TRANSPORTATION SYSTEM INTELLIGENCE: THE PROMISE AND CONTINUING OPPORTUNITIES

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ADVANCING CANADA’S COMPETITIVE ADVANTAGE
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Key Motivating Phenomena....
Increasing role of containerization and container handling

Intermodal freight fastest growing form of rail traffic

Major revitalization of rail transport through intermodal
Intermodal freight transportation vulnerability

Transfer nodes: points of high vulnerability

Greater exposure through multiple transfers

Transfer nodes also “choke” points or bottlenecks in system: amplifies economic impact severity of additional delay
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)
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

**Resilience**
Ability to withstand shocks and recover from extreme man-made and natural events

**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.

CRITICAL FACTOR FOR BUSINESS AND SERVICES THAT RELY ON PHYSICAL MOBILITY
Intelligent Transportation Systems

Convergence of location, sensing, telecommunication and automotive technologies for better transportation system safety, efficiency, and user convenience.
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.
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
PARETO EFFICIENCY AND TRADE-OFFS

- PARETO FRONTIER
- Ideal Point
- INEFFECTIVE REGION
- INFEASIBLE REGION
- time
- cost
PARETO EFFICIENCY AND TRADE-OFFS

Competing operational performance goals in large-scale transportation systems: Are we on the Pareto envelope?
How to Push the Envelope?

ROLE OF EMERGING TECHNOLOGIES AND ADVANCED OPERATIONAL CONCEPTS
Throughput vs. Reliability

Breakdown
PUSHING THE ENVELOPE

More Reliability

Higher Throughput
THROUGH TECHNOLOGY INTELLIGENT MANAGEMENT SYSTEMS
Technological Drivers

4 DEVELOPMENT TRENDS
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

e-logistics
m-logistics

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
Example: Sense Networks Inc.

Citysense

Tracking cell phone signals for social networking

→ travel pattern prediction
PROBE-BASED CONNECTED NAVIGATION SYSTEM: Third-Party Private Subscriber ITS Service

TruTraffic
The most accurate and current traffic data

Routing: Choice is good.
Most portable GPS devices today offer you only a single route choice to your destination. Dash goes the extra mile by presenting up to three different routes to a destination, and uses its traffic information to calculate your Estimated Time of Arrival (ETA) for each route. The traffic-based arrival times you get from Dash are more accurate, helping you decide which route is best for you. Even after you’ve selected a route, Dash even automatically alerts you when traffic conditions change significantly.

Traffic snapshot
Dash can also give you a quick snapshot of traffic in your area. Our map views let you easily visualize current traffic conditions around your location on major and secondary roads. Additionally, traffic conditions on your route are easily identifiable by color. Dash uses accepted conventions to quickly convey traffic at a glance: stop-and-go traffic is red, moderate congestion is yellow, relatively unobstructed is orange, and free-flowing roads are... you guessed it, green. If the lines are solid, they represent live traffic derived from the Dash Driver Network—the most timely and accurate source available. If they are dashed, the traffic data is either 3rd party sensor or historical data. As the Dash Driver Network grows in your area you’ll see more and more of the dashed lines become solid. You’ve never had this much traffic information on the road before, and knowledge is power.
Satellite-based mobile asset tracking and communication: Tool for truck fleet management and freight tracking
Deployment Key Technologies: Field Elements

AVI and E-Seal Readers (Overhead)

E-Seal

In-Truck AVI Transponder

Disposable Electronic Container Seal

Weigh-In-Motion (CVISN)
eSeal Readers at Border
Telemobility and Telelogistics

• Internet + mobility --→

**TELEMOBILITY** and **TELELOGISTICS**

May entail changes in:

– **Nature** of the activities themselves (doing what?)
– **Location/spatial** characteristics of the activities
– **Inter-person and inter-firm interaction** in activities
– **Process of activity generation and scheduling**: more dynamic (real-time) activity generation and scheduling;
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)
Giesen, Mahmassani and Jaillet (2006) developed dynamic routing methods for collaborative Vendor-Managed Inventory logistics systems.

On-Line Inventory Routing Strategies:
- **Decrease average total cost by 21%** vs. off-line static methods
- **Decrease Variability** in average cost
  - Benefits tend to be higher when clusters of customers are close to each other and/or near to the depot (case 3)

Benefits of dynamic strategies tend to increase:
- with higher inventory costs
- with greater demand variability
PUTTING IT ALL TOGETHER: EXAMPLE I

Anticipatory Pricing Strategy for Managed Lane Operation

Breakdown

Reliability

Throughput
Effective **flow and lane management** calls for **dynamic (state-dependent) pricing**
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
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

INTRODUCE PREDICTION IN THE CONTROL LOOP

Link Toll Generator  \[
\text{Toll values} \rightarrow \text{Real World Traffic}
\]

Traffic Prediction  \[
\text{Traffic data} \rightarrow \text{Predicted data}
\]
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)
Illustrative Results – Toll Variation

![Graph showing toll variation over time intervals]

- **Static pricing (high)**
- **Reactive pricing**
- **Anticipatory pricing**
- **Static pricing (low)**

The graph illustrates the toll value (in dollars) over time intervals (in minutes). The variations in toll value are depicted for different pricing strategies.
CRITICAL ROLE OF PREDICTION IN REAL-TIME INTELLIGENT TRANSPORTATION SYSTEM MANAGEMENT

Information Provision  Pricing
Traffic Control  Container Handling
Collaborative Fleet Management
Concluding Thoughts:
What Stands in the Way of Pushing the Envelope?
FUNDAMENTAL SOURCE OF DIFFICULTY: HUMAN BEINGS

The Problem: Optimize dynamic stochastic systems in which people are essential elements

Physics of the problem involve:
Complex interaction among humans/vehicles over time and space in physical environment (under real-time information)
(Some Vexing)
Characteristics of transportation systems

Cognitive and behavioral limitations of human drivers are at the root of system inefficiency

Perception time lags, reaction times, and a natural tendency towards over-reaction under stressful situations or perceived risk result in

volatility, congestion, instability, frustrating stop-and-go patterns, “phantom bottlenecks”, capacity loss, and other component- and system-level phenomena
Characteristics of transportation systems

- Behavioral considerations and attitudes of human drivers, households and logistics managers are at the root of fuel inefficient patterns.

  - Activity patterns and resource allocation decisions reflect individual preferences and lifestyles acquired in times where fuel supply concerns were minimal.

  - Different time frames for interventions—different impacts from short to medium to long runs.

  - Small changes at the margin could have meaningful impact.

TO DO GOOD PHYSICS, YOU NEED GOOD OBSERVATION
Characteristics of transportation systems

– Attitudes of bureaucracies, turf wars. Lack of coordination often hinder successful implementation of network management approaches

➢ Need to evolve institutional frameworks that can support and evolve the processes needed to sustain and improve the transportation system over the medium and long runs

➢ Technology alone will not push the envelope
The Human Factor

Technology alone will not push the envelope
LIGHT AT THE END OF THE TUNNEL?

Thank you

Q & A

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