Control of Freeway Corridors: Objectives, Performance Measures, Strategies

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Outline

- Integrated Corridor management
  - Background/Problem Statement
  - National Programs: ICM
  - Research Challenges/Opportunities
- Signalized Intersections: Performance Measurement
- Ramp Metering
- 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
USDOT ICM Program (1)

US-75 ICM Corridor, Dallas, TX
I-15 ICM Corridor, San Diego, CA

Managed Lanes

Direct Access Ramps

Access Road

Park-and-Ride

BRT Station
Modeling Framework

Findings

- Delay reduction
- Travel time reliability improvement
- Fuel savings
- Emissions reduction
- Agency cooperation
- Decision support systems
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

Source: Alek Stevanovic, NCHRP Synthesis 403
Traffic Flow Variability vs. Control

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

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

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

D
- Adaptive control
- Measure & predict arrivals per cycle
- Extensive detection
Data Collection System
Selected Test Site: Beaufort, SC
February 28, 7AM to 8PM

Peak Period, 4-7 PM

Total volume (veh/cycle)

Total volume (veh/15 minutes)
Peak Period 4-7 pm: Turning Movements

Leg 1

Leg 2

Leg 3

Leg 4
Seasonal Volume Variation

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

- Feb
- Mar
- Jul
- Aug
- Sep
- Dec
Signal Control Data

Green Times per Phase

MAIN STREET: Phases 1, 2, 5, 6

CROSS STREETS: Phases 4, 8
**Wasted green time:** time phase is active with no vehicle present and conflicting phase call

**Max Wait time:** Max time to receive green
Performance: V/C and LOS

(V/C): \( (v \times C/g \times s) \)

S: sat flow (max discharge rate)

LOS: Level of Service per HCM

Shift green time
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
Summary

- Reliable data collection system
- Performance measures for travelers and operators
- Uses existing infrastructure
- No interference with controller operation

- Ongoing/Future Work
  - Safety
    - Red-light running
  - Traffic Volume Prediction
  - Robust Signal Timing Plans
II. Freeway Ramp Metering

Control on-ramp flows to preserve freeway capacity

\[
\begin{align*}
\text{MAX} & \sum_{i=1}^{N} X_i \\
\sum_{i=1}^{N} a_{ij} X_i & \leq c_j
\end{align*}
\]

- \(X_i\) : 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 \(j\)
Freeway Ramp Metering: Issue

Issue

Limited Ramp Storage
Spillback to local street network
Excessive delays

Freeway Mainline

Ramp Queues
Example: Fixed-Time Metering (3)

Ramp constraints: min on-ramp rates, max delays

Freeway Mainline

Queue Override

Ramp Queues

Trade-off: Mainline Congestion vs. Ramp Queue
III. 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 field test results
Figure 12. Chart. Example of development of corridor operations plans.
Determine the green times for the signal phase(s) serving the on-ramp direction to avoid queue spillover from ramp metering and result in queue override.
Proposed on-Ramp Access Control (2)

**Assumptions:**
- On-ramp is metered with ALINEA control strategy
- There are $k$ intersections on the arterial
- Signals are coordinated with common cycle time $C$
- Intersections are undersaturated

**Objectives/Constraints:**
- Determine signal settings (green times & offsets)
- Avoid on-ramp queue spillback
- Serve the traffic demand on arterial phases
- Arterial link storage (arterial spillback)
- Minimum phase green times
- Common fixed cycle length
Minimize the ratio of actual and desired green times per signal phase

Desired green time: minimum green time to serve the traffic demand
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:
  \[
  \sum_{i \in R} f_{sat,ik} \cdot g_{ik}(t) \leq RA_r
  \]

<table>
<thead>
<tr>
<th>Phases for on-ramp access</th>
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</thead>
<tbody>
<tr>
<td>Available on-ramp storage space</td>
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<table>
<thead>
<tr>
<th>Total flow onto freeway on-ramp</th>
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<table>
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<th>Freeway</th>
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<table>
<thead>
<tr>
<th>Arterial</th>
</tr>
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<table>
<thead>
<tr>
<th>RA</th>
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<tr>
<th>On-Ramp Access Control (3)</th>
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</thead>
</table>
Proposed on-Ramp Access Control (4)

Constraint: Arterial link storage

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

- Offset
- Lost time
- Flow into downstream link

- Link length
- Downstream queue length
- Available queue storage space

- Available queue storage space
- Existing queue

\[ \sum_{i \in L} q_{i,k+1}(t) \]
**Test Site: I-680, San Jose CA**

- **AIMSUN Microscopic Simulator**
- **API**

<table>
<thead>
<tr>
<th>Arterial Performance</th>
<th>Before</th>
<th>After</th>
<th>% Difference</th>
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</thead>
<tbody>
<tr>
<td><strong>Average Delay on Parallel Arterial (min/veh)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capitol Ave NB</td>
<td>7.55</td>
<td>7.4</td>
<td>-1.95%</td>
</tr>
<tr>
<td>Capitol Ave SB</td>
<td>2.05</td>
<td>1.79</td>
<td>-12.73%</td>
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<tr>
<td><strong>Arterial--Average Delay on Cross Street (sec/veh)</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Alum Rock WB</td>
<td>34.96</td>
<td>36.57</td>
<td>4.62%</td>
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<tr>
<td>Alum Rock EB</td>
<td>9.52</td>
<td>8.01</td>
<td>-15.88%</td>
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<tr>
<td>McKee WB</td>
<td>10.04</td>
<td>10.62</td>
<td>5.80%</td>
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<td>2.03</td>
<td>1.34</td>
<td>-34.10%</td>
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<tr>
<td>Berryessa WB</td>
<td>9.95</td>
<td>11.23</td>
<td>12.86%</td>
</tr>
<tr>
<td>Berryessa EB</td>
<td>7.71</td>
<td>6.71</td>
<td>-12.86%</td>
</tr>
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**Freeway Performance --VMT**

| I-680 NB**             | 13749.1 | 14220 | 3.4         |
Looking Ahead: Connected Vehicles

“Here I am”

V2V and V2I

V2I Example: SPaT message

Application: Dynamic Speed Advisory (source: BMW)
Looking Ahead: Beyond Connected Veh

- Automation
- Connected Veh
- Air quality
- Current technologies
- Capacity
- Safety
- ATMIS

Graph showing relationships between capacity, current technologies, air quality, automation, and safety.