How Managed Lanes Can Be Analyzed Using Advanced Travel Demand Models

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The Starting Point:
What 4-Step Models May Be Capable of

- Creating HOV/non-HOV trip tables
  - In a limited way
- Considering (aggregately) how tolls affect route choices
- Considering (aggregately) how tolls affect mode (and possibly destination) choices
- Effects of broad temporal differences in prices (peak vs. off-peak) on route/mode choice
  - But not time of day choice

General Advantages of Activity-Based Models

- Disaggregate application – reduces aggregation error
- More realistic behavioral basis than four-step models
- Modeling of entire tours (trip chaining)
- Ability to present results for any definable market segments

Specific Features of Activity-Based Models Related to Managed Lanes

- More complete consideration of carpool formation
- Time of day choice modeled explicitly
- Finer temporal resolution for time-varying pricing
- Ability to simulate individual values of time
- Ability to provide person characteristics (including VOT) into traffic simulation

HOWEVER…there are some "howevers"

More Complete Consideration of Carpool Formation

- Carpool mode choices simulated at tour and trip levels, including mixed-mode tours
- Consideration of intra-household interactions
  - Most non-work carpooling is among household members
  - Escort activities are considered as a separate purpose in activity-based models
  - Joint travel is usually considered explicitly in modern ABMs

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Time of Day Choice Modeled Explicitly

- Time of day choice modeled at the tour and stop levels
- So the effects of time-varying tolls on time of day choices can be modeled
  - Peak spreading
- HOWEVER…activity-based models still apply choices as sequential

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Finer Temporal Resolution for Time-Varying Pricing

- Half hour resolution typical in modern ABMs
- Choice models can accept separate cost (and time) skims (depending on programming) for each period
- HOWEVER…tolls may vary at finer time intervals than the model accommodates

Ability to Simulate Individual Values of Time

- Activity-based models simulate each individual in a synthetic population
- Values of time are known to vary among similar individuals
  - Some people are just cheapskates
- So in the simulation, a probability distribution can be used to simulate each individual's value of time
- HOWEVER…nearly all existing ABMs use aggregate assignment
  - So the individual VOTs must be aggregated
  - However, segmentation of trip tables for highway assignment by VOT level can be done

Modeling Express Lanes Using Dynamic Traffic Assignment Models

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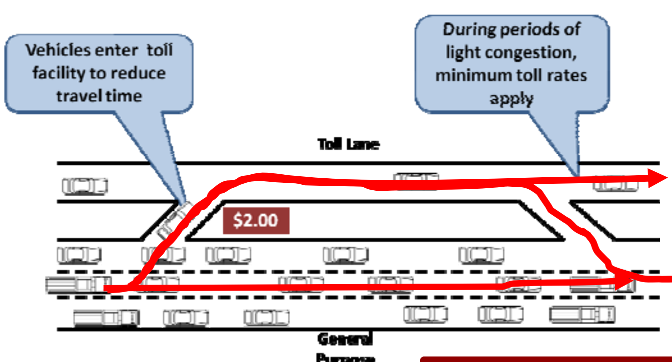
DynusT Laboratory
University of Arizona

Florida DOT Managed Lane Workshop
May 22, 2013

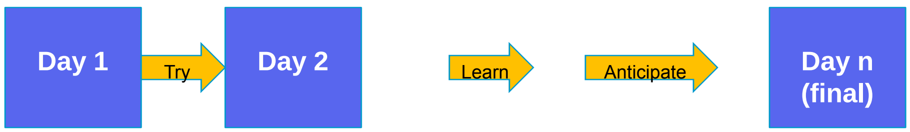
DTA Assumptions

- By using DTA, you accept the following assumptions
  - Estimating lane demand is a **route/departure** choice, not a mode choice problem.



DTA Assumptions

- By using DTA, you accept the following assumptions
  - **Learning** and **adaptation** is part of route choice decisions (in lieu of instantaneous or reactive route choice behavior).



DTA Components for Pricing Analysis

- Pricing model (optional, depending on pricing scheme)
- Route/lane choice model
- Departure time choice model
  - Developed separately
  - Loop back to demand model
- Network needs to large enough to include most trips through the facility. A small area over-penalizes tolled facility.

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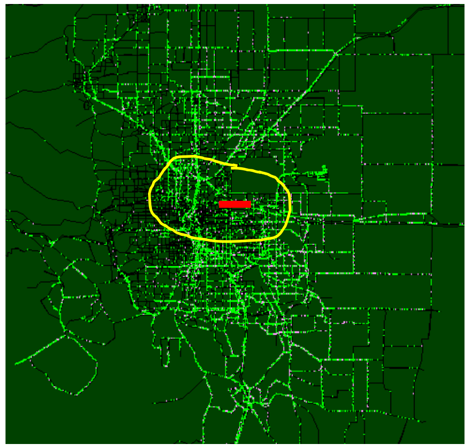
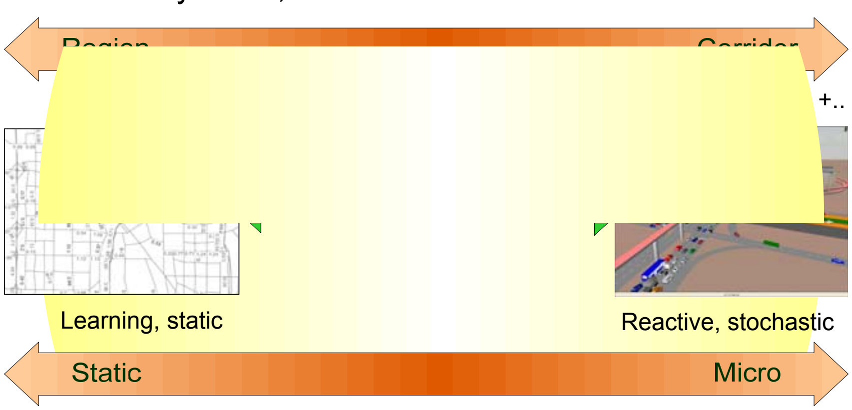
Sub-Area Scope Implication



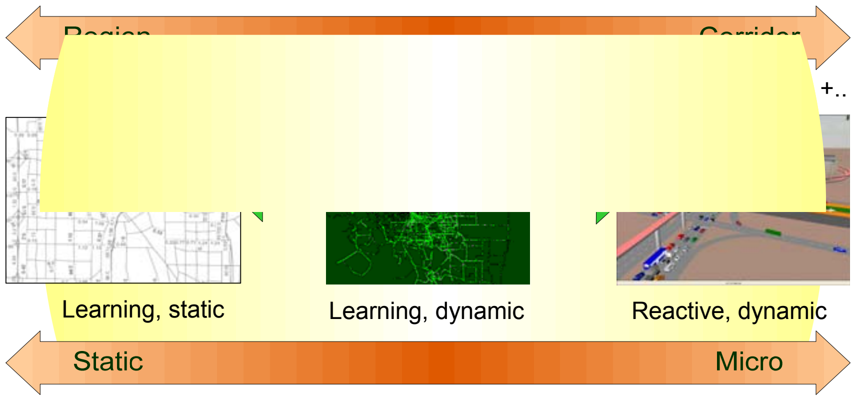
Why DTA for Express Lane Analysis Given We have had Macro-Micro

- Macro-Micro inconsistency
  - Traffic dynamic, route choice behavior



Why DTA for Express Lane Analysis Given We have had Macro-Micro

- Better consistency with Macro-Meso-Micro integration



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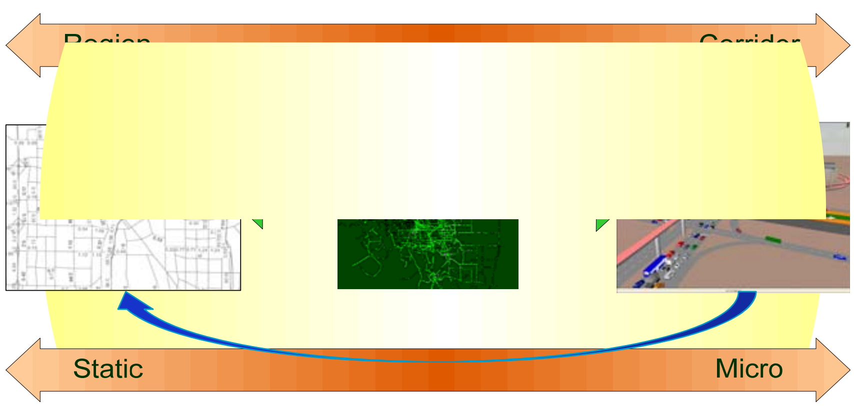
Why DTA for Express Lane Analysis Given We have had Macro-Micro

- Critical Bridge from Macro to Micro and feedback



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Pricing Schemes in Real World

- Samples of a wide range of configurations

DUE (HOV Lanes, Toll Roads, Managed Lanes); DUE/Non-Eq (Managed Lanes – Congestion Responsive)

Facility	HOV	SOV/Two-Axial	Commercial/3 + Axial
HOV Lanes	✓ (Free)	⊘ (Very High)	⊘ (Very High)
Toll Roads - Fixed rate - ToD rate	✓ (Free/Normal/ Low)	✓ (Normal)	✓ (High)
Managed Lanes - Fixed rate - ToD rate - Congestion Responsive	✓ (Free)	✓ (Varying)	? (Varying, higher)

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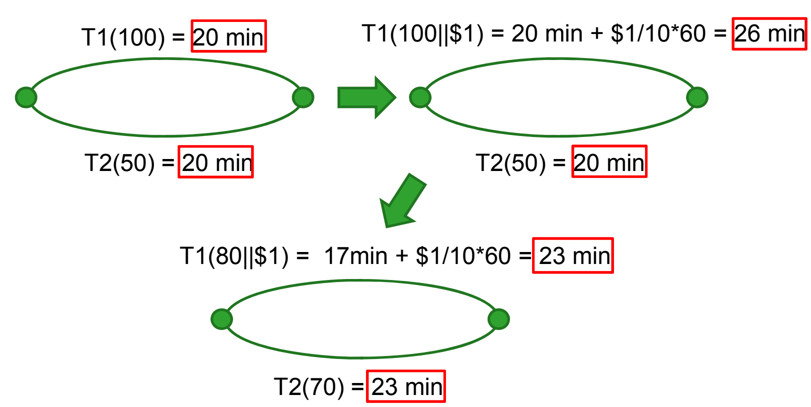
Analyzing Tolling in a Simple Static Case



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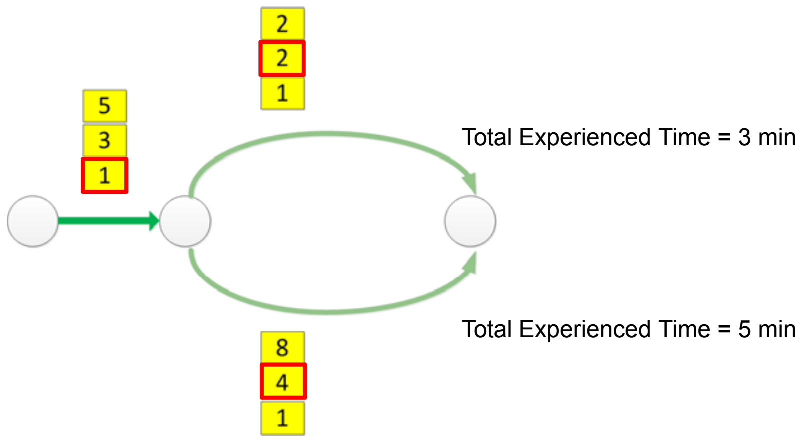
Dynamic Case Fundamental



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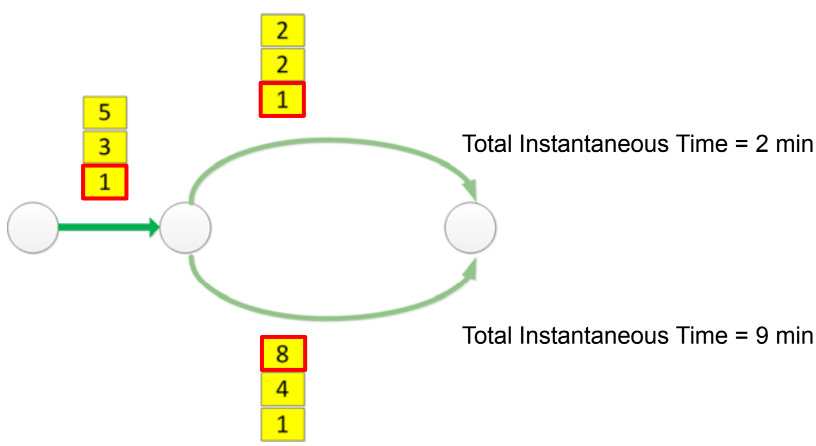
State/Instantaneous View of the Same Situation



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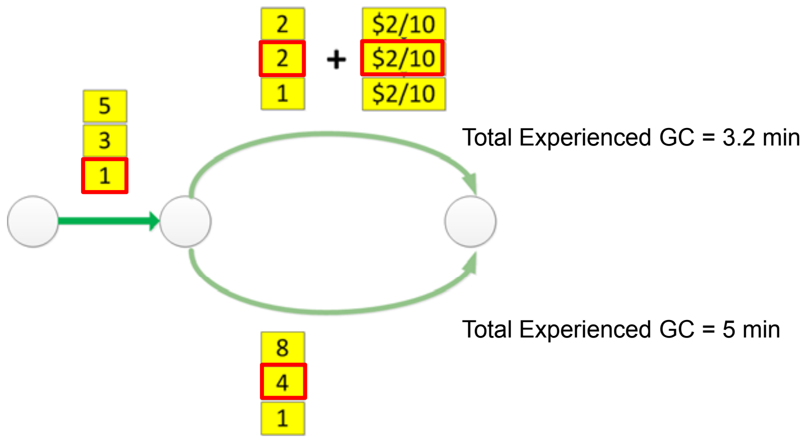
Dynamic Case With Static Toll



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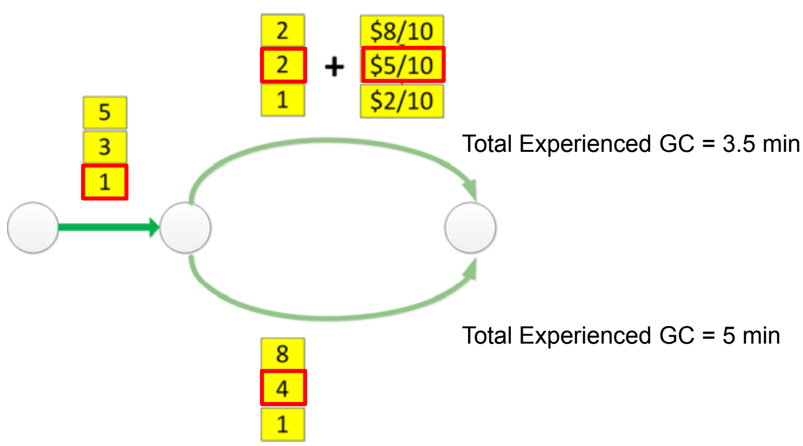
Dynamic Case With Dynamic Toll



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Revenue/Throughput Maximizing Pricing Model

- Pricing Model (vary by software)

+ $8/10
$5/10
$2/10

$$\max Z = \sum_{l \in L} \sum_{t \in T} k_l^t v(k_l^t)$$

Subject to,

$$v(k_l^t) \geq v_l^0, \qquad \forall\, l \in L, t \in T$$

$$\frac{d_l}{\theta_n}\left(\frac{1}{\bar{v}_l^t} - \frac{1}{v(k_l^t)}\right) \leq \pi, \qquad \forall\, l \in L, t \in T$$

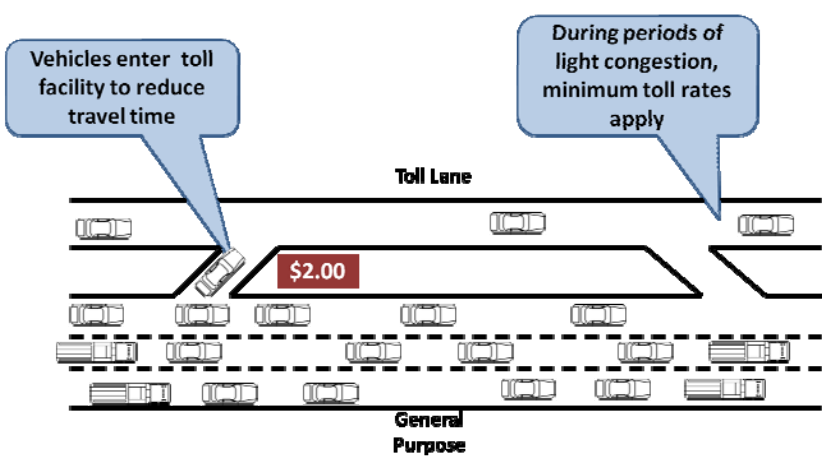
$$\frac{d_l}{\theta_n}\left(\frac{1}{\bar{v}_l^t} - \frac{1}{v(k_l^t)}\right) \geq \pi - \varepsilon, \qquad \forall\, l \in L, t \in T$$

Other DUE Conditions

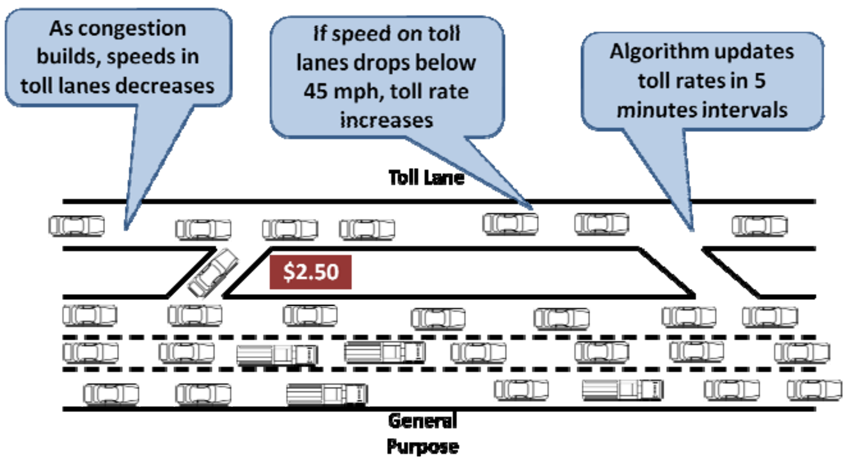
Where,

k_l^t : density of CP segment l at time t
$v_l^t(k)$: speed of CP segment l at time t
v_l^0 : required minimal operating speed inside HOT lane
$\bar{v}_l^t$: average speed on the GP lane
d_l : distance of the CP segment l
π_l^t : toll rate for CP segment l at time t; this is the decision variable.
θ_n : value of time for vehicle type n
ε : threshold

Congestion Responsive Tolling



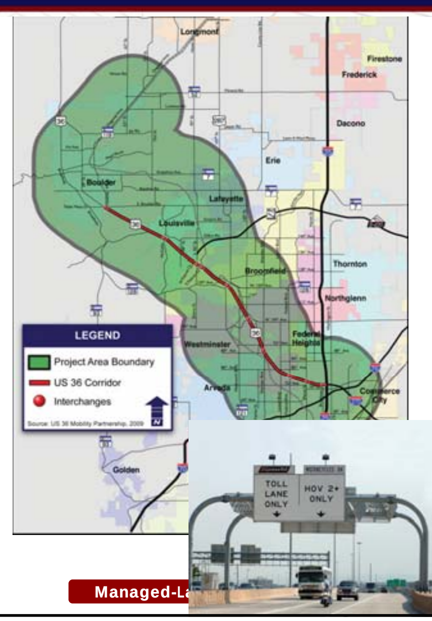
Congestion Responsive Tolling



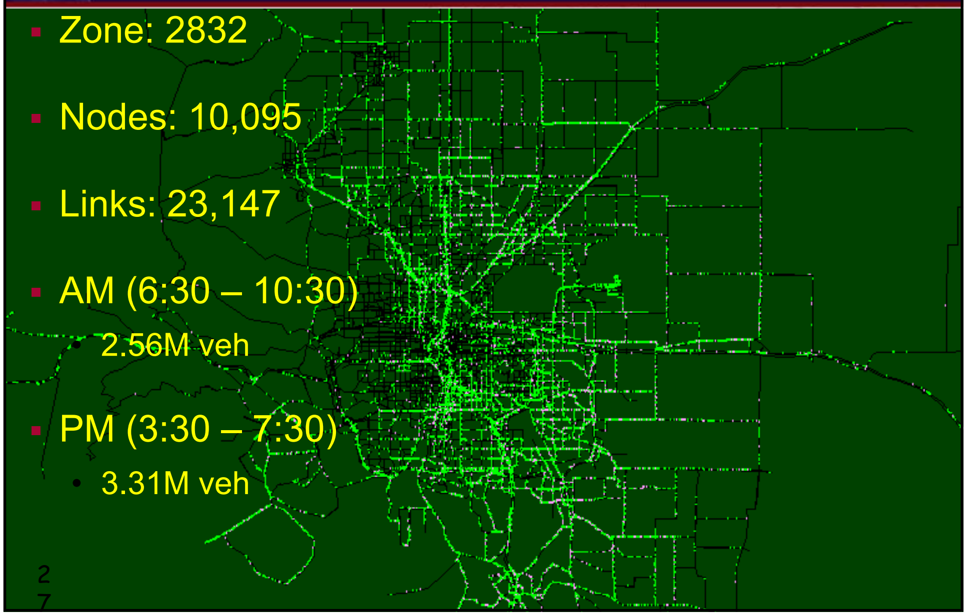
Maximize throughput while maintaining target speed

Denver-Boulder US36 Congestion Pricing

- TIGER Applications
- Modeled 3 buildout strategies
- Estimated
  - Congestion
  - Revenue
  - Travel time
  - Fuel consumption
  - Emission



DRCOG Regional Model in DTA



- Zone: 2832
- Nodes: 10,095
- Links: 23,147
- AM (6:30 – 10:30)
  - 2.56M veh
- PM (3:30 – 7:30)
  - 3.31M veh

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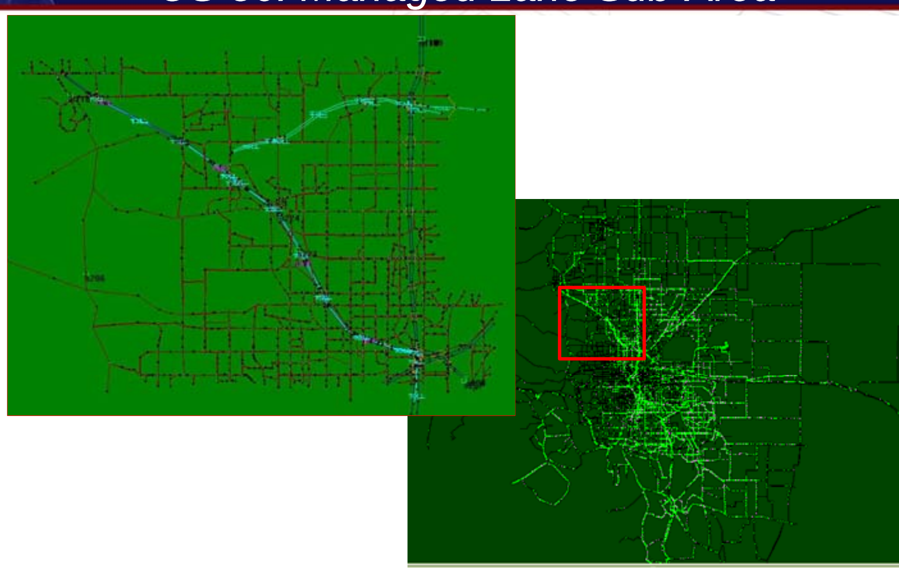
US 36. Managed Lane Sub-Area



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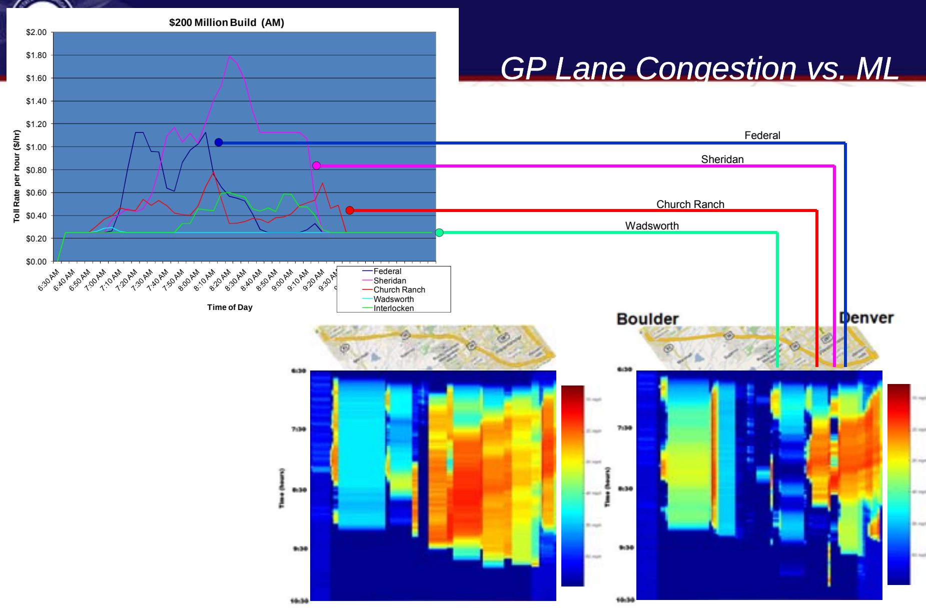
GP Lane Congestion vs. ML



No Build

$260 Million Build

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Addressing Heterogeneity

- Value-of-Time (VoT) plays a critical role in generalized cost type of DTA approach.
- VoT differs by trip purpose/socio-economic/ location attributes.
- Increasing interesting in DTA and Activity-Based Model (ABM) integration
  - ABM produces trip/person specific VoT.

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Addressing Heterogeneity

- Existing approaches

Discrete Choice Model	Multi-Class/Stratified Assignment
- Individual route choice - Utility functions for toll and non-tolled routes	- Stratify population by VoT distribution - Multi-class assignment for each VoT strata
Pros **- Flexible, easy to implement** **- Computational efficient**	**Pros** **- Seek to converge** **- Stable results for scenario comparison**
Cons - Hard to converge - Implication/interpretation	Cons - Computational demanding and becomes intractable with increasing problem size

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Summaries - Toll modeling with DTA

- Include alternate routes to model diversion
  - ✓ Static models do this well.
  - × Microsim not suitable for equilibrium DTA.
    - × Network too small.
    - × Not solving time-dependent shortest path.
  - ✓ DTA networks need to be large enough.
- Local congestion can affect tolls from far away
  - × Static models do not do queues and spillback.
  - ✓ Microsim has lots of detail.
  - ✓ DTA combines sufficient realism with larger-area networks.

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Overall Summary

- Advantage of applying DTA for pricing analysis appears to be obvious (hopefully).
- Various approaches are being offered for the following pricing schemes
  - Fixed toll
  - Time-of-day toll
  - Congestion responsive
- Addressing heterogeneity is desired
  - Ongoing research (SHRP2 L04, C10, etc.)
- Importance of feedback

Impact of Congestion Pricing & Travel Time Reliability on Travel Demand

Peter Vovsha, Bob Donnelly, Parsons Brinckerhoff,
Mark Bradley, Bradley Research & Consulting

Acknowlegments

- SHRP 2 C04
- Steve Andrle and project panel members

- Hani Mahmassani, Northwestern University
- Tom Adler, Resource System Group, USA

- Full project report available soon

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Primary Objectives and Focus

- Select and analyze travel behavior data in order to formulate approaches to better model impacts of congestion and pricing on travelers and transportation systems
- Focus on key challenging issues:
  - Generalized cost formulation – assessment of delays /time in congestion
  - Traveler heterogeneity (w/r time, cost, VOT)
  - Reliability of travel
- Site specific testing - estimation of new relationships with validation of findings and testing for cross sites / transferability

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Data Sources

- Principal Sites: Integrated regional data and implementation testing:
  - Seattle (PSRC)
  - New York (NYMTC, MTA, NYCDOT, PANYNJ)
  - Synthetic travel time variability "skims"
- Supporting Sites: Project site specific analysis / transferability testing:
  - San Francisco (SFCTA, MTC)
  - Minneapolis: I-394 MnPASS HOT (MnDOT)
  - Chicago (CMAP)
  - San Diego: I-15 ML (SANDAG)
  - Orange County: SR-91 (OCTA)
  - Baltimore Region: DYNASMART-P
  - NY BPM Region: Mode and Route choice demand model implementation with DYNASMART-P

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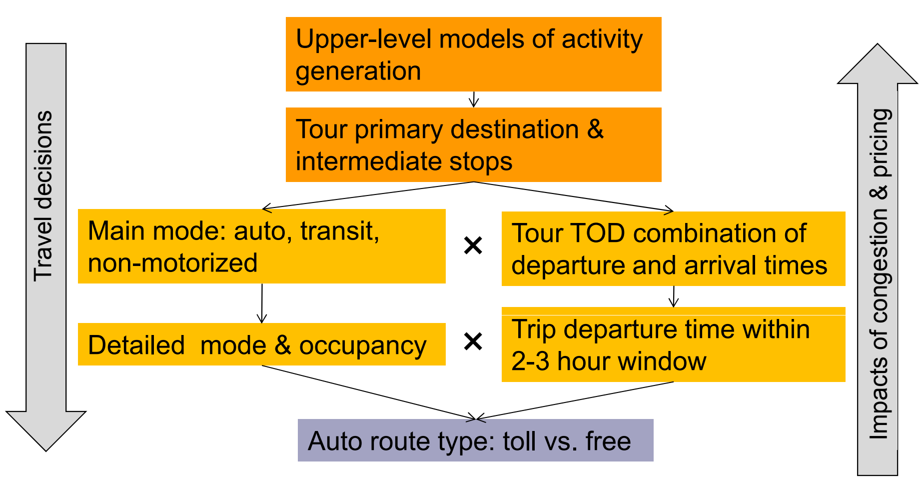
Choice Frameworks



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Model Estimation Approach

- Progressive testing of increasingly more complicated model specifications
  1. Basic – estimate parameters for time and cost only in linear function,
  2. Explore non-linear effects and distance effects
  3. Perceived travel time by congestion levels and facility type
  4. Impact of income
  5. Impact of car occupancy
  6. Impact of gender, age, and other person characteristics
  7. Incorporation of reliability measures
  8. Toll-averse bias
  9. Situational variability & unobserved heterogeneity, random coefficient logit analysis
- Assessment
  - Statistical goodness of fit measures
  - Reasonable value range for coefficients on time, cost and VOT
  - Feasibility of implementation in applications in existing and emerging application frameworks

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Extending Choice Dimensions

- Auto trip route (type) choice:
  - ***U=f(Time, Cost, Reliability)***
- Tour mode/occupancy/route (type) choice:
  - ***V=Σ(MSC)+U***
- Tour joint TOD & mode/occupancy/route (type) choice:
  - ***W=Σ(TSC)+V***

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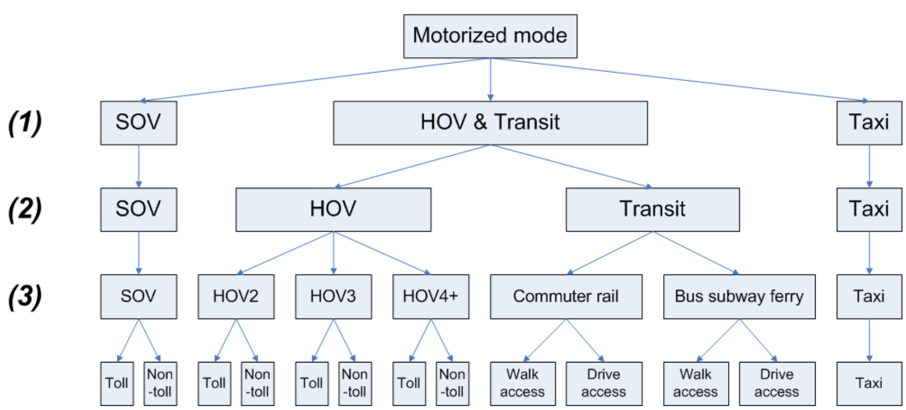
NY Binary Route (Type) Choice Model

- Toll route
- Non-toll route

NY Mode/Occupancy/Route Type Choice

- 13 alternatives:



NY Joint TOD & Mode Choice

- 20 hourly tour departure alternatives from 5:00am to 11:00pm (5 night hours combined)
- 20 hourly tour arrival alternatives from 5:00am to 11:00pm (5 night hours combined)
- 20×21/2=210 feasible tour TOD alternatives
- Joint NL structure:
  - (upper level) 210 TOD alternatives
  - (lower levels) 13 mode/occupancy/route type alternatives
  - 210×13=2,760 alternatives

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Basic Generalized Cost Function (Starting)

- ***U=b×Time+c×Cost***
  - ***b*** = travel time coefficient
  - ***c*** = travel cost coefficient
  - VOT = ***b/c*** (constant)
- 99% of research and 100% of models in practice use this function
- This function is simplistic and masks many important effects of congestion and pricing

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VOT Growth with Journey Lengths

- Cost damping:
  - Poor perception of car operating cost vs. parking and tolls
  - Relative rather than absolute perception of cost
  - Cheaper housing and higher disposable income for long-distance commuters
  - Trip frequency inversely proportional to trip length (for non-work travel)
  - Higher car occupancy for longer trips (if car occupancy is not accounted)
- Time valuing:
  - Risk aversion (if reliability is not accounted)
  - Unfamiliarity with distant locations
  - Time budget constraints

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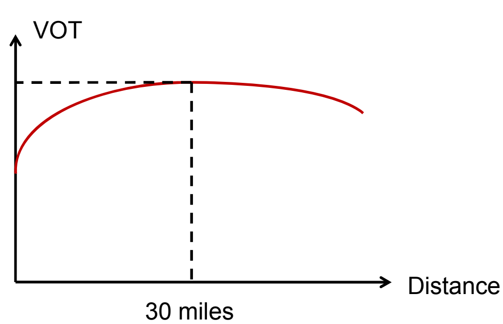
Non-Linear Distance Effects

- $U=b \times Time+c \times Cost$
- $U=(b_1+b_2 \times Dist+b_3 \times Dist^2+\ldots) \times Time+c \times Cost$



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VOT Drop for Long-Distance Commuters

- Self-selection of low-VOT commuters by residential choice
- Long commuting time used productively (laptops, cell phones)
- Restructured (simplified) daily activity pattern:
  - Compressed work week with no other out-of-home activities on regular workday
  - Compressed shopping and discretionary activities on (extended) weekends

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Perceived Time by Congestion Levels

- $U = b \times Time + c \times Cost$
- $U = b_1 \times FFTime + b_2 \times Delay + c \times Cost$
- $b_2 / b_1 \approx 1.5\text{-}2.0$
- Every minute spend in congestion conditions is perceived as 1.5-2.0 min of free driving!
- Proxy for travel time reliability:
  - Loses significance if reliability is incorporated directly
  - Useful for simple models that cannot incorporate reliability directly

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Household Income Effects (NY)

- Tested specifications:
  - Segmentation by income group:
    - Constants !!
    - Cost coefficient !
    - Time coefficient ?
    - Reliability coefficient ?
  - Scaling by income:
    - Time coefficient ?
    - Cost coefficient !!

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Impact of Income on Sensitivity to Cost

- $U = b \times Time + c \times Cost$
- $U = b \times Time + c \times (Cost / Inc^{e})$
- $e \approx 0.5\text{-}0.7$
- VOT grows with income (constant elasticity)
- Commuting VOT range:

Household Income	VOT
$12,500	$5/hour
$25,000	$8/hour
$50,000	$15/hour
$75,000	$22/hour
$100,000	$27/hour
$150,000	$39/hour
$200,000	$46/hour

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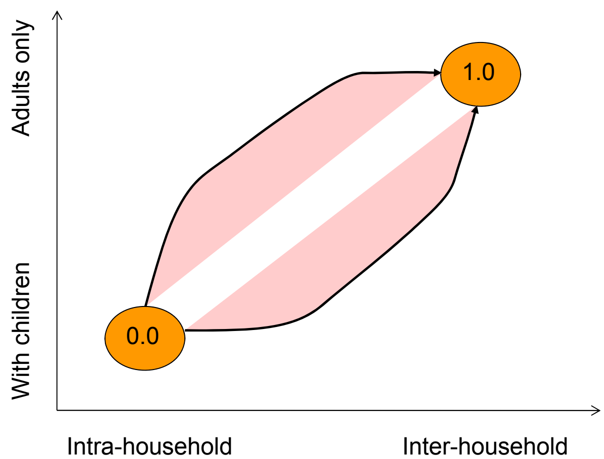
Car Occupancy Effects (NY)

- Tested specifications:
  - Segmentation by car occupancy:
    - Constants **?**
    - Cost coefficient **!**
    - Time coefficient **!**
    - Reliability coefficient **?**
  - Scaling by occupancy:
    - Time coefficient **?**
    - Cost coefficient **!!**

Impact of Car Occupancy

- *U=b×Time+c×Cost*
- ***U=b×Time+c×(Cost / Occ^{f})***
  - ***f ≈ 0.6-0.8***
- VOT grows with occupancy but not linearly:
  - Less cost sharing for intra-household carpools
  - Almost proportional cost sharing for inter-household carpools
- Typical cost sharing:
  - SOV=1.00
  - HOV2=0.57
  - HOV3=0.41

Cost Sharing Parameter for HOV



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Combined Income-Occupancy Effects

- Captured by:
  - Constants in mode choice framework
  - Explicit modeling of joint travel in advanced ABMs
- Low-income workers have more opportunities to form inter-household carpools:
  - Fixed schedules
  - Residential clusters
  - Job clusters
- Mitigates equity concerns regarding pricing:
  - Cost is shared
  - Low-income workers can switch from HOV or transit
  - High-income workers can only switch to transit

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Impact of Travel Purpose, Gender, Age, and Other Person Characteristics

- $U=b\times Time+c\times Cost$
- $U_s=b_s\times Time+c_s\times Cost$
  - s = population segments
- Segmentation by travel purpose is significant:
  - Difference between work and non-work travel
- Segmentation by gender, age, and other person characteristics is not extremely significant:
  - Rather lower VOT for females except females with small children

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Reliability Measures

- Tested Specifications:
  - (RP) STD
    - Generic **?**
    - Segmented by facility type **?**
  - (RP) 90^{th}-50^{th}, 80^{th}-50^{th} **?**
  - (RP) STD/Distance **!!**
  - (SP) Frequency of certain delay **!**
  - (SP) Delay of certain frequency **!**

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Incorporation of Reliability

- $U=b \times Time+c \times Cost$
- $U=b \times Time+c \times Cost+d \times STD/Dist$
  - d = coefficient for reliability measure
  - VOR = $(d/c)/Dist$
  - VOR/VOT= $(d/b)/Dist$ (Reliability Ratio ≈ 0.5-1.5)
  - VOR range:

Trip purpose	Distance	VOR
Work	5 miles	$54.9/hour
	10 miles	$27.5/hour
	20 miles	$13.8/hour
Non-work	5 miles	$40.8/hour
	10 miles	$20.4/hour
	20 miles	$10.2/hour

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Toll-Averse Bias

- $U=b \times Time+c \times Cost$
- $U_t=a+b \times Time_t+c \times Cost_t$ (for toll routes)
- $U_{nt}=b \times Time_{nt}+c \times Cost_{nt}$ (for non-toll routes)
  - a = toll bias (toll-averse bias if negative)
- Toll bias represents psychological perception beyond time-cost tradeoffs:
  - Significant toll-averse bias equivalent of 15-20 min even in NY where tolling has long history
  - Toll-averse bias is intertwined with very high VOT

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Situational / Unobserved Heterogeneity

- $U=b\times Time+c\times Cost$
- $U=\int(b\times Time+c\times Cost)\times g(b)db$
  - b = randomly distributed with density $g(b)$
  - VOT= b/c (becomes randomly distributed)
- Unobserved heterogeneity is significant:
  - VOT is subject to many additional unknown parameters (for example, person taste and psychological type)
  - VOT is subject to situational variability for the same person and trip (trip to important meeting vs. routine trip to work)
  - VOR variance was difficult to explore; the result are inconclusive, better data on travel time variation is needed

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Improved Final Generalized Cost Function

- $U=b\times Time+c\times Cost$
- Deterministic version:
  - $U_s=a_s+(b_{1s}+b_{2s}\times Dist+b_{3s}\times Dist^2)\times Time+c_s\times Cost/(Inc^{e_s}\times Occ^{f_s})+d_s\times STD/Dist$
  - Applicable with any model that generates STD reliability measure
  - If STD reliability measure cannot be produced perceived highway time can be used as a proxy
- Probabilistic version:
  - $U_s=\int[a_s+(b_{1s}+b_{2s}\times Dist+b_{3s}\times Dist^2)\times Time+c_s\times Cost/(Inc^{e_s}\times Occ^{f_s})+d_s\times STD/Dist]\times g(b_{1s})db_{1s}$
  - Applicable only with advanced microsimulation model

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Principal Conclusions for Modeling

- Universal fully transferable model:
  - Impossible
  - Regional specifics, data / model limitations
  - Seed conceptual structures become clear
- Complete operational models incorporating reliability:
  - Definitely yes!
  - Reliability is extremely important and statistically significant
  - Integrated ABM+DTA framework is the best
- Policy implications might be quite significant for:
  - Toll roads and managed lanes with guaranteed reliability
  - Other transportation projects featuring reliability

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Thank you!

Questions/Discussion

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Behavioral Insights (Top 10)

1. VOT and Willingness to Pay have a wide range from $5/hour through $50/hour across income groups and major travel purposes. There is a significant situational variation (unobserved heterogeneity) on the top of it with the "tail" of the distribution going beyond $100/hour.

> ***Policy Implications*:**
>
> Prices have to be at significant levels to influence congestion. Variability by time of day, vehicle occupancy, and frequency of travel allows prices to have more effect.

Behavioral Insights (Top 10)

2. In parallel with relatively high VOT (Willingness to Pay for Travel Time Savings) there is a significant negative toll bias ("threshold" effect equivalent to 15-20 min). This is generally found in both Revealed Preference and Stated Preference data, and supported by research in behavioral economics.

> ***Policy Implications:***
>
> Pricing makes sense if it is associated with significant travel time savings and reliability improvements to overcome psychological toll bias.

Behavioral Insights (Top 10)

3. Traveler's responses to congestion and pricing are dependent on the range of available options. They generally follow the sequence:
   - Primary: route/lane type change, small shifts in departure time (up to ±60 min),
   - Secondary: switch to transit (in transit-rich areas), carpooling
   - Tertiary: principal rescheduling of trips & activities by time-of-day periods
   - Longer term changes in home, work, other locations.

***Policy Implications*:**

Impact of peak period pricing on congestion level may be minor if the peak period is already spread for 2-3 hours and transit service is limited. (Could increase in the longer term.)

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Behavioral Insights (Top 10)

4. Improvements in travel time reliability are as important as improvements in average travel time. Reliability Ratio (cost of 1 minute of standard deviation versus cost of 1 minute of average time) is in the range of 0.5-1.5

***Policy Implications*:**

Dynamic pricing, traffic accident management and other strategies that specifically guarantee stable travel times (and avoid non-recurrent congestion) are highly valued by travelers.

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Behavioral Insights (Top 10)

5. Savings in average travel time are more highly valued for longer trips, but for the value of reliability, there is a relative dampening effect for longer trips (STD per mile variable is applied in route, mode, and TOD choice)

Policy Implications:

Users value a network of toll facilities that provide more substantial time savings for longer trips. Dynamic pricing to ensure reliability can be used selectively for critical facilities while the rest of the network can be subject to predetermined toll schedules.

Behavioral Insights (Top 10)

6. Income has a strong although not linear effect on VOT and Willingness to Pay. To account for income effect Cost/Toll variables in travel models should be scaled by Income powered by 0.6-0.8.

Policy Implications:

Pricing studies need to explicitly consider income distributions and future income growth in each region, corridor, and area. In the absence of locally calibrated models, model parameters from he other region have to be scaled by income differences.

Behavioral Insights (Top 10)

7. Auto occupancy has a strong (although non-linear) effect on VOT and Willingness to Pay. To account for occupancy effect Cost/Toll variables in travel models should be scaled by occupancy powered by 0.7-0.8.

***Policy Implications*:**

HOT lane strategies for different user groups (HOT3, HOT4) should be considered; Social equity considerations for low-income commuters should take into account opportunities to carpool to reduce costs.

Behavioral Insights (Top 10)

8. While carpools are characterized by a higher Willingness to pay they are also most inflexible to shift commuting departure time from the peak period and hour.

***Policy Implications*:**

Congestion pricing should be differentiated by auto occupancy; SOV are the major target of congestion pricing, while it is unreasonable to expect major departure time shifts for HOV. (Lower prices for HOV may not cause much additional ridesharing, but it recognizes benefits and constraints of existing carpools.)

Behavioral Insights (Top 10)

9. While certain general effects and tendencies can be formulated and seem generic across regions, there are many specific effects associated with person types, household composition, transit availability, land use, etc. The final behavioral models for C04 have hundreds of parameters and simplified surrogates and/or elasticity calculations have to be taken and applied with caution.

***Policy Implications*:**

Congestion pricing studies should be undertaken with detailed, best-practice travel models in terms of choice structure, market segmentation and local detail. A "simple & robust" approach is not possible. (The good news is that typical household travel survey data will support most of the modeling done in this study.)

Behavioral Insights (Top 10)

10. The availability of datasets adequate to support the C04 study, in particular the travel time reliability aspect, was extremely limited. The culture of collecting travel time trajectory (OD) data (not just link-level data!) on a daily basis is still in its infancy although the use of GPS/ probe vehicles to collect supply data is growing rapidly.

***Policy Implications*:**

Congestion pricing studies need to be supported by new data collection efforts; State DOTs and MPOs need to start creating regional datasets (demand and supply) for new generation of travel models and network simulation tools.