Control of Freeway Corridors: Strategies and Impacts

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Miami, FL
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Outline

- Freeway Corridor management
  - Background/Problem Statement
  - National Programs: ICM

- Freeway-Arterial Coordination
  - Recurrent Congestion
  - Non-Recurrent Congestion

- Looking Ahead
Background: Freeway Management

1971 Los Angeles – 42 mile loop
Background: Corridor Management

Cooperative management of freeways and adjacent arterial networks

Los Angeles, Smart Corridor 1988
Integrated Corridor Management (ICM)

Corridor Traffic Management & Information Vision

1988
The I-10 Smart Corridor Goal/ConOps

Improve traffic efficiency and reliability through the coordinated use of management measures utilizing advanced technology.

Link different TMCs currently operating independently by Caltrans (freeway), Los Angeles (ATSAC - traffic signals), Highway Patrol (freeway), and SCRTD (buses).

Full detection on freeway and city streets within the corridor.

Information systems: CMS, HAR, telephone response, cable TV, in-vehicle navigation system, and computer bulletin boards.

Traffic management strategies will provide drivers with suggested alternate routes to avoid congestion and traffic incidents.

Expert system technology will assist TMC operators in the selection of appropriate management strategies.
Multimodal operations
Complex modeling approaches
Operational procedures/plans
Institutional constraints
Decision support systems
Limited field evaluation
Limited research
USDOT ICM Program (2)

US-75 ICM Corridor, Dallas, TX
USDOT ICM Program (3)

I-15 ICM Corridor, San Diego, CA

Managed Lanes
Park and-Ride
Access Road
Direct Access Ramps
BRT Station

[Image of a busy highway and a map of the I-15 ICM Corridor, San Diego, CA]
I-210 ICM Corridor—Los Angeles

14 fwy miles-62 metered ramps
450 signals
**Multimodal:** Light rail line + 35 bus lines
I-210 ICM: Data Sources
CA CC I-210: Decision Support

- **Historical data**
  - Measured $\rho,v,f$
  - Incidents, CHP, etc.

- **State estimation**
  - Current $\rho,v,f$ state

- **Demand prediction**
  - Demand management strategy
  - Supply management strategy
  - Predicted OD and routes

- **Performance prediction**

- **Interface**
  - Data scopes

- **Normalization and fusion**
- **Heterogeneous data**

- **Actuation**

- **Data**

- **Knowledge**
  - Strategy bank
Example: San Diego DSS

Example: Activate Response Plan when *predicted* travel time increase > x %
ICM Programs: Lessons Learned

- Multimodal operations
  - Coordination gaps (real-time)
- Agencies Cooperation
  - Institutional constraints
  - Sharing information vs. sharing control
- Data
  - Data Sources/Types
  - Data Processing/Integration
- Impacts
  - Limited Field Tests
  - Benefits Reporting
  - Assessment of Corridor Component Strategies
Freeway – Arterial Coordination

- 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
  - NCHRP 15-57 “HCM Methodologies for Freeway and Surface Street Corridors”
Background: Freeway Ramp Metering

Control on-ramp flows to preserve freeway capacity

\[
\text{MAX} \sum_{i=1}^{N} X_i \quad \sum_{i=1}^{N} a_{ij} X_i \leq c_j
\]

\(X_i\): input flow rate at on-ramp \(i\), \(N\): # on-ramps
\(a_{ij}\): proportion of traffic entering on-ramp \(i\) going through section \(j\)
\(C_j\): capacity of freeway segment \(j\)
Ramp Metering Impacts (1)

Freeway:
- Maximize freeway throughput
- Minimize time spent
- Preserve freeway capacity

Fwy mainline: no metering

Fwy mainline: metering
On-Ramps:
- Excessive delays to on-ramp vehicles
- Spillback to local streets

Freeway Mainline

Queue Override (Suspend metering)
- Diminishes ramp metering benefits
- Capacity drop
Field Study: Impacts of Queue Override (1)

Study Location:
- NB I-680, San Jose, CA
- McGee Rd, bottleneck

Time Period:
- Weekdays (May 9 – My 20, 2015)
- AM Peak (7-10 am)
Data Processing: Cumulative Curves (Example: 5/10/2015)

- Capacity Drop
- Recovery
- Queue Override

- Location 1
- Location 2
- Location 3

Time (measured upstream)
### Field Study: Impacts of Queue Override (3)

<table>
<thead>
<tr>
<th></th>
<th>Total Outflow (Mainline and On-ramp)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Queue Override</td>
<td>After Queue Override</td>
</tr>
<tr>
<td><strong>Week 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 9 (Monday)</td>
<td>Not Activated</td>
<td></td>
</tr>
<tr>
<td>May 10 (Tuesday)</td>
<td>7847 vph</td>
<td>6891 vph</td>
</tr>
<tr>
<td>May 11 (Wednesday)</td>
<td>6752 vph</td>
<td>6058 vph</td>
</tr>
<tr>
<td>May 12 (Thursday)</td>
<td>Downstream spillback</td>
<td></td>
</tr>
<tr>
<td>May 13 (Friday)</td>
<td>Not Activated</td>
<td></td>
</tr>
<tr>
<td><strong>Week 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 16 (Monday)</td>
<td>Not Activated</td>
<td></td>
</tr>
<tr>
<td>May 17 (Tuesday)</td>
<td>7214 vph</td>
<td>6672 vph</td>
</tr>
<tr>
<td>May 18 (Wednesday)</td>
<td>7109 vph</td>
<td>6493 vph</td>
</tr>
<tr>
<td>May 19 (Thursday)</td>
<td>7532 vph</td>
<td>6612 vph</td>
</tr>
<tr>
<td>May 20 (Friday)</td>
<td>Not Activated</td>
<td></td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td></td>
<td>----</td>
</tr>
</tbody>
</table>
On-Ramp Queue Control Regulator

Existing RM Algorithm
- failed to limit the queue within the limits
- large variation in queue length

Proposed RM Algorithm
- RM rate considers on-ramp queue length (measured in real time)
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)

- Mitigate both on-ramp and arterial spillback
- Example signalized intersection near freeway on-ramp
Proposed on-Ramp Access Control (3)

\[ Q(t) + G_1 \cdot s_1 \cdot \beta_1 + G_2 \cdot s_2 \cdot \beta_2 - G_1 \cdot r(t) - G_2 \cdot r(t) \leq Q_r \]

- Residual on-ramp excess accumulation
- Upstream arrival
- Downstream departure
- Available queue storage
Proposed on-Ramp Access Control (4)

- On-ramp residual queue estimation:
  \[ Q(0) = 0 \]
  \[ Q(1) = Q(0) + A(1) - D(1) \]
  \[ \vdots \]
  \[ Q(t) = Q(t - 1) + A(t) - D(t) \]

- Green time distribution:
  \[ g_1 = \frac{y_1}{Y} \cdot (C - 3l) \]
  \[ g_2 = \frac{y_2}{Y} \cdot (C - 3l) \]

- Cycle length upper limit:
  \[ C \leq \frac{[Q_r - Q(t) + r(t) \cdot 2l] \cdot Y + 4l \cdot [\sum_{i=1,2} s_i \beta_i y_i - \sum_{i=1,2} r(t) y_i]}{[\sum_{i=1,2} s_i \beta_i y_i - \sum_{i=1,2} r(t) y_i]} \]
Application: Simulation Test (1)

Test Site:
NB I-680, San Jose CA

- AIMSUN Microscopic Simulator
Application: Simulation Test (2)

Simulation Tests
- Before: adjacent signals operate independent of ramp metering
- After: adjacent signals coordinate with ramp metering

Study Period:
- Date: Wednesday September 23, 2015
- Time of day: 7:00 AM to 9:30 AM

Input Data
- Freeway: detector data from PeMS and video recordings
- Arterial: manual counts and video recordings

Calibration:
- Loop Detector data: Bottleneck locations, volumes
- INRIX: Travel times
<table>
<thead>
<tr>
<th></th>
<th>Before Coordination</th>
<th>After Coordination</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Freeway Mainline</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Delay (veh-hr)</td>
<td>799.06</td>
<td>655.81</td>
<td>-17.93%</td>
</tr>
<tr>
<td>Total Distance Traveled (veh-mile)</td>
<td>37295.75</td>
<td>37788.13</td>
<td>1.30%</td>
</tr>
<tr>
<td><strong>Arterial</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Delay on Main Parallel Arterial (min/veh)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capitol Ave NB</td>
<td>8.63</td>
<td>10.51</td>
<td>21.84%</td>
</tr>
<tr>
<td>Capitol Ave SB</td>
<td>5.72</td>
<td>5.91</td>
<td>3.33%</td>
</tr>
<tr>
<td>Average Delay of Cross Street (sec/veh)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alum Rock WB</td>
<td>48.05</td>
<td>47.33</td>
<td>-1.43%</td>
</tr>
<tr>
<td>Alum Rock EB</td>
<td>37.27</td>
<td>37.82</td>
<td>1.47%</td>
</tr>
<tr>
<td>McKee WB</td>
<td>56.76</td>
<td>52.34</td>
<td>-7.79%</td>
</tr>
<tr>
<td>McKee EB</td>
<td>28.92</td>
<td>16.51</td>
<td>-42.91%</td>
</tr>
<tr>
<td>Berryessa WB</td>
<td>47.27</td>
<td>39.26</td>
<td>-16.73%</td>
</tr>
<tr>
<td>Berryessa EB</td>
<td>50.50</td>
<td>37.55</td>
<td>-34.48%</td>
</tr>
<tr>
<td><strong>Total System</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Delay (veh-hr)</td>
<td>2847.02</td>
<td>2642.36</td>
<td>-7.19%</td>
</tr>
</tbody>
</table>
Updated Simulation Results
Updated Simulation Results

AIMSUN Model Limitation

- AIMSUN cannot replicate capacity drop, underpredicts queue override avoidance benefits
- Modified AIMSUN version
  - Based on acceleration/deceleration asymmetry
  - Calibrated with NGSIM data
  - Used in CACC Modeling

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<tr>
<td></td>
<td>Total Delay (veh-hr)</td>
<td>Total Distance Traveled (veh-mile)</td>
<td>Total Delay (veh-hr)</td>
</tr>
<tr>
<td>I-680 NB</td>
<td>833.41</td>
<td>43104.13</td>
<td>740.64</td>
</tr>
</tbody>
</table>
Non-Recurrent Congestion: Diversion Strategies

- Key Issues:
  - Freeway Operating conditions (congestion level)
  - Incident characteristics (location, severity)
  - Characteristics of freeway control & freeway surveillance
  - Characteristics of traveler information system
  - Characteristics of parallel arterial(s)

Incident at Bottleneck

Incident Upstream of Bottleneck
Maximum Amount of Diverted Volume? = f(remaining capacity at critical intersection)

\[ dV_i = \frac{RC_i}{X_i} \times 100 \]

where:
- \( dV_i \) : additional traffic volume on approach \( i \) (%)
- \( X_i \) : volume/capacity (degree of saturation) on approach \( i \) (%)
- \( RC_i \) : reserve capacity on approach \( i = 1- X_i \)
Diversion: A Planning for Operations Approach (2)

Freeway Lost Capacity vs. Critical Intersection Remaining Capacity
Looking Ahead: CAVs

- Capacity
- Air quality
- Automation
- Connected Veh
- ATM
- Safety

Current technologies

6,000

2,000

10

90