Control of Freeway Corridors: Objectives, Performance Measures, Strategies

Alex Skabardonis
UC Berkeley
Chania, Greece
June 2, 2016
Outline

- Freeway Corridor management
  - Background/Problem Statement
  - National Programs: ICM
- Signalized Intersections: Performance Measurement
- Freeway-Arterial Coordination
- Looking Ahead
Background: Corridor Management

Cooperative management of freeways and adjacent arterial networks

Los Angeles, Smart Corridor 1988
Background: Corridor Management

Corridor Traffic Management & Information Vision
Multimodal operations
Complex modeling approaches
Operational procedures/plans
Institutional constraints
Decision support systems
Limited field evaluation
Research Gaps
- Data analytics
- Control Algorithms
US-75 ICM Corridor, Dallas, TX
USDOT ICM Program (3)

I-15 ICM Corridor, San Diego, CA
CA CC I-210: Decision Support

Heterogeneous data

Historical data

Current \( \rho, v, f \) state

State estimation

Demand prediction

Performance prediction

Predicted OD and routes

Demand management strategy

Supply management strategy

Predicted performance

Interface

Data scopes

Measured \( \rho, v, f \)

Incidents, CHP, etc.

Normalized and fusion

Heterogeneous data

Strategy bank

Actuation

Knowledge

Data

Measured \( \rho, v, f \)

All

Measured \( \rho, v, f \)

Data scopes

Incidents, CHP, etc.
Urban Arterials/Networks: Traffic Flow Variability vs. Control

- Fixed-Time Plans
- Time of Day (TOD)
- No Detection
- May be actuated

- Fixed time plans
- Traffic responsive plan selection
- System detection

- Traffic responsive control
- On-line timing development
- Approach & system detection

- Adaptive control
- Measure & predict arrivals per cycle
- Extensive detection
Arterial Networks: Traffic Control

- Most signal systems fixed-time control
  - Limited data
  - Out-dated timing plans

- Adaptive systems
  - High cost
  - Complex to understand and operate
Approach: Use of HR data*

- Performance measures for operators and travelers
  - Use of existing infrastructure
  - No interference with controller operation

- Improving Signal Timing Plans
  - Performance derived signal settings
  - Robust timing plans

- On-Going/Future Work
  - Traffic volume prediction
  - Safety (red light running)
  - Multimodal (pedestrians, bicycles)

*Work with P. Varaiya & Sensys Networks
“Management of Urban Traffic with H-R Data” IEEE ITSC 2014
Data Collection System

- Stop bar detectors
- Departure lane detectors
- Advance lane detectors

Sensys SNAPS Server
Data fusion, and application deployment

Cellular

Sensys networks

NEMA/2070/170
ED/Conflict Monitor
AP
NETWORK HUB
Modem
Selected Test Site: Beaufort, SC
Traffic Volume Patterns

Median turn movement count by month: EB, Left turn lane

- Feb
- Mar
- Jul
- Aug
- Sep
- Dec

Time [hr]

Veh per hr
Wasted green time: time phase is active with no vehicle present and conflicting phase call
Vehicle arrivals: % arrivals on green
Performance: Average Delay (sec/veh)
HCM Level of Service (LOS)

Through movement, Leg 1

Through movement, Leg 2

Left turn movement, Leg 1

Right turn movement, Leg 2
Performance: V/c and LOS

(V/C): \( \frac{v \cdot C}{g \cdot s} \)

S: sat flow (max discharge rate)

LOS: Level of Service per HCM
HR Data and Timing Plan Development

**Traditional Approach**

- Local adjustments based on spot observations (complaints)
- Field data collection of turning movement counts (one day)
- Apply signal optimization software to develop timing plan(s)
- Field implementation-fine tuning. Before and after studies (limited)

**Availability of HR Data**

- Assess existing intersection operations
  - Progression (% arrival on green)
  - Capacity (V/c ratio)
  - Delay

- Develop and Implement Improved Settings

- Evaluate performance
  - Approach/intersection/system Over time
Improving Signal Timing Plans

- Volume clustering – best set of volumes for the three timing plans available
- New timing plans reduce intersection signal delay by 10% on average*
Summary: Use of HR data

- Performance measures for operators and travelers
  - Use of existing infrastructure
  - No interference with controller operation

- Improving Signal Timing Plans
  - Performance derived signal settings
  - Robust timing plans

- On-Going/Future Work
  - Traffic volume prediction
  - Safety (red light running)
  - Multimodal (pedestrians, bicycles)
II. Freeway – Arterial Coordination

- Important element of corridor management
- Existing coordination guidelines mostly address institutional issues (*example: FHWA Handbook*)
- Most approaches consist of scenarios with “flush” signal timing plans on arterials in case of freeway incidents
- Lack of Methodologies for Freeway-Arterial Interactions
- Spillbacks to/from ramps
Freeway Ramp Metering: Impacts

Excessive delays to on-ramp vehicles
Spillback to local streets
Queue override – diminishes ramp metering benefits

Freeway Mainline

On Ramp Queues
On-Ramp Queue Control Regulator

Queue Override
- failed to limit the queue within the limits
- large variation in queue length

Queue Estimation & Control
Application: Los Angeles I-210W

Improvements: 6% Travel Time/16% Delay Reduction


Proposed on-Ramp Access Control (1)

Determine the signal settings to avoid **queue spillover** from ramp metering and result in queue override

**Constraints**
- Serve the traffic demand on arterial phases
- Arterial link storage (arterial spillback)
- Minimum phase green times
Proposed on-Ramp Access Control (2)

Minimize the ratio of actual and desired green times per signal phase

Desired green time: minimum green time to serve the traffic demand

\[
\sum_k \left\{ \frac{g_{ik}(t)}{f_{sat,ik}} \left( \frac{q_{ik}(t) + d_{ik}(t) \cdot C}{f_{sat,ik}} \right) \right\} - 1
\]
Proposed on-Ramp Access Control (3)

Constraints

- Minimum green time constraint: \( g_{ik}(t) \geq G_{ik,min} \)
- Cycle length constraint: \( \sum_i g_{ik}(t) = C \)
- On-ramp storage constraint:

\[
\sum_{i \in R} f_{sat,ik} \cdot g_{ik}(t) \leq RA_i
\]
Proposed on-Ramp Access Control (4)

Constraint: Arterial link storage

\[ f_{sat,ik} \cdot [o_{ik}(t) + l_{acc}] \leq s_L - \sum_{i \in L} q_{i,k+1}(t) \]

- Flow into downstream link
- Offset
- Lost time
- Downstream queue length
- Link length
- Available queue storage space
- Existing queue
- Available queue storage space
- \( s_L \)
Application: Test Site

Test Site: I-680, San Jose CA

- AIMSUN Microscopic Simulator
Application: Findings

- FWY DELAY
- FWY VMT
- ARTERIAL DELAY
- ARTERIAL DELAY

% CHANGE

SYSTEM / MOE

FWY DELAY
FWY VMT
ARTERIAL DELAY
ARTERIAL DELAY
Looking Ahead: Connected Vehicles

“Here I am”
V2V and V2I

V2I Example: SPaT message
Application: Dynamic Speed Advisory (source: UC & BMW)
Field Test Results*

Uninformed Driver (Baseline Scenario): no speed recommendation

Informed Driver: follow speed recommendation

Individual Vehicle Priority & Uninformed Driver: no speed recommendation. Intersection adapts timing with individual vehicle priority

Individual Vehicle Priority & Informed Driver: follow speed recommendation. Intersection adapts timing with individual vehicle priority

<table>
<thead>
<tr>
<th></th>
<th>Uninformed Driver</th>
<th>Informed Driver</th>
<th>Uninformed Driver &amp;APIV</th>
<th>Informed Driver &amp;APIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (L/100KM)</td>
<td>10.23</td>
<td>8.84</td>
<td>8.28</td>
<td>7.33</td>
</tr>
<tr>
<td>Improvement</td>
<td>Base Scenario</td>
<td>-13.60%</td>
<td>-19.10%</td>
<td>-28.40%</td>
</tr>
</tbody>
</table>

*https://www.fhwa.dot.gov/multimedia/research/advancedresearch/index.cfm

Looking Ahead: Beyond Connected Veh