Increasing Freeway Capacity by Efficiently Timing its Nearby Arterial Traffic Signals

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Introduction

Currently, freeway ramp metering and the adjacent traffic signals operate independently. The traffic signals respond to peak hour demand, by employing long signal cycles to maximize intersection capacity. This leads to long green times and therefore large vehicle platoons entering the freeway on-ramps. As a result, metering the large influx of on-ramp traffic requires sufficient space to store queued vehicles. Unfortunately, land use constraints do not allow for longer on-ramps, and consequently lead to queue spillback prior to the long green time terminates. Due to the interference from queue spillback, vehicle movements completely stop during a portion of the green time, this causes reduction in the intersection capacity and severe delays. Most of the operational freeway ramp metering systems employ a “queue override” feature that is intended to prevent the on-ramp queue from obstructing traffic flow along the adjacent surface streets. The override is triggered whenever a sensor placed at the entrance of the on-ramp detects a potential queue spillover of the on-ramp vehicles on the adjacent surface streets. This clears the on-ramp queue by temporarily turning off ramp metering. However, commonly employed metering is intended to maintain high capacity at freeway merge bottlenecks by restricting the flow of on-ramp traffic. Unfortunately, queue override reverses the intended benefit during the peak period, when the ramp metering is most needed. Therefore, it is important to control the arrival of arterial traffic to the freeway on-ramp. This would prevent on-ramp oversaturation and avoid queue override, thereby preserving the capacities of both the freeway bottleneck and the arterial intersection.

Proposed Signal Control Strategy

- Readily implementable at most freeway-arterial interchanges
- Maintains existing ramp metering algorithms
- Reduces long cycle lengths

Consider the example below
- On-ramp is metered with a rate \( r(t) \) and has queue storage capacity \( Q_r \)
- On-ramp access for phase 1 and 2

Mathematical expression:

\[
Q(0) = 0 \\
Q(1) = Q(0) + A(1) - D(1) \\
Q(2) = Q(1) + A(2) - D(2) \\
Q(0) = Q(1) + A(0) - D(0)
\]

Queueing Diagram of on-ramp:
- Phases 1 and 2 terminate when on-ramp excess accumulation reaches \( Q_r \)
- Phase 3 initiates early to allow for dissipation of on-ramp queue
- Maintains the same green distribution

Estimation of excess accumulation:

\[
\begin{align*}
Q(0) & = 0 \\
Q(1) & = Q(0) + A(1) - D(1) \\
Q(2) & = Q(1) + A(2) - D(2) \\
Q(0) & = Q(1) + A(0) - D(0)
\end{align*}
\]

Phase 3 initiates early to allow for dissipation of on-ramp queue

Maintains the same green distribution such that only a short platoon feeds the adjacent traffic in smaller but more frequent platoons, without imposing significant penalties. This approach also increase the intersection capacity by avoiding wasted green caused by queue spillback.

Case Study: I-680/Capitol Ave. Corridor

- Calibrated Aimsun micro-simulation using real world data from the morning peak (7:00 AM – 9:30 AM)
- 3 mile section from the Alum Rock Ave. interchange to the Berryessa Rd. interchange in San Jose, CA
- 4 on-ramps and 3 off-ramps
- High on-ramp demand is the main cause of the observed bottlenecks

Simulation Results

<table>
<thead>
<tr>
<th></th>
<th>Freeway Mainline</th>
<th>Before</th>
<th>After</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-680 NB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Distance Traveled</td>
<td>833.41</td>
<td>43704.13</td>
<td>740.64</td>
<td>44792.95</td>
</tr>
<tr>
<td>Average Delay on Main Parallel Arterial (min/veh)</td>
<td>8.63</td>
<td>10.51</td>
<td>21.64%</td>
<td></td>
</tr>
<tr>
<td>Average Delay of Cross Street (sec/veh)</td>
<td>5.72</td>
<td>5.91</td>
<td>3.33%</td>
<td></td>
</tr>
<tr>
<td>Freeway &amp; Arterial Delay</td>
<td>2881.37</td>
<td>2727.19</td>
<td>-5.65%</td>
<td></td>
</tr>
</tbody>
</table>

Summary Remarks and Next Steps

Nearby arterial traffic signals can help avoid queue spillback at freeway on-ramps if the signal control systems were integrated with those of the freeway ramp metering and if the traffic signals were timed effectively based on the current ramp metering rate and on-ramp queue lengths.

We recommend reducing the arterial signal cycle length and maintaining the same green time distribution such that only a short platoon feeds the adjacent freeway on-ramp every cycle. This can prevent queue spillback and subsequently avoid queue override by sending on-ramp bound traffic in smaller but more frequent platoons, without imposing significant penalties. This approach also increase the intersection capacity by avoiding wasted green caused by queue spillback.

A section of the I-680 Northbound freeway with Capitol Ave. as the parallel arterial in the city of San Jose, California was selected as the test site to evaluate the proposed signal control. The simulation results of the AM peak show the proposed signal control strategy eliminated the queue spillback on the metered on-ramps reduced the freeway, arterial, and system-wide delay, at a modest penalty for on-ramp bound traffic.

Acknowledgment

This research is supported by the State of California Department of Transportation (Caltrans) under Interagency Agreement No. 65A0518.