Congestion Management in a Rapidly Growing Economy: Optimizing Transportation Network Performance

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MTTBR 08  Mass Transit and Travel Behavior Research
Guwahati, February 12-15, 2008
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Passenger and Freight Mobility to Support Rapid Economic Growth

Major focus in mature economies has been on managing demand – in space and time, with VMT reduction an explicit objective of policy.

VMT reduction is not realistic in rapidly growing economies – vast reserve of latent demand for personal mobility.

⇒ Demand suppression is NOT the solution, as this means stifling economic growth, which is an essential element of improving quality of life.

Collective transport not necessarily incompatible with individual mobility.

Novel approaches to urban mobility – hybrid approaches that combine efficiency of collective transport with the flexibility afforded by personal mobility – WHY DON’T TRANSPORTATION PLANNERS DREAM ANY MORE?

OUR FOCUS: METHODOLOGICAL SUPPORT FOR MEETING MOBILITY NEEDS THROUGH INTEGRATED MANAGEMENT APPROACHES
THE REALITY...

Existing Mass Transit in Large Cities: Crushing densities, Crawling speeds

PUSHING THE LIMIT?
THE PROMISE…
BUS RAPID TRANSIT (BRT)
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: strategic guided partnership vs. reactive lagged disequilibrium
1. Pricing increasingly viewed as one instrument along with \textit{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
Objectives for Network Performance Optimization

Operational Efficiency (Capacity)
Maximize Total Throughput

Economic Efficiency
Allocation to Competing User Classes

Reliability
Consistency and Predictability of Service Levels

Sustainability
Energy and Environmental Quality
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 IN INDIA FOR BUSINESSES AND MANUFACTURING THAT RELY ON PHYSICAL MOBILITY**
Technological Drivers

Operations Control Center

Communications Satellite

Internet Connection

POS Information

Integrated Mobile Communications Terminal

Source: Qualcomm.com
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:

- Provides 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
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
  - 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
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
- 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**
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):
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
• **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 (same as 1 + BRT)</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 (same as 2 + BRT)</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 (same as 3 + BRT)</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 (same as 3 + BRT + more BRT access points)</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) + <em>aggressive</em> peak spreading (same as 3 + flexible work hours)</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) + <em>aggressive</em> peak spreading (same as 3 + BRT + more BRT access points + flexible work hours)</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

-20.4%  
-2.5%   
-17.5%  
-16.7%
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

- Congested Small Corridor - Non-recurrent
- Less-congested Large Corridor - Non-recurrent
- Congested Small Corridor - Recurrent
- Less-congested Large Corridor - Recurrent
SOME CONSIDERATIONS FOR APPLICATION TO INDIA CONTEXT
SOME CONSIDERATIONS FOR APPLICATION TO INDIA CONTEXT

• TRAFFIC MIX CONSIDERATIONS: WIDER RANGE OF VEHICLE AND QUASI-VEHICLE TYPES, WITH DISPARATE PERFORMANCE CHARACTERISTICS

• USER BEHAVIOR AND RESPONSE TO INFORMATION

• GROWING PENETRATION OF MOBILE PHONES AND BROADBAND DATA OFFER MAJOR OPPORTUNITIES FOR VEHICLE PROBE DATA AND PERSONALISED ITS INFORMATION

• IMPLEMENTATION IN CHALLENGING INSTITUTIONAL SETTING, SOCIOLOGICALLY AND PSYCHOLOGICALLY COMPLEX ENVIRONMENT
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
  - Conduct sensitivity analyses, what if…

• The ultimate approach to dealing with unreliability is ONLINE traffic management: provision of information on realized instances, setting of controls to deal with specific instances on the fly
  - DTA for REAL-TIME ESTIMATION and PREDICTION DYNASMART-X
FOUR BIG THEMES FOR RESEARCH

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

• 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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NORTHWESTERN UNIVERSITY
Challenge Areas:

Processes and Phenomena

Methods and Algorithms

Application
Challenge Areas: Processes and Phenomena

- Modeling multiclass interactions in heterogeneous network traffic flow:
  - Buses of varying sizes and degrees of right of way sharing/conflict; BRT one extreme of the spectrum
  - Modeling interactions in and around terminals: important for BRT
  - Non-motorized travel: pedestrians/crowds, bicycles
  - Phase transitions and stability under non-linear interactions in complex heterogeneous traffic systems
  - System behavior under extreme events (accidents, man-made and natural disasters); implications for critical system management

- Tripmaker behavior processes.

- Representation of BRT (and other transit) operational strategies, and modeling their impact on user behavior and traffic interactions.
Challenge Areas: Processes and Phenomena (ctd.)

- **Tripmaker behavior processes.**
  - Intermodal choice processes and models:
    - Critical interdependence between choice dimensions, especially “mode” and “path”
    - Path enumeration/generation issues and behavioral realism: linkage to spatial cognition and search dynamics
    - Is there a “pure bias” in favor of BRT? Same issues as LRT (le plus ca change…)

  - Traveler responses to **multimodal** real-time information
    - Multimodal information and cross-mode effects
    - Responses to information from multiple sources: short, medium and long-term effects
    - **TELEMOBILITY:** Use of Internet (fixed and mobile)-based services for various activity purposes
    - Learning and day-to-day evolution of network flows
    - Effect of information on dynamics of activity and travel patterns: Opportunities lie in examining telecommunications and tripmaking jointly in an activity participation framework
    - Dynamics in activity and travel patterns
Challenge Areas: Methods and Algorithms

- Path search algorithms:
  - Path generation for mode-path choice behavior modeling
  - Non-dominated path generation and “optimum” path computation for multi-criteria, time-dependent intermodal networks

- Iterative procedures for integrated intermodal activity-based assignment models

- Large-scale system challenges: intermodal network modeling to reduce curse of dimensionality

- Algorithm implementation aspects: path representation schemes, memory management, parallel execution

- Advanced methodologies for real-time intermodal system management (traffic control, information supply, pricing) under real-time information
Challenge Areas: Application

- OBSERVATION, OBSERVATION, OBSERVATION, OBSERVATION!

  To support traffic interaction modeling
  - exploiting sensors and sensor networks
  - video image processing

  To study travel behavior processes
  - novel survey approaches (technology-driven): Internet-based, electronic diaries, GPS
  - laboratory experiments now well established and accepted; extend to live tests via wireless telecoms
  - rich data sources from Internet and ITS (incl. Real-time data from various sources)

- Wide range of professional practice Issues
  - Network and data input preparation: compatibility with existing software and database investment.
  - Intermodal system responsibility
  - Are DTA models too complicated for agency personnel? Implications for user interfaces, decision support frameworks, education and training.
Challenge Areas: Application

- Decision Support Strategy Design
  - How to provide 'good' predicted information
  - Interactions between network control (e.g. signals) and ATIS information
  - System management and information supply strategies for different policy goals (e.g. air quality, smart growth, “balanced” transportation…)
  - Planning and design for Extreme Events