INTEGRATED MULTIMODAL URBAN CORRIDOR MANAGEMENT: THE POTENTIAL ROLE OF BUS RAPID TRANSIT

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Outline

• Motivation and problem context: ICM and BRT
• Problem statement and assumptions
• Multidimensional simulation-based dynamic micro-assignment approach
  – Multidimensional choice decision-making process
  – Fixed-point formulation of the dynamic Stochastic User Equilibrium problem
  – Dynamic micro-assignment solution approach
• CHART corridor case study
• Conclusion
THE PROMISE…
BUS RAPID TRANSIT (BRT)

return
Bus Rapid Transit (BRT) -- Subway on the Surface

BRT design for New York City

Bus stop in Curitiba, Brazil

BRT on expressway

BRT station
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, including dynamic pricing, coupled with operational (access) control
to bring about improvement in travel time, delay, fuel consumption and emissions, and *increase the reliability and predictability of travel.*
BRT service on HOT/HOV lanes in an ICM corridor

Arterial

Park & Ride (Train)

Train

Expressway

BRT on HOT/HOV Lane

BRT on HOT Lane

Local Jurisdiction 1 — Traffic Signal System

Regional Rail Agency — Train Management System

State DOT — Freeway Management System

Bus Company — AVL System

Local Jurisdiction 2 — Traffic Signal System

Park & Ride (BRT)

Bus

Park & Ride (BRT)
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
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
Problem statement and assumptions

• Assumptions
  – An urban multimodal transportation network: Drive Alone, Shared-Ride, and Transit Intermodal modes
  – Tripmaker characteristics: OD demand with estimated PAT pattern, Value of Time (VOT), and Value of Reliability (VOR)
  – Travel decision-making process models: Departure time, mode, and route choice models

• Solve for
  – Assignment of travelers to a congested time-varying stochastic network under DMSUE conditions

• Methodology
  – Multidimensional simulation-based dynamic micro-assignment approach
  – Path generated and augmented to a grand path set at each iteration
  – A mesoscopic traffic simulator (DYNASMART-P) is used to obtain network cost and flow dynamics
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
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):
Multidimensional simulation-based dynamic micro-assignment approach

1. Attributes and characteristics
   - Network flow pattern and performance (Average travel time, travel time standard deviation, and travel cost)
   - Traveler characteristics (Preferred arrival time, and value of time)

2. Choice
   - Multidimensional choice set generation (Time-dependent intermodal least-cost path algorithm)
   - Travel decision-making process (Mode choice, departure time choice, ridesharing choice, and route choice)

3. Assignment
   - Stochastic User Equilibrium network micro-assignment

4. Simulation
   - Mesoscopic network flow simulation
Multidimensional Choice Process

- **Systematic utility function**
  \[ V_{\tau,m,k}^{\tau,m,k} = \text{Const}_m + \alpha_1 \cdot GT_{o,d}^{\tau,m,k} + \alpha_2 \cdot SDE_{o,d,PAT}^{\tau,m,k} + \alpha_3 \cdot SDL_{o,d,PAT}^{\tau,m,k} \]

- **Generalized travel time time function**
  \[ GT_{o,d}^{\tau,m,k} = TT_{o,d}^{\tau,m,k} + TC_{o,d}^{\tau,m,k} / VOT + TTSD_{o,d}^{\tau,m,k} \]

- **Multinomial logit (MNL) choice function**
  \[ \Pr_{o,d,PAT}^{\tau,m,k} = \frac{\exp(V_{o,d,PAT}^{\tau,m,k})}{\sum_{\tau'} \sum_{m'} \sum_{k'} \exp(V_{o,d,PAT}^{\tau',m',k'})} \]

- Schedule delay
- Reliability ratio (i.e. \( \frac{VOR}{VOT} \))
Fixed-point formulation of the Dynamic Stochastic User Equilibrium problem

• Definition 1: DMSUE (dynamic multimodal SUE)
  – For each OD pair \((o, d)\), and for each preferred arrival time \(PAT\), no traveler can reduce his/her perceived generalized travel cost/disutility by unilaterally changing mode, departure time, or route.

• Fixed-point formulation

\[ r^* = q \times \Pr(r^*) \]
Dynamic micro-assignment solution approach

- Aggregated flow-based assignment updating function
  \[
  r_i(l+1) = r_i(l) + \lambda(l) \times (\bar{r}_i(l) - r_i(l))
  \]

- Disaggregated individual-based assignment updating function
  \[
  r_i(l+1) = [1 - \lambda(l)] \times r_i(l) + \lambda(l) \times q_{o,d,PAT} \times \text{Pr}_i(l)
  \]

- Auxiliary flow function
  \[
  \bar{r}_i(l) = q_{o,d,PAT} \times \text{Pr}_i(l)
  \]

- Flow updating convergence checking gap function
  \[
  \phi(l+1) = \frac{\sum_i \frac{1}{2} \times [r_i(l+1) - q_{o,d,PAT} \times \text{Pr}_i(l)]^2}{I}
  \]

A portion of tripmakers will re-select alternative based on auxiliary probability.
ICM Application to Maryland CHART Network

DYNASMART-P Representation: Maryland Corridor Network
The MD CHART corridor network

Three types of corridor systems:
(1) Expressway systems: I-95 and MD-295;
(2) Arterial systems: RT-29 and RT-1;
(3) Transit systems: MARC Train and BRT.

Network topology and demand:
(1) 2182 nodes and 3387 links
(2) 111 OD demand zones
(3) Planning horizon: 4:00AM to 11:00AM
(4) Departure time interval: 15min
(5) Critical OD pairs: Baltimore-Washington
<table>
<thead>
<tr>
<th>Scenario #</th>
<th>Scenario</th>
<th>Mode choice</th>
<th>Departure time choice</th>
<th>BRT line</th>
<th>BRT access points</th>
<th>BRT fare</th>
<th>BRT frequency</th>
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<tr>
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<td>Do-nothing case (imperfect information to users, limited knowledge)</td>
<td>No</td>
<td>No</td>
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<td>1</td>
<td>ICM and demand management targeting mode use with estimated PAT</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
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<td></td>
<td>(joint mode and departure time choice)</td>
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<td>BRT + ICM and demand management targeting mode use with estimated PAT</td>
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<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
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<td>Low</td>
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<tr>
<td></td>
<td>(same as 1 + BRT point-to-point service)</td>
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<td>3</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Adequate</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td></td>
<td>(same as 1 + BRT + more BRT access points)</td>
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<td>4</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
<td>High</td>
<td>Low</td>
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<tr>
<td></td>
<td>(same as 1 + BRT + increased fare)</td>
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<tr>
<td>5</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
<td>High</td>
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Scenario 3 provides the most benefit for Network-wide MOEs.
Scenario 2 exhibits the most benefit for critical OD pairs MOEs.
# Network-wide MOEs (percent improvement)

<table>
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<tr>
<th>Scenario #</th>
<th>Scenario</th>
<th>Avg Travel Time (min)</th>
<th>Avg Schedule Delay (min)</th>
<th>Avg Travel Time Std Dev</th>
<th>Avg Disutility</th>
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<tbody>
<tr>
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<td>Do-nothing case (imperfect information to users, limited knowledge)</td>
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<td></td>
<td>ICM and demand management targeting mode use with estimated PAT</td>
<td>14.3%</td>
<td>6.9%</td>
<td>29.7%</td>
<td>12.5%</td>
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<td>(joint mode and departure time choice)</td>
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<tr>
<td>1</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT</td>
<td>11.0%</td>
<td>5.9%</td>
<td>29.7%</td>
<td>9.4%</td>
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<td>2</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT</td>
<td>24.9%</td>
<td>21.8%</td>
<td>20.3%</td>
<td>25.0%</td>
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<td>(same as 1+ BRT + more BRT access points)</td>
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<td>3</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT</td>
<td>6.8%</td>
<td>10.6%</td>
<td>29.7%</td>
<td>10.4%</td>
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<tr>
<td>4</td>
<td>BRT+ICM and demand management targeting mode use with estimated PAT</td>
<td>7.6%</td>
<td>11.2%</td>
<td>35.9%</td>
<td>11.5%</td>
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Scenario 3 has the most benefit network-wide MOEs
Scenario 5 has more benefit than Scenario 4
# MOEs for critical OD pairs (% improvement)

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<td></td>
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<tr>
<td></td>
<td>ICM and demand management targeting mode use with estimated PAT (joint mode and departure time choice)</td>
<td>26.6%</td>
<td>34.6%</td>
<td>15.3%</td>
<td>31.0%</td>
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<tr>
<td>1</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT (same as 1+ BRT point-to-point service)</td>
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<tr>
<td>2</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT (same as 1+ BRT + more BRT access points)</td>
<td>41.7%</td>
<td>36.3%</td>
<td>30.3%</td>
<td>42.7%</td>
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<td>3</td>
<td>BRT + ICM and demand management targeting mode use with estimated PAT (same as 1+ BRT + increased fare)</td>
<td>31.5%</td>
<td>22.7%</td>
<td>15.0%</td>
<td>31.3%</td>
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<tr>
<td>4</td>
<td>BRT+ICM and demand management targeting mode use with estimated PAT (same as 1 + BRT + increased fare and frequency)</td>
<td>32.6%</td>
<td>30.2%</td>
<td>6.7%</td>
<td>34.9%</td>
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<tr>
<td>5</td>
<td>BRT+ICM and demand management targeting mode use with estimated PAT (same as 1 + BRT + increased fare and frequency)</td>
<td>34.8%</td>
<td>34.8%</td>
<td>8.9%</td>
<td>37.9%</td>
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</table>

Scenario 2 has the most benefit for critical OD pairs MOEs.
Potential Benefits of ICM

![Graph showing potential range of benefits across different categories of traffic management strategies.

- 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
- Pink: Congested Small Corridor - Recurrent
- Blue: Less-congested Large Corridor - Recurrent

Corridor Travel Time Reduction Benefits:
- 0% to 35%

Potential Range of Benefits: A shaded area indicating the range of potential benefits across different strategies.

NORTHWESTERN UNIVERSITY
Conclusion

• BRT has emerged as a high capacity, lower cost bus transit option, and a strategy of BRT running on HOV/HOT lanes could efficiently utilize current highway facilities by providing high quality transit services for ICM deployment.

• A case study using a large-scale multimodal transportation network is presented to illustrate the capability of the proposed transportation network analysis system.

• ICM measures are not additive in their impacts, and a best combination needs to be carefully determined for specific OD pairs, park and ride locations, BRT service network, and fare scenarios.

• Moreover, this study provides a novel tool for evaluating the benefit of BRT service along expressways, which is more attractive in many metropolitan areas (part of Chicago city’s vision 2020 (Pace Bus, 2008).