Predictive Strategies for Real-Time Pricing, Information and Traffic/Access Control

Hani S. Mahmassani
Transportation Center
Northwestern University

University Transportation Research Center, Region II
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Two Key Motivating Phenomena...

Growing Congestion....
Highway Authorities....
Why Road Pricing?

• Motivating Phenomena:
  – Growing congestion in metropolitan areas…
  – Budget constraints for highway authorities…

• Objectives of road pricing:
  – Revenue generation: road/bridge tolls
  – Congestion management: congestion pricing, cordon tolls and high occupancy toll (HOT) lanes…toward dynamic pricing (with time-varying tolls)…

• Examples of road pricing applications
  – London cordon pricing: charging private vehicles in downtown area to reduce traffic congestion and raise revenues for transport improvements.
  – Stockholm: similar to London, different technologies, dynamic
  – I-15 HOT lanes in San Diego: allowing solo drivers to pay a dynamic toll to use the express lanes normally reserved for high occupancy vehicles (HOV).
  – Highway 407, the Express Toll Route (ETR), in Toronto: collecting tolls based on distance traveled in the multi-lane electronic highway.
  – State Route 91 in Orange County, California: express toll lanes constructed and operated by private company.
Rationale for Congestion Pricing

First articulated by Nobel winning economist W. Vickrey, ~ 1952

1. Market-clearing prices: charge whatever it takes to achieve desired service levels – use prices instead of wasted time/queues to rationalize use of transport infrastructure; efficiency argument.

2. To induce more efficient use of transport infrastructure –

Network Equilibrium Theory: Use pricing to induce (Time-minimizing) system optimal (SO) flow pattern instead of inefficient user equilibrium (UE) attained without pricing.

First-best pricing: Charge users marginal cost (imposed on system) on all network links;

Second-best pricing: Impose tolls only on selected links (usually for practical reasons)
THE BROADER CONTEXT:
URBAN NETWORK MANAGEMENT ESSENTIALS

Multimodal, multi-jurisdictional perspective

Aggressive use of tools for economically efficient (but fair) allocation of resources: PRICING

Flexible operational strategies, dynamically adaptive (e.g. lane use, contraflow, access control, transit preemption)

Managing spatial and temporal pattern of demand along with the network’s operational features (supply-side) integral to managing network performance

City logistics (goods distribution) integral element of network management in areas with sensitive urban fabric

Strategic connection between transport infrastructure/services and land use development
Congestion Pricing as Demand Management Tool

1. Pricing increasingly viewed as one instrument along with two main other controls for integrated transportation system management:
   1. Traffic controls: ramp metering, signal coordination
   2. Information Supply: advanced traveler information systems, parking information systems, variable message signs (VMS)...

2. In real-time: with improved sensing and information technologies, can determine prices, traffic controls and information strategies adaptively, online, based on current and anticipated state of the system
HOT LANES

Single Occupant Vehicles allowed to use HOV lanes for a toll

Toll rates vary based on traffic conditions or time of day so as to maintain high level of service on managed lane

Facilitated by AVI and automatic toll collection

Hot lanes typically considered with new facilities or addition of a lane to existing facilities. Conversion of general purpose lanes discouraged in US.
Value Pricing, Managed Lanes

• Value pricing
  – Let travelers choose between two adjacent roadways: priced but free-flowing vs. free but congested

• Applications
  – Predetermined toll values
    • SR-91 in Orange County, California
    • Harris County, Texas
  – Reactive
    • I-394 Minnesota
    • I-15 FasTrak in San Diego, California
CITY LOGISTICS

• “The process of totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, traffic congestion and energy consumption within the framework of a market economy”

Taniguchi et al. (2001)
CITY LOGISTICS

KEY CHARACTERISTICS

TWO WAY INTERACTION

Impact on traffic congestion
Impact on urban fabric and environment

CITY LOGISTICS

Impacted by traffic congestion and constraints of urban fabric and environment

Urban Traffic Congestion and Environment
**CITY LOGISTICS**

**IMPLICATIONS**

NEED TO INCLUDE EFFECT OF CITY LOGISTICS DELIVERIES AND COMMERCIAL ACTIVITIES IN SIMULATION MODELS OF URBAN TRAFFIC

MUST CONSIDER TIME-VARYING TRAFFIC CONGESTION AND OPERATIONAL CONSTRAINTS IN ROUTING AND LOGISTICS OPTIMIZATION MODELS
Reliability of Travel

Many sources of unreliability:
- Interactions over space and time; e.g. traffic flow regime change under congested conditions
- External perturbations (changes in demand and supply characteristics)
- Individual link and/or particle stochasticity

Result: Tripmakers traveling between an origin and destination in the same departure window experience different travel times; lack of travel time predictability affects ability to schedule business and personal activities; delay and loss of productivity.

HUGE ISSUE FOR BUSINESSES AND SERVICES THAT RELY ON PHYSICAL MOBILITY
THE BROADER CONTEXT: Technological Drivers

Operations Control Center

Internet Connection

Communications Satellite

Integrated Mobile Communications Terminal

POS Information

Source: Qualcomm.com
TWO STAGES OF ITS DEPLOYMENT

Like any application of computers and communications to complex systems, the process is moving through two major stages:

1. The first stage mainly applies technology to specific tasks, but without changing their character or basic sequence.

2. In the second stage, entirely new approaches to solving problems and conducting business begin to appear.
THE BROADER CONTEXT:
Technological Drivers

Information & Communication Technologies (ICT)

ITS for Commercial Vehicle Operations (CVO)
  2-way Communication Systems
  Automatic Vehicle Localization (AVL); GPS

and Supply Chain Management (SCM)
  EDI; ERP; MRP; RFID

=> Large amounts of real-time information on state of system at lower cost
Development trend # 1:
Handset Capabilities, Wireless Internet

Precise Location Enables Wide Variety of LBS Apps

GAMING
Interactive Gaming
GeoCaching
Location aware games for individuals/groups

PERSONAL SECURITY
Roadside Assistance
Weather Warning
Child Finders
GeoFencing

ENTERPRISE
Fleet Management
Asset Monitoring
Personnel
Productivity

POINTS OF INTEREST
City Guides
Mobile Yellow Pages
Navigation
Traffic reroute

PEER-TO-PEER
Buddy Groups
Dating
Geo-marked photo sharing
Mobile Blogging

COMMERCE
Mobile Coupons
Customer Service

m-commerce
e-logistics
m-logistics
Development trend # 2:
Inexpensive wireless sensor networks
Coming to markets near you in next few months...

Relative low cost and high performance of such systems would enable deployment at larger scale than envisioned originally.

In the limit, nano-scale sensors with massively parallel deployment.
Mobile units + wireless internet:

Provided particle (user-centric) views of system

Inexpensive wireless sensors

Provides view from perspective of infrastructure or fixed assets

REAL-TIME INFORMATION
Explosion of real-time information on system state

- Calls for methods geared for shorter term engineering and business applications

- Calls for methodologies for real-time decision making under real-time information

  REAL-TIME DECISION-MAKING METHODOLOGIES, e.g. DYNASMART-X for traffic estimation and prediction.

- Calls for methods to extract knowledge from undifferentiated data

  KNOWLEDGE EXTRACTION, e.g. through data mining
Development trend # 3:
Network Simulation-Assignment Modeling for Advanced Traffic System Management

- Irvine network overview:
  - 326 nodes and 626 links.
  - 70 actuated-controlled urban intersections.
  - 61 traffic demand zones

- Morning peak period (4:00 AM – 10:00 AM)
- 30-second observation intervals on 19 freeway links
- 5-minute observation interval on 28 arterial links
Link Density Estimation and Prediction

Subject to considerable academic development in the area of algorithm development and testing

Rapidly coming to market, in conjunction with asset tracking and management technologies

Prospect for tie-ins with predictive traffic management tools, e.g. DYNASMART-X
Example of Collaborative Logistics: Vendor-management Inventories (VMI) Online Inventory Routing Problem (OIRP)
Anticipatory Pricing Strategy for Managed Lane Operation

What differentiates anticipatory from reactive pricing?
- Network state prediction
- Use predicted traffic conditions
- Calculate link toll within the prediction horizon and implement it in real time

PUTTING IT ALL TOGETHER: EXAMPLE 1
Motivation

- Anticipatory pricing
  - Set toll values based on predictive traffic measures in order to prevent traffic breakdown before it occurs
- Managed lanes
  - Anticipatory ramp metering
- Advanced Traveler Information Systems (ATIS)
  - Anticipatory travel time information provision
- Anticipatory measures are expected to be more effective than the prevailing measures when prediction is reliable
Descriptive conditions;

**PREDICTION**

Anticipatory information control pricing

Traffic Management Center

Guidance (VMS, Info to users), Signal control Prices

Real-time Traffic Estimation / Prediction System

Fundamental core

- Flow Models
- Behavior
- Algorithms

Advanced Traffic Models

Historical data

Network

Sensor systems

Real-time traffic data

2008
Reactive Pricing Strategy

How does reactive pricing work?
- obtain the **prevailing** traffic measures/conditions
- adjust **current link tolls** accordingly
- communicate to drivers via local VMS at the entry point
- could also disseminate via radio, in-vehicle equipment, mobile, internet etc.
Anticipatory Pricing Strategy for Managed Lane Operation

- What differentiates anticipatory from reactive pricing?
  - Network state prediction
  - Use predicted traffic conditions
  - Calculate link toll within the prediction horizon and implement it in real time
The Test Bed Network: CHART

- I-95 corridor between Washington, DC and Baltimore, MD, US
- 2 toll lanes
- 2241 nodes
- 3459 links
- 111 TAZ zones
- 2 hours morning peak demand
Pricing Strategies Compared

• No pricing (base case)
• Static pricing
  – Predetermine the time-varying link tolls based on the historical information
• Reactive pricing
  – Set time-varying link tolls based on prevailing traffic conditions
• Anticipatory pricing
  – Set time-dependent link tolls based on predicted traffic conditions

OBJECTIVE: AVOID BREAKDOWN—optimize throughput, reliability, under economically efficient allocation
Illustrative Results – Travel Time

- Warm-up period: increase in travel time at the beginning
- With the anticipatory pricing strategy, the travel times become steady after 1 hour (free flow condition)
- Static pricing strategy provides free flow condition on the toll lanes, but reduces the LOS on the alternative freeway lanes
Illustrative Results – Traffic Measures

- Concentrations averaged over links along the congested portion of toll road, weighted by the link length
- Throughputs measured at downstream of where traffic breaks down in base case (no pricing)
- Anticipatory pricing strategy can provide higher throughput while maintaining lower concentration (steady traffic flow)
Integrated Corridor Management (ICM) refers to the

- Coordination of individual network operations between adjacent facilities to create an interconnected system capable of cross-network travel management, along major corridors in metropolitan areas.

- Aggressive and targeted application of intelligent transport system (ITS) technologies to influence not only operational performance of highway facilities, but also
  - operational performance of highway facilities, but also
  - the demand for travel in the corridor.

- Combined application of judiciously matched operational strategies (supply-side) with travel demand management (TDM) approaches to bring about improvement in travel time, delay, fuel consumption and emissions, and increase the reliability and predictability of travel.
Generic Corridor

Source: Freitas and Harding, FHWA
A VARIETY OF TRANSIT-ORIENTED AND INTERMODAL OPERATIONAL CONCEPTS

Contraflow lanes

Multiple access modes

Bus Priority at Signals

Bus Rapid Transit
System Integration and Coordination

Integration of

- control and information provision strategies in response to non-recurring traffic congestion,

- dynamic value pricing and information provision strategies to encourage route diversion and departure time changes and relieve congestion on the corridor

- control, information provision and demand management strategies

- multimodal traveler information and dynamic pricing strategies to encourage balanced capacity utilization on transit and road networks
Implications for Evaluation Methodology

1. Consideration of time-variation (within day) of traffic demand and during peak-periods: dynamic analysis

2. Network perspective: cannot consider highway facility in isolation; need to consider traffic distribution across paths in a network

3. Need to capture congestion phenomena and queueing

4. Representation of operational aspects associated with coordinated measures: e.g. managed lanes, BRT, transit priority

5. User responses to prices (and to information, service design and performance):
   1. Short-term: route choice
   2. Medium-term: trip timing, mode choice
   3. Longer-term: destination choice, forsake trip (or telecommute); location and activity decisions
Network Simulation-Assignment Modeling for Advanced Traffic System Management
**Road Pricing Applications with DYNASMART-P**

- DYNASMART-P is a simulation-based DTA model representing a new generation of tools to support transportation network planning and operations decisions.

- Pricing capabilities of DYNASMART-P
  - Pricing types:
    - road/bridge toll
    - high occupancy toll (HOT) lanes: charge SOV vehicles on HOV lanes
  - Pricing schemes:
    - distance-based
    - entry-based
    - time-dependent
    - state-dependent

- Realistic modeling considerations
  - **Value of time** varies significantly across individuals because of different socio-economic characteristics, trip purposes, attitudes and inherent preferences.
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.

**Essential Aspect: USER HETEROGENEITY**
Why is DUE Model important for Dynamic Pricing Applications?

Estimated (dynamic) origin-destination (OD) demand

Network characteristics and traffic control data

Dynamic User Equilibrium Models (or Dynamic Traffic Assignment)
- Address the dynamic nature of traffic flows
- Describe path choices of network users based on the user equilibrium/optimal
- Obtain DUE path flow patterns

Evaluation of dynamic pricing scenarios: predicted intermodal path and departure time choices (toll road usage, profit and revenue) and network performance (average travel time and average delay).

Decision support for toll operators and traffic system managers

Time-varying road pricing scenario (as a set of time-dependent link tolls)
Methodological core for ICM Decision Support System

Dynamic Trip Micro-Assignment Model for Intermodal Transportation Networks

- Represents the supply side of the system;
- Captures the interaction between mode choice, trip timing, and traffic assignment;
- Implements a multi-objective assignment procedure.

**DYNASMART-IP** (w. K. Abdelghany): DTA for intermodal network planning applications

**DYNASMART-ICM**: Enhanced behavior response for ICM applications (pricing, reliability, transit, demand management)
RECENT GENERALIZATION: DYNASMART-ICM

Modeling Intermodal Choice and Departure Time Dynamics in Simulation-based DTA Framework

Considers Congestion Pricing, Travel Time Reliability, in addition to Transit Operational Strategies and Traveler Information, with Heterogeneous Users

Example of integrating demand and supply in a micro-assignment simulation-based platform
CONCEPTUAL FRAMEWORK

Network flow pattern
Travel time (mean and variance), travel cost

Trip maker characteristics
Preferred arrival time (PAT), value of time (VOT)

Travel decision-making process models
Mode choice model
Departure time choice model
Ridesharing model

Find
Travel alternative j for traveler i
Departure time, mode, route, rideshare choices

DYNASMART SIMULATOR
Traveler Choice Alternatives

- An **alternative** is a path $P_{rstm}(k)$, departing from origin $r$ to destination $s$ at time $t$ by mode $m$ using $k^{th}$ route

  - Departure time interval (15 mins)
  - Modes: HOV, LOV, {Train, BRT, auto-train, auto-BRT}
  - Routes (with mean trip time and variance):
Disutility function

$$V_{i,j,\text{PAT}}^{1,m,k} = Const_m + \alpha_1 \cdot GT_{i,j}^{1,m,k} + \alpha_2 \cdot SDE_{i,j,\text{PAT}}^{1,m,k} + \alpha_3 \cdot SDL_{i,j,\text{PAT}}^{1,m,k}$$

Where,

$$v_{i,j,\text{PAT}}^{1,m,k} = \text{systematical disutility for an alternative from origin } i \text{ to destination } j \text{ with the preferred arrival time interval } \text{PAT}, \text{ departing in time interval } \tau \text{ with mode } m \text{ and route } k.$$ 

$$GT_{i,j}^{1,m,k}, TT_{i,j}^{1,m,k}, TC_{i,j}^{1,m,k}, TTSD_{i,j}^{1,m,k} = \text{path generalized travel time, travel time, travel cost and travel time reliability (in terms of standard deviation), respectively, from origin } i \text{ to destination } j \text{ departing in time interval } \tau \text{ with mode } m \text{ and route } k.$$ 

$$SDE_{i,j,\text{PAT}}^{1,m,k}, SDL_{i,j,\text{PAT}}^{1,m,k} = \text{early schedule delay and late schedule delay, respectively, of an alternative from origin } i \text{ to destination } j \text{ with the preferred arrival time interval } \text{PAT}, \text{ departing in time interval } \tau \text{ with mode } m \text{ and route } k.$$ 

$$GT_{i,j}^{1,m,k} = TT_{i,j}^{1,m,k} + (TC_{i,j}^{1,m,k} + TTSD_{i,j}^{1,m,k} \cdot \beta \cdot VOT) / VOT$$

$$= TT_{i,j}^{1,m,k} + (TC_{i,j}^{1,m,k} + TTSD_{i,j}^{1,m,k} \cdot \beta \cdot VOT) / VOT$$

$$= TT_{i,j}^{1,m,k} + TC_{i,j}^{1,m,k} / VOT + TTSD_{i,j}^{1,m,k} \cdot \beta$$

$$\beta = \text{reliability ratio (i.e.} \frac{VOR}{VOT} \text{).}$$
Choice Probability Function (e.g. under MNL assumptions)

\[
Pr_{i,j,PAT}^{\tau,m,k} = \frac{Exp(V_{i,j,PAT}^{\tau,m,k})}{\sum_{\tau} \sum_{m} \sum_{k} Exp(V_{i,j,PAT}^{\tau,m,k})}
\]

Flow for each alternative:

\[
r_{i,j,PAT}^{\tau,m,k} = d_{i,j,PAT} \times Pr_{i,j,PAT}^{\tau,m,k}
\]
User Heterogeneity: 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)
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.

- 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 $Tr(\alpha)$ is optimal
Given a time-dependent extreme efficient path tree \( T_T(b) \) corresponding to the VOT subinterval \([\alpha^{b-1}, \alpha^b] \), the parametric analyses of VOESD and VOLSD are conducted in an expanded network.
• 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.

Sequential Parametric Analysis Method (SPAM)

Repeat the two stages for each destination: \( d = 1, \ldots, D \)

Stage 1: parametric analysis of VOT
\[ \alpha_{\text{min}}, \alpha^1, \alpha^2, \alpha^3, \alpha_{\text{max}} \]

Stage 2: parametric analysis of VOESD
\[ \beta_{\text{min}}, \beta^1, \beta^2, \beta_{\text{max}} \]

parametric analysis of VOLSD
\[ \lambda_{\text{min}}, \lambda^1, \lambda^2, \lambda_{\text{max}} \]

Repeat the second stage for each VOT subinterval: \( b = 1, \ldots, 3 \)
Numerical Experiments and Results

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

<table>
<thead>
<tr>
<th>Pricing Scenario</th>
<th>0-20 minutes</th>
<th>20-40 minutes</th>
<th>40-60 minutes</th>
<th>60-80 minutes</th>
<th>80-100 minutes</th>
<th>100-120 minutes</th>
<th>120-150 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 (low)</td>
<td>$0.05</td>
<td>$0.20</td>
<td>$0.35</td>
<td>$0.50</td>
<td>$0.35</td>
<td>$0.20</td>
<td>$0.05</td>
</tr>
<tr>
<td>#2 (mid)</td>
<td>$0.25</td>
<td>$0.40</td>
<td>$0.55</td>
<td>$0.70</td>
<td>$0.55</td>
<td>$0.40</td>
<td>$0.25</td>
</tr>
<tr>
<td>#3 (high)</td>
<td>$0.45</td>
<td>$0.60</td>
<td>$0.75</td>
<td>$0.90</td>
<td>$0.75</td>
<td>$0.60</td>
<td>$0.45</td>
</tr>
</tbody>
</table>
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 (random parameter model)
• 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

![Graph 1: Departure time distribution](image1)

![Graph 2: Time-varying toll road usage](image2)
ICM Application to Maryland CHART Network

DYNASMART-P Representation: Maryland Corridor Network
MARC Train Service Network
Off-Line Calibration Results

OD Trip Distribution

Observed vs. Simulated Link Volume
ICM Strategy Design

• LEVEL I Freeway and Arterial Traffic Control Strategies; Traffic Information Provision
  – Identify heavy movement origin-destination pairs in terms of impacted vehicles (by work zone or incident)
  – Identify dominant paths as candidates for signal coordination and VMS detour diversion
  – Develop variable message signs, signal and ramp metering plans to support network-wise corridor management goals

• LEVEL II Value Pricing Strategies
  – Determine HOV/HOT pricing locations
  – Design time-dependent link pricing schemes to reduce recurring and non-recurring traffic congestion

• LEVEL III Travel Demand Management Strategies; Transit and Multimodal Corridor Management Strategies
  – Traveler departure time redistribution strategies
  – New bus/BRT routes and park-and-ride lot locations for corridor-wise mobility.
  – Impact of transfer time, transit travel time and monetary cost
## MOE for Critical OD Pairs (Percentage Improvement)

<table>
<thead>
<tr>
<th>#</th>
<th>Scenario</th>
<th>Avg Travel Time</th>
<th>Avg Schedule Delay</th>
<th>Avg Travel Time Std Dev</th>
<th>Avg Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Do-nothing case (imperfect information to users, limited knowledge)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Information and other ICM strategies targeting HOV/HOT use <em>(mode choice)</em></td>
<td>18.4%</td>
<td>26.8%</td>
<td>23.9%</td>
<td>23.0%</td>
</tr>
<tr>
<td>2</td>
<td>Information-based demand management strategies with limited peak spreading, with given (empirically estimated) PAT <em>(departure time choice)</em></td>
<td>23.1%</td>
<td>28.6%</td>
<td>4.6%</td>
<td>26.3%</td>
</tr>
<tr>
<td>3</td>
<td>ICM and demand management targeting mode use and limited peak-spreading, with given PAT <em>(joint mode and departure time choice)</em></td>
<td>26.6%</td>
<td>34.6%</td>
<td>15.3%</td>
<td>31.0%</td>
</tr>
<tr>
<td>4</td>
<td>BRT + Information and other ICM strategies targeting mode use <em>(same as 1 + BRT)</em></td>
<td>42.3%</td>
<td>30.5%</td>
<td>46.2%</td>
<td>42.7%</td>
</tr>
<tr>
<td>5</td>
<td>BRT + Demand management strategies, limited peak-spreading with estimated PAT <em>(same as 2 + BRT)</em></td>
<td>35.3%</td>
<td>33.2%</td>
<td>13.1%</td>
<td>37.9%</td>
</tr>
<tr>
<td>6</td>
<td>BRT + ICM and demand management targeting mode use and limited peak-spreading with estimated PAT <em>(same as 3 + BRT)</em></td>
<td>41.7%</td>
<td>36.3%</td>
<td>30.3%</td>
<td>42.7%</td>
</tr>
<tr>
<td>7</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT <em>(same as 3 + BRT + more BRT access points)</em></td>
<td>31.6%</td>
<td>22.7%</td>
<td>14.9%</td>
<td>31.3%</td>
</tr>
<tr>
<td>8</td>
<td>ICM and demand management targeting mode use (HOV/HOT) + aggressive peak spreading <em>(same as 3 + flexible work hours)</em></td>
<td>33.9%</td>
<td>29.6%</td>
<td>61.5%</td>
<td>33.4%</td>
</tr>
<tr>
<td>9</td>
<td>BRT + ICM and demand management targeting mode use (HOV/HOT) + aggressive peak spreading <em>(same as 3 + BRT + more BRT access points + flexible work hours)</em></td>
<td>43.2%</td>
<td>32.8%</td>
<td>43.1%</td>
<td>40.9%</td>
</tr>
</tbody>
</table>
MOE Comparison: with BRT (limited access) vs. without BRT for Critical OD Pairs
Potential Benefits of ICM

Potential Range of Benefits

Corridor-wide Travel Time Reduction Benefits

- Corridor-wide Information (Passive Diversion/Roadway Only)
- Proactive Diversion (Multi-Modal where applicable) + operational strategies
- Demand Management/Increased Corridor Capacity

Legend:
- Red: Congested Small Corridor - Non-recurrent
- Green: Less-congested Large Corridor - Non-recurrent
- Purple: Congested Small Corridor - Recurrent
- Blue: Less-congested Large Corridor - Recurrent
Concluding Thoughts

• Role of DTA and simulation models in evaluating reliability of networks: Part of DECISION SUPPORT SYSTEMS—provide the information needed to support
  - operational planning decisions, identifying bottlenecks and vulnerable links (using disruption and vulnerability indices)
  - Support design of robust demand and supply management strategies over longer run, including pricing
  - Conduct sensitivity analyses, what if…

• Adaptation of predictive approaches for area pricing schemes: requires more extensive sensor coverage and calibration of flow relationships; but same basic framework

• Heterogeneity—substantial effect on forecasts; essential for evaluation

• User behavior will remain an unknown, because it will adapt—hence need for adaptive dynamic pricing schemes. Longer term adjustments (re: land use/location decisions) must be monitored

• Important success factor: availability of high quality transit alternatives
SEVEN BIG THEMES FOR RESEARCH

• EXPLOSION OF REAL-TIME INFORMATION and REAL-TIME DECISION METHODOLOGIES for OPERATIONS: DYNAMIC NETWORK MANAGEMENT (incl. PRICING), INTERMODAL SYSTEMS, COLLABORATIVE LOGISTICS

• WIRELESS INTERNET, PERSONAL MOBILE DEVICES, RF TAGS, E_SEALS:
  – TELEMOBILITY and TELELOGISTICS (CHANGES IN DEMAND), AND
  – PEOPLE/VEHICLES/SHIPMENTS AS PROBES (SOURCE OF REAL-TIME DATA FOR OPERATION, SURVEY DATA FOR PLANNING)
  – From a REAL-TIME ECONOMY to the REAL-TIME SOCIETY

• AUCTIONS and REAL-TIME INTERACTIVE MARKET-BASED MECHANISMS (INCL. PRICING) FOR PROCUREMENT AND CAPACITY ALLOCATION

• PEER-TO-PEER, AD-HOC NETWORKING AS SYSTEM MANAGEMENT APPROACHES: IMPLICATIONS FOR SYSTEM RESILIENCY
SEVEN BIG THEMES FOR RESEARCH (ctd.)

• UNDERSTANDING SYSTEM VULNERABILITY AND RESILIENCY; IMPLICATIONS OF OPERATIONAL CONSIDERATIONS FOR PLANNING AND DESIGN

• USER BEHAVIOR AND RESPONSE: KEY BUILDING BLOCK FOR USE OF INFORMATION AS TOOL FOR POLICY AND CONTROL; BEHAVIOR CHANGE TOWARDS SUSTAINABLE PATTERNS

• NEW BUSINESS MODELS FOR INFRASTRUCTURE DEVELOPMENT, OWNERSHIP AND OPERATION; FOR SYSTEM AND SERVICE DEVELOPMENT AND MANAGEMENT.
LIGHT AT THE END OF THE TUNNEL?

Thank you

Q & A

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