Integrating Freeway and Arterial Traffic Control under Vehicle-to-Infrastructure Communications Environment

Alexander Skabardonis, David Kan
PATH UC Berkeley
July 9, 2018, San Francisco, CA
Problem Statement

- Ramp metering: common strategy to manage freeway congestion and prevent “capacity drop” ¹
- Independent signal control: cause of queue spillback

¹ Cassidy and Rudjanakanoknad, 2005; Zhang and Levinson, 2010; Kim and Cassidy, 2012
Queue Override

- Prevents on-ramp queue spillback
  - Suspends or adjusts ramp metering
  - Freeway congestion/capacity drop ~ 10%
Vehicle to Infrastructure Communication

- Vehicles can send real-time on-ramp queue length data to the traffic signal

- Traffic signals can adjust the cycle length in real-time
  - Avoid long platoons entering the freeway on-ramp from the nearby arterials
  - Prevent queue spillback
Proposed Signal Control Strategy (1)

- Ramp metering control unchanged
- Integrate ramp metering controllers
- Reduced and variable cycle length
- Mitigate both on-ramp and arterial spillback
- Example signalized intersection near freeway on-ramp
Proposed Signal Control Strategy (2)

On-ramp excess accumulation

\[ Q(t) + G_1 \cdot s_1 \cdot \beta_1 + G_2 \cdot s_2 \cdot \beta_2 - G_1 \cdot r(t) - G_2 \cdot r(t) \leq Q_r \]
**Proposed Signal Control Strategy (3)**

- Phases 1 and 2: shorter green times
- Clear on-ramp queues in phase 3

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Vehicles</td>
<td>Number of Vehicles</td>
</tr>
<tr>
<td>$Q(t)$</td>
<td>$Q(t)$</td>
</tr>
<tr>
<td>$A(t)$</td>
<td>$A(t)$</td>
</tr>
<tr>
<td>$D(t) = r(t)$</td>
<td>$D(t) = r(t)$</td>
</tr>
</tbody>
</table>

- Before: $A(t)$, $Q(t)$, $D(t) = r(t)$
- After: $A(t)$, $Q(t)$, $D(t) = r(t)$

**Graphs:**

- **Before:**
  - Green time $G_1$, $G_2$, $G_3$
  - $Q(t)$, $A(t)$, $D(t) = r(t)$

- **After:**
  - Green time $G_1$, $G_2$, $G_3$
  - $Q(t)$, $A(t)$, $D(t) = r(t)$
  - Cycle

---

**Equations:**

- $D(t) = r(t)$
Proposed Signal Control Strategy (4)

- On-ramp residual excess accumulation can be determined by tracking vehicles entering and leaving the on-ramp:

\[
Q(0) = 0 \\
Q(1) = Q(0) + A(1) - D(1) \\
\vdots \\
Q(t) = Q(t - 1) + A(t) - D(t)
\]

- Maintain the same green time distribution:

\[
g_1 = \frac{y_1}{Y} \cdot (C - 3l) \\
g_2 = \frac{y_2}{Y} \cdot (C - 3l)
\]
Proposed Signal Control Strategy (5)

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

- Updated every cycle
- Does not provide progression/maximum bandwidth
Simulation Test

- Test site: NB I-680/Capitol Ave Corridor, San Jose, CA

- Recurrent bottleneck – AM peak (7:00AM – 9:30AM)
- Aimsun Model
  - Enhanced driving behavior model \(^1\)
  - Calibrated to replicate field data
- **Before:** metering with queue override, long cycle lengths
- **After:** metering without queue override, short cycle lengths
- 20 replications

\(^1\) Lu, Kan, Shladover, 2017
Simulation Results: Test Corridor (1)
## Simulation Results: Test Corridor (2)

### I. Freeway

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Freeway Mainline</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<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>

### II. Arterial

#### Average Delay on Main Parallel Arterial (min/veh)

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<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>
</tbody>
</table>

#### Average Delay of Cross Street (sec/veh)

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<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>
</tbody>
</table>

### III. Total System

<table>
<thead>
<tr>
<th></th>
<th>Total Delay (veh-hr)</th>
<th>Total Delay (veh-hr)</th>
<th>Change in Total Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway &amp; Arterial</td>
<td>2881.37</td>
<td>2727.19</td>
<td>-5.65%</td>
</tr>
</tbody>
</table>
Summary

• Vehicle-to-infrastructure communication allows for traffic signals to adjust cycle lengths based on on-ramp queue length
• Improved arterial signal timing can reduce arterial and freeway delay
• Sensitivity analysis: similar improvement when peak (7:30 AM – 8:30 AM) demand increases by 5-10%.