Leveraging Sensor Technologies for Smarter Mobility

Hani Mahmassani

Smarter Cities/Smarter Mobility

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Outline

1. THE CONTEXT: MOBILITY AS PROCESS IN CONNECTED SYSTEMS
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3. PREDICTION AND REAL-TIME TRAVELER INFORMATION
4. PREDICTIVE CONTROL: PRICING
5. WEATHER-RELATED TRAFFIC MANAGEMENT
6. LOGISTICS OPERATIONS IN CONGESTED URBAN ENVIRONMENTS
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I.

The Context: Mobility as *Process* in Connected Systems
The user is at the center of this web of connectivity and “always aware” systems and devices.

Why is this relevant to transportation?
WHY IS THIS RELEVANT TO TRANSPORTATION?

SEAMLESS CONNECTIVITY

TRANSPORTATION DELIVERS PHYSICAL MOBILITY IN A VIRTUALLY CONNECTED MOBILE ENVIRONMENT
Everybody is talking about it

The real value of the Internet of Everything lies in the value of connections among people, process, data, and things, not simply in the sheer number of things that are connected.

When your car becomes connected to the Internet of Everything...

...more numerous, valuable, and relevant connections with other cars, stop signs, your home, and even the road itself will make your driving experience safer, more fun and informed, and even more efficient.

It’s the connections that matter most.

The Internet of Everything

#InternetofEverything
#IoE

CISCO
KEY TECHNOLOGY ENABLERS

SENSORS

NETWORKS
Peer to peer
Wide area wireless
Backbone

SERVERS AND DATA STORAGE
NOT LIMITED TO CARS AND OBJECTS
II. System Intelligence through Predictive Analytics
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
How is more data allowing me to

**Do things differently** (better- faster, cheaper, safer, higher impact, customer-pleasing...)

**Do different things** (grow activities, revenue, improve image, employee retention...)

?
Traffic Estimation and Prediction System (TrEPS)

**DYNASMAART-X**

**ESTIMATION**
- Current traffic conditions

**PREDICTION**
- Prediction (no intervention)
- Prediction (with intervention)

Prospect for tie-ins in urban contexts with predictive traffic management tools, e.g. DYNASMArt-X.
Descriptive conditions;

**PREDICTION**

Anticipatory information control pricing

Traffic Management Center

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

Real-time Traffic Estimation / Prediction System

Advanced Traffic Models

- Flow Models
- Behavior
- Algorithms

Fundamental core

Real-time traffic data

Historical data

Network

Sensor systems
III.

Prediction and Real-time Traveler Information
Consistent Anticipatory Travel Time Information

(Reference: Dong and Mahmassani, 2010)
WHAT WE KNOW

Information on currently prevailing conditions may not be effective: overreaction, time lags, stochastic and dynamic variation

Anticipatory information effective, but poses three challenges:

- capturing user responses to provided information: CONSISTENCY
- users care about reliability of information
- computation for large networks
RH approach is a practical method for generating and implementing solutions to dynamic programming problems.

Closed-loop structure allows the control policies obtained in traffic prediction model to be implemented in real world and transferred to state estimation model.
The Test Bed Network: Irvine

- **Network**
  - Freeways I-405, I-5, state highway 133
  - 326 nodes
  - 626 links
  - 61 TAZs
  - 57 road detectors

- **Demand**
  - Two hours morning peak
  - 15min warm-up period + 45 min clearance time

- **Parameters**
  - Roll period: 5 minutes
  - Prediction horizon varying from 30 to 60 minutes
Anticipatory information works better than prevailing information.

 Longer prediction horizon provides better performance.
• Provision of anticipatory travel time information improve the overall network performance

• Solve the overreaction problem caused by providing prevailing (instantaneous) information
Scenarios:

- only anticipatory travel time information is provided
- both anticipatory travel time and reliability information provided

- Significant time savings are observed when travel reliability information is provided in addition to travel time information
- Providing travel reliability information contributes to *delaying the onset of breakdown* and alleviating its extent, with higher and more stable flow indicating an increase in freeway’s utilization
IV. Predictive Control: 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

![Diagram showing the relationship between Link Toll Generator, Real World Traffic, and Traffic Prediction.]

- Link Toll Generator
- Real World Traffic
- Traffic Prediction

- Predicted data
- Traffic data
- Toll values
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)
V. Weather-Related Traffic Management (WRTM)
Weather-sensitive Traffic Estimation and Prediction System (TrEPS)

Weather-sensitive traffic operations model

**Estimation**: weather-sensitive traffic simulation-assignment model

**Prediction**: weather-sensitive traffic simulation-assignment model

Weather-responsive traffic management strategies

Weather data

- Weather monitoring systems
- Weather forecast
- Alert weather conditions
Model impacts of adverse weather on transportation networks

Supply-side Parameter Calibration

* Weather Adjustment Factor (WAF) *
  * Free-flow speed,
  * Saturation flow rate,
  * Section capacity,
  * etc.

Weather Scenario Specification
* Rain intensity ($r$)
* Snow intensity ($s$)
* Visibility ($v$)

Simulate Traffic Flow under Adverse Weather
Chicago

- 40443 links
  - 144 links are tolled
  - 1400 freeways
  - 201 highways
  - 2120 ramps
  - (96 of them are metered)
  - 36722 arterials

- 13093 nodes
  - 2155 signalized intersections

- 1961 zones
  - 1944 internal
  - 17 external

- Demand period
  - 5am -10am hourly demand
  - 355 unique link counts
  - Observation Interval: 5 min
Salt Lake City

- 2,250 zones
- 17,947 links
  - 16,293 arterials
  - 576 ramps
  - 136 highways
  - 791 freeways
  - 151 HOV lanes
- 8,309 nodes
  - 1,134 signalized intersections
- Demand horizon
  - 6am – 9am
- Simulation horizon
  - 6am – 10am
Study Networks

Long Island

- 1,431 zones
- 21,790 links
  - 17,942 arterials
  - 2,059 ramps
  - 31 highways
  - 1,588 freeways
  - 170 HOV lanes
- 9,402 nodes
  - 4,691 signalized intersections
- Demand horizon
  - 5am – 10am
- Simulation horizon
  - 5am – 11am
Off-line Implementation: Effectiveness of VSL/VMS Strategies

- **Test Scenarios**
  - **Clear Day**: Maximum visibility with zero precipitation.
  - **Snow**: Visibility ranges from 10 to 1.75 miles, snow intensity ranges from 0.01 to 0.15 inches per hour network-wide.
  - **Snow with VMS – Variable Speed Limit**: Speed reduction strategies are implemented on freeway corridors.
  - **Snow with VMS – Mandatory Detour**: Vehicles are detoured from some heavily impacted links to alternative routes.
6:30 am

07-00.Regular
07-01.NoWRTM
07-02.VSL7
07-03.VMS2
8:00 am

25-00.Regular
25-01.NoWRTM
25-02.VSL7
25-03.VMS2
9:00 am

37-00.Regular
37-01.NoWRTM
37-02.VSL7
37-03.VMS2
Case Study II

Off-line Implementation (Salt Lake City)

- Demand Management
  - Analysis Results

(a) Time-dependent network throughput measure

(b) %Change in performance measures for different demand levels relative to base-case
- **Target weather event:**
  - Snow on April 6, 2012

- **Before the event**
  - Retrieved a set of VSL strategies from the WRTM strategy repository.
  - Performed the off-line simulation analysis to select the best strategy given the predicted weather scenario.
  - Selected VSL strategy
    - **Deploy VSL on Veterans Memorial Highway (Southbound)**

- **Selected VSL strategy under the given snow scenario**
On-line Implementation (Salt Lake City)

At 7:16AM, predicted traffic states for 7:26AM

RT-DYNA: Estimation of Current Traffic conditions

P-DYNA0: Prediction without VSL

P-DYNA1: Prediction with VSL
On-line Implementation (Salt Lake City)

At 7:54AM, predicted traffic states for 8:04AM

RT-DYNA: Estimation of Current Traffic conditions

P-DYNA0: Prediction without VSL

P-DYNA1: Prediction with VSL
Deploy and evaluate calibrated TrEPS for an arterial corridor (RIVERDALE) to support WRTM interventions, especially signal control strategies.
VI.

Logistics Operations in Congested Urban Environments
Challenges for City Logistics Carriers

- Deliveries in urban areas suffer from time-varying congestion, and various traffic events, such as lane-closure, accidents, construction, weather etc.
- Real time customer requests.
- Customers expect on-time deliveries within service time windows.
Research Objective

- To develop an integrated system which has the following features:
  - Capable of mapping real-life operational components into analytical VRP models.
  - Respond to real-time customer requests.
  - Consider traffic variations on road networks (including effect of weather, incidents, special events, etc...)
  - Applicable to problems of practical sizes.
Overall Architecture

Dynamic Traffic Assignment Model and Simulator

Real-Time Traffic Data and Events
- Travel Times
- Traffic Incidents

State Prediction Module

Real-Time Requests

Online Booking Processor

A Priori Requests

A Priori Routing Planner

Service Network:
Nodes: Unserved customers and NEWLY accepted customers, locations of fleets
Links: time-dependent shortest paths linking nodes

Online Re-routing Planner
Online Booking Processor & Re-routing Planner

Current Routing Plan ➔ Urban Road Network ➔ Historical or Daily TD OD Matrix ➔ Traffic Events

DYNASMART-Estimation ➔ DYNASMART-Prediction

Online Booking Processor ➔ Acceptance/Rejection Decisions ➔ Service Network ➔ Online Re-routing Planner

Updated Routing Plans ➔ Updated Routing Plans
An Illustration of VRP with TDTT

Legend:
- Green diamond: Arrival Time
- Blue circle: Depart Time
- Red arrow: Selected TD Path
- Dashed arrow: TD Path
- Purple line: Service Time
- Blue line: Waiting Time

Time Window
Heuristic Algorithm: Local Search Operators

a) 2-opt*
b) Exchange
c) Segment Exchange
d) Insertion
Case Study: Chicago Network

- Nodes: 1,578
- Links: 4,805
- TAZ: 218
- TD OD: 16hr (5am-9pm), ~1.6mil vehicles
Numerical Results: Feasibility

The graph illustrates the feasibility of different solutions across various customer and time-hour scenarios. The x-axis represents different scenarios: 100CustTW3hr, 200CustTW3hr, and 500CustTW3hr. The y-axis represents the number of vehicles.

The graph compares four different solutions:
- `staticSol`
- `TDSol`
- `evalStaticSol`

For each scenario, the graph shows the number of vehicles required for each solution, indicating the feasibility and efficiency of each approach.
VII. Takeaways
PREDICTION essential in real-time traffic management and urban logistics

Considerable opportunities: new sources of personal information, emerging technologies

Computational challenges remain

User behavior: will remain moving target, because users will adapt hence need for adaptive schemes

Growing role of private sector as business models become more compelling
Leverage system state information and individual characteristics (and preferences) in generating interventions that are

- dynamic (timely)
- localized (consider network and non-network factors)
- anticipatory (consider predicted events and system evolution)
- adaptive (learn about individual responses and system impacts)
- distributive (across modes, times of day, user groups)
- economically efficient (e.g. consider value of time distribution)
Thank you