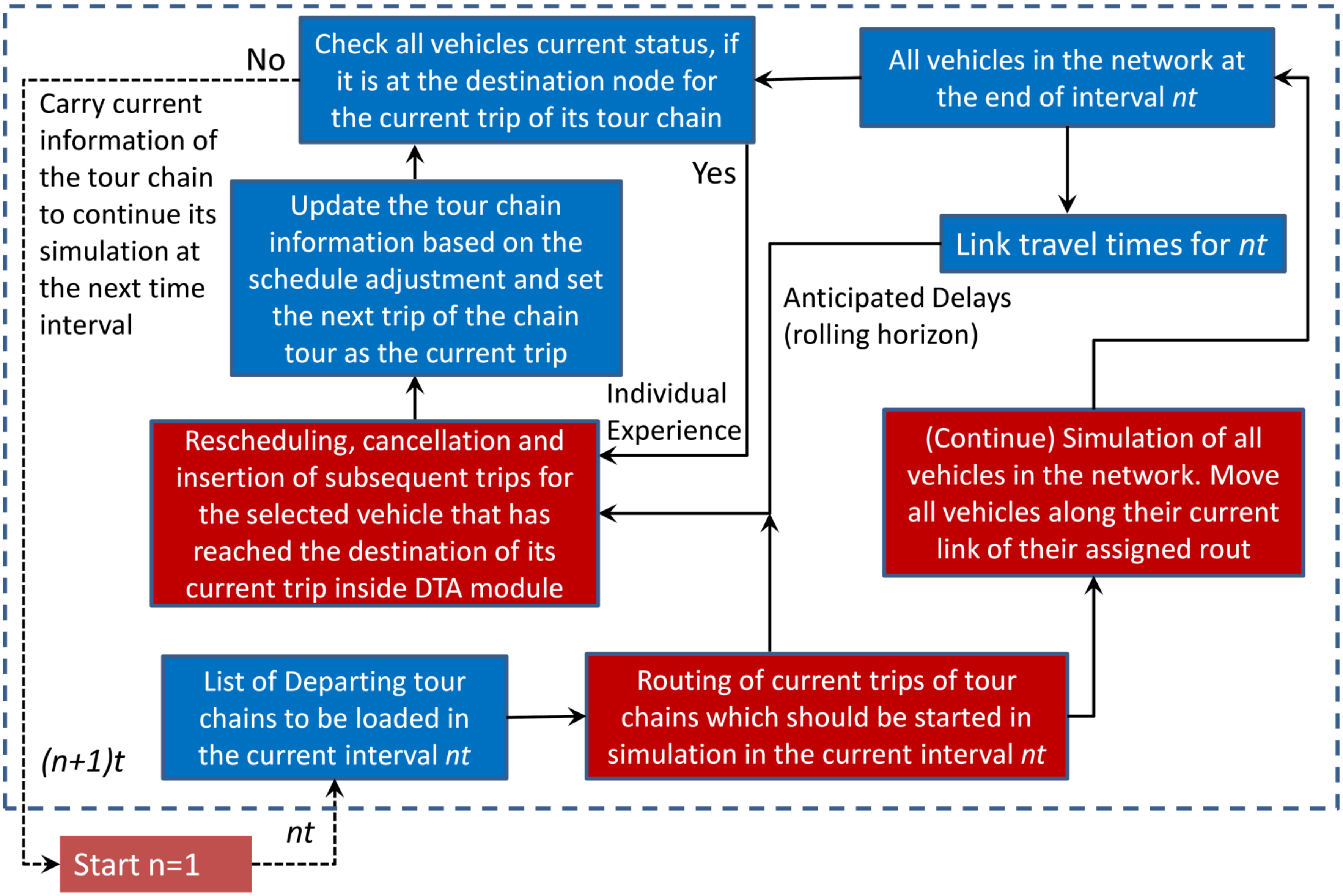
Then based on **anticipation**, individual can postpone/cancel/depart immediately subsequent trips of the activity chain and update activity chains

4- Set *n = n+1*

End For

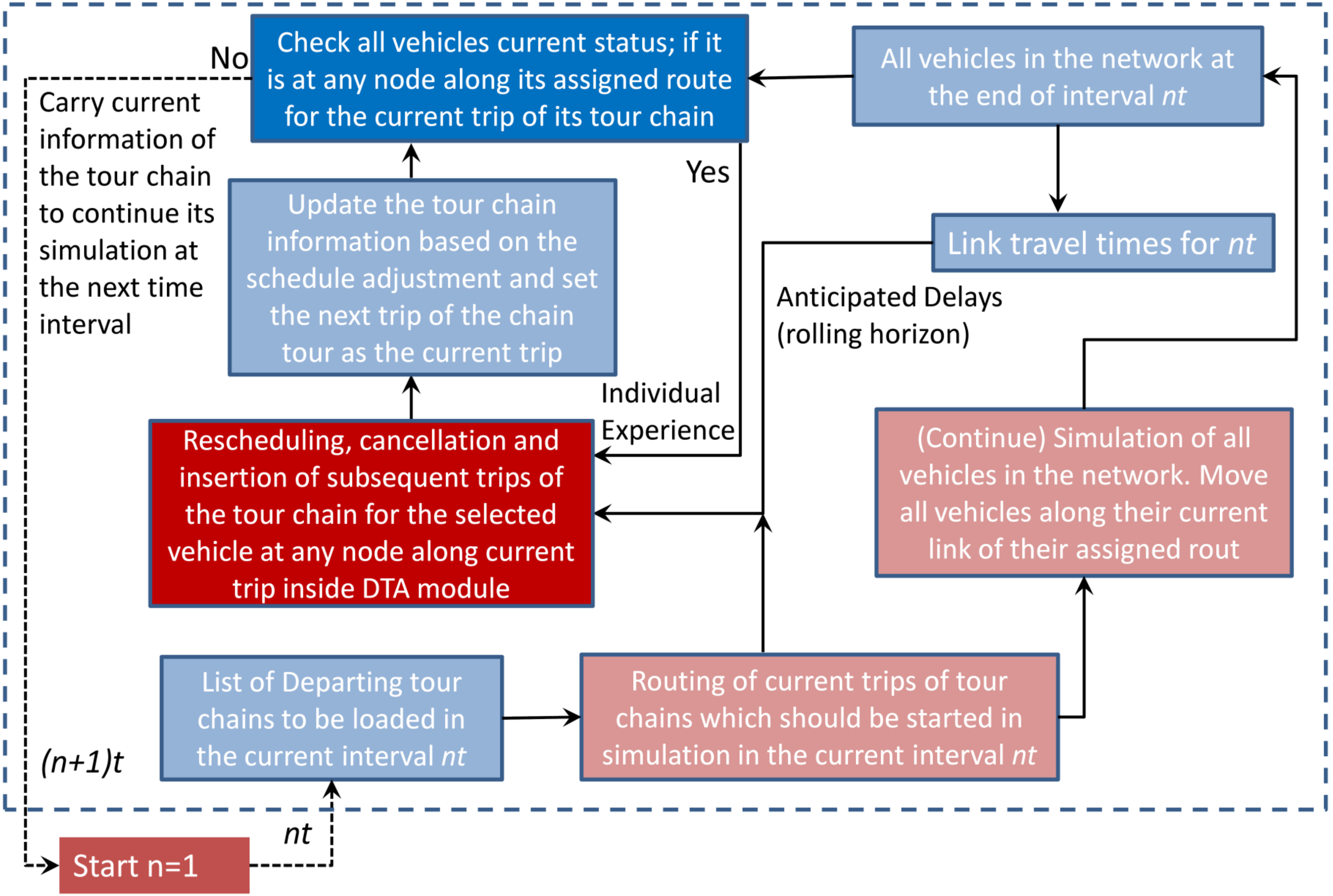
Trip Level Integration

At single time interval *nt. t is the simulation interval (6 sec, default value in DTA). Done for n=1 to T/t.*

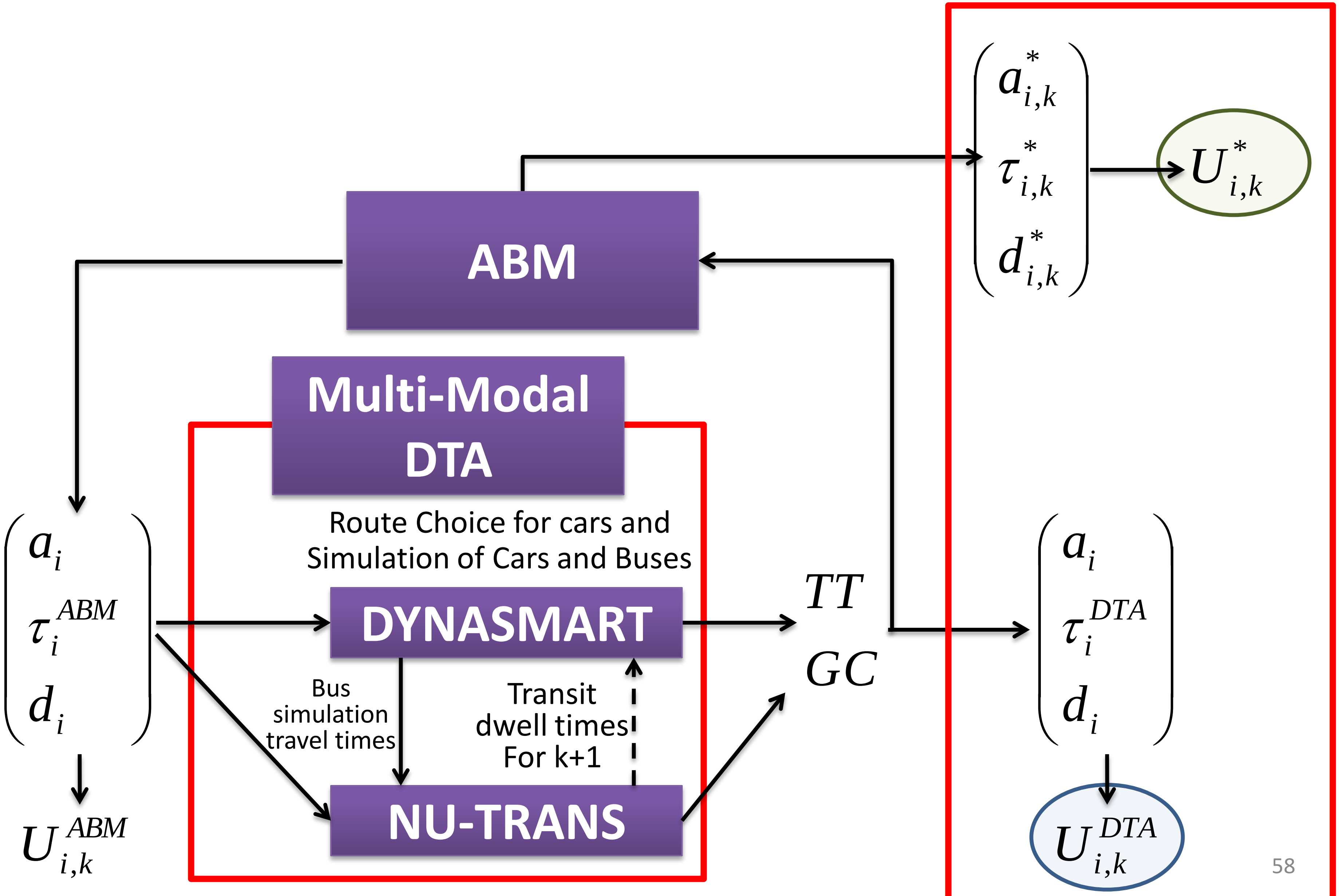


Real Time Integration

At single time interval *nt. t is the simulation interval (6 sec, default value in DTA). Done for n=1 to T/t.*



Multi-Modal DTA



Conclusion and Next Steps

- Network representation for CMAP network well developed and extensively debugged; currently operational
- Demonstrated framework for integrated ABM and DTA for Chicago network, with subset of choice dimensions: route, mode, and departure time, in applications to toll pricing and weather-related operational planning
- Real-Time Activity Adjustment and Rescheduling: Important frontier in extending ABM logic into dynamic mechanisms for integration in DTA simulation
- Generalized Equilibrium Concept proposed with activity schedules: practical operational definition for integrating long-term ABM and DTA.