Improving Travel Reliability Through Predictive Traveler Information

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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**
Throughput vs. Reliability

Breakdown
Challenge:

Maximize Throughput

Maintain Reliability
Avoid Breakdown!
SUPPLY-SIDE APPROACH: RAMP CONTROL

In Practice:

High ramp demand pressure ➔ Minimum in-rate even when facility is congested

Breakdown + Queues on facility

on ramps and access roads
DEMAND-SIDE PERSPECTIVE

Real-time Information

Dynamic Pricing
Traveler Information

Advanced traveler information systems call for

- consistent travel time information provision
- reliability information associated with the trip
Effective **flow and lane management** calls for **dynamic (state-dependent) pricing**
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
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

Fundamental core

• Flow Models
• Behavior
• Algorithms

Historical data

Real-time traffic data

Sensor systems

Network
JING DONG

Dissertation

Integrated formulation and solution approach to real-time traffic management problems—

Anticipatory traveler information

Anticipatory pricing

Traffic control
Real-Time Traffic Management Problem

Problem definition

- **Given**
  - traffic network
  - historical demand matrix
  - real-time measurements
  - users behavioral assumption (homogeneous vs. heterogeneous)

- **Find** dynamic control policies

Formulation

- **Objective:** min/max $\theta(\omega)$
- **Feasibility constraint:**
  - Control variable $\omega \in \Omega(\omega)$
  - Flow variable $r \in P(\omega)$
- **User equilibrium constraint**
  - $c(r)^T(q-r) \geq 0, \forall q \in P(\omega)$
- **System dynamics:**
  - Network loading $s^t = L(r^{t-1})$
  - User decisions $r^t = \Theta(\omega^t, s^t, s^t)$

Applications

- Adaptive signal control (e.g. OPAC, Gartner, 1982)
- State-dependent pricing (e.g. I-15 in San Diego)
- Real-time traffic info (e.g. INRIX)
Formulation (cont’d)

• Notation
  – $\omega^t$: control policy to be determined for time interval $t$
  – $\hat{s}^t$: vehicles generated in time interval $t$
  – $s^t$: vehicles generated in previous time interval and still in the network at time $t$
  – $r^t$: path flow assignment at time $t$

• Control policy $\omega^t$
  – determines traffic assignment at time $t$
  – affects future traffic states that contribute to the objective function

• Network loading equation
  – depicts current states of existing vehicles in the network
  – depends on flow assignment in previous time interval: $s^t = L(r^{t-1})$

• User decisions [Traffic assignment]
  – Given current control policy $\omega^t$, all vehicles in the network $\hat{s}^t$ and $s^t$, and behavioral assumption of route choice, path flow assignment at time $t$:
    $r^t = \Theta(\omega^t, \hat{s}^t, s^t)$
Solution Approach: Anticipatory Traffic Management

- **Anticipatory traffic management**
  - An approximate solution approach to real-time traffic management problems
  - Predict future traffic conditions based on up-to-date information
  - Generate control policy considering its impact on future traffic conditions

- **Rolling horizon framework**
  - To generate and implement solutions to the dynamic program

- **A real-time traffic estimation and prediction system to**
  - Interface with surveillance systems and integrate real-time measurements
  - Estimate and predict traffic conditions

- **Solution algorithms**
  - One-shot algorithm to generate control policy based on look-ahead traffic forecast vs.
  - Iterative algorithm to maintain consistency between predicted and experienced conditions: more effective control, heavier computational burden
• 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.
Network Simulation-Assignment Modeling for Advanced Traffic System Management

REAL TIME DYNAMIC TRAFFIC ASSIGNMENT SYSTEM

- 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
**Solution Algorithms Embedded in TrEPS**

**One-shot algorithm**

- ATIS/ATMS Database → Initial $\omega$ → State Estimation
  - OD Estimation → State Estimation
  - OD Prediction → State Prediction
  - State Prediction → Update $\omega$ → roll forward

**Iterative algorithm**

- ATIS/ATMS Database → Initial $\omega$ → State Estimation
  - OD Estimation → State Estimation
  - OD Prediction → State Prediction
  - State Prediction → Update $\omega$ → Converge?
    - Converge? → Yes
    - Converge? → No → State Estimation
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
Anticipatory Travel Time Information

- **Objective:** to provide travel time information that is consistent with users experience
- **Decision variables:** time-dependent link travel times \( c \)
- **Fixed-point formulation**
  - Composite map \( T: c \rightarrow g \) (guidance info) \( \rightarrow r \) (path flow) \( \rightarrow c \)
  - Find the fixed point \( c^* : c^* = T(c^*) \)
- **Look-ahead route information generation**
  - One-shot prediction to obtain \( T(c_{\eta-1}) \)
  - Updating equation \( c_{\eta} = c_{\eta-1} + \alpha \cdot (T(c_{\eta-1}) - c_{\eta-1}) \), \( \eta = \) stage number
- **Recursive averaging algorithm**
  - Iterate within each state prediction
  - Recursive equation \( c_k = c_{k-1} + \alpha_{k-1} \cdot (T(c_{k-1}) - c_{k-1}) \), \( k = \) iteration number
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
  - 15 min warm-up period + 45 min clearance time

- **Parameters**
  - Roll period: 5 minutes
  - Prediction horizon varying from 30 to 60 minutes
Sensitivity to **Prediction Horizon**

- **Anticipatory** information works better than **prevailing** information
- Longer prediction horizon provides better performance
Sensitivity to **Market Penetration Rate**

- Provision of *anticipatory travel time information* improve the overall network performance
- Solve the overreaction problem caused by providing *prevailing (instantaneous) information*
**Consistency:** Average OD Travel Time

- **look-ahead algorithm**
- **recursive averaging algorithm**

- **Scenario:** 50-minute prediction horizon, 30% MPR
- Vehicles with **anticipatory information** experience less delay
- The **recursive averaging algorithm** provides more consistent information than the **look-ahead algorithm**
How to Incorporate Reliability in Anticipatory Travel Time Information?

How to quantify?
How to predict?
Does it work?
Travel Reliability

• **Travel time reliability**
  - Chen et al. (2002) studied, at the OD level, the relative performance in a degraded state to the one in a non-degraded state.
  - Nicholson et al. (2003) defined reliability, for a path or a OD, as the probability that a trip could reach its destination within a given period.
  - Clark and Watling (2005) examined reliability at the network level and estimated the probability density function for the total travel time.

• **Traffic flow reliability (capacity reliability)**
  - Elefteriadou et al. (1995) stated that breakdown might occur with some probability at various flow rates.
  - Brilon et al. (2005) viewed the “capacity” as a random variable, with traffic breakdown occurring when demand exceeds the capacity.
Flow Breakdown

![Graph showing flow breakdown vs density.](image)
Flow Breakdown

- **Pre-breakdown flow rate:** immediately before the onset of breakdown
- **Breakdown flow rate** determines the extra delay travelers encounter
- Recovery might due to demand drop or recovery of traffic flow
- **Onset of breakdown:** the speed drop between two consecutive time intervals exceeds a threshold and low speed is sustained for some time
Probabilistic Description of Flow Breakdown

- Pre-breakdown flow rate is viewed as a random variable.
- MLE of the pre-breakdown flow rate distribution function based on censored observations.
- Kaplan-Meier estimate provides the empirical distribution.

![Graphs showing cumulative distribution functions for I-405N Jeffrey and Red Hill sections.](image)
• **Extra delay**, the difference between congested and uncongested travel times, is a function of breakdown flow rate: $t' = h(q_b)$

• **Breakdown flow rate** correlates the pre-breakdown flow rate: $q_b = g(q)$

• **Probability of breakdown** at flow rates less than or equal to $q$: $F(q)$

• **Travel reliability measure**: $\delta(q) = h(g(q)) \cdot F(q)$

![Speed-density relation](image1)

![Travel time-flow rate relation](image2)
• Reliability of a link is a function of flow rate \( \delta(q) \)
• Extra delay caused by flow breakdown is additive
• Travelers choose the least generalized cost path
  \[ GC = \beta_1 \cdot t(q) + \beta_2 \cdot \delta(q) \]
• Conventional shortest path algorithm is used to search for least generalized cost path

Test bed network: Irvine
  – Reliability measure calibrated for freeways
  – 30-minute prediction horizon
Scenarios:
- only anticipatory travel time information is provided
- both anticipatory travel time and reliability information is available

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
• Higher and more stable flow is observed under the reliability scenario, indicating an increase in freeway’s utilization
Summary

- Provide operational measure of travel reliability based on basic traffic flow properties
- Empirically realized through the specification and parameter estimation of its components, using common detector data
- From the travelers’ point of view, path selection based on both travel time and variability information could help them avoid actual or likely bottlenecks that experience unstable flow
- Network-wide benefits also achieved by guiding travelers towards socially preferred paths—routing towards more stable flow levels, avoiding or delaying breakdown
Concluding Thoughts

Prediction essential in real-time traffic management

Considerable opportunities: new sources of personal information, emerging technologies
Concluding Thoughts (II)

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
Concluding Thoughts (III)

Growing role for DTA models in evaluating (off-line) and improving (on-line) reliability of networks

As DECISION SUPPORT SYSTEMS and Real-time Predictive Traffic Management Systems
LIGHT AT THE END OF THE TUNNEL?

Thank you

Q & A

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