Coordination of Freeway Ramp Meters and Arterial Traffic Signals (FOT)

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Project PI: Alex Skabardonis

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Outlines

• Project Objectives
• More Literature Review (Task 2)
• Site Selection for Phase I
• Data Collection
• Traffic Analysis of SR87 near Taylor
• Higher Level Coordination Strategy
• Modeling and Simulation
• Next Step
• Discussion
Project Objectives – Long Term

• Large scale system problem:
  – Freeway corridor traffic and control
  – Related arterial(s) intersections traffic and control
  – Dynamic interaction between the two

• To resolve any (or potential) inconsistency and conflict between the two traffic control systems;

• To balance the traffic flows overall system for accommodating more traffic in peak hours;

• To eventually minimize Total Travel Time (TTT) system wide and to improve mobility, reduce emission and energy consumption;
Project Objectives – Short Term

• To coordinate one (feeding) intersection and one onramp meter
• To identify
  – Where and when coordination is necessary
  – Where and when is feasible
  – Technical hurdles in coordination of the two subsystems
  – Conflict of interests between the two and how to resolve
• To hopefully improve the performance of the system in some aspect in some level which could be quantified;
• To set an example for overcoming any hurdle(s) caused by multiple jurisdictions;
• To laid down a good foundation for a large project involving a freeway corridor and related arterial corridor(s) if it is successful.
More Technical Literature Review (Task 2)

- **Coordinated Freeway Corridor Ramp Metering and Arterial Traffic Signal Control:**
  - Tian, Z., Messer, C., and Balke, K., Modeling the impact of ramp metering queues on diamond interchange operations, Transportation Research Record 1867, 2004, pp. 172-182.
Site Selection for Phase I - Main Factors

- Recurrent congestion in a peak hour(s)
- System Isolation: To make sure that the congestion is mainly caused by the interaction of freeway and arterial traffic flow
  - Capacity of the subject section
  - Freeway demand upstream
  - Freeway demand downstream (not caused by back-propagation)
  - Traffic demand from current onramp (eventually from arterial)
  - Arterial intersection traffic signal control
- Onramp length and number of lanes (storage capacity)
- Sensor locations and density
- Data quality
- Complexity of the system
Data Collection for SR87-Taylor

- Video data collection on 04/03/12
- PeMS Data Collection on 04/03/12
  - 30s Lane by Lane (flow, occupancy, speed)
  - 5min Lane by Lane (flow, occupancy, speed)
Video Data Collection - Taylor Intersection on 04/03/12
4:50-6:10pm

• Three Camera Locations
Traffic Analysis of SR87 near Taylor

- SR87-Taylor SB Sensor Locations
- Traffic Situation Details for Freeway Section
  - Upstream at Bayshore
  - Taylor
  - Downstream at Julian
SR87-Taylor SB Sensor Locations
SB Traffic at SR87-Bayshore on 04/03/12
SB Traffic at SR87 - Bayshore on 04/03/12

Mainline VDS 401816 - Guapalupe Parkway

Raw Data for Mainline 401816 - All Lanes
Mainline VDS 401816 - Guapalupe Parkway
Tue 04/03/2012 00:00:00 to Tue 04/03/2012 23:59:59

Graph showing traffic data with speed (mph) on the y-axis and time (00:00-23:59) on the x-axis.

Legend:
- 401816 Lane 1 Speed
- 401816 Lane 2 Speed
- CB OFF TO FAC
- CB ON F
- CB OFF TO DOLPMO

Map of the area showing the location of Guapalupe Parkway in San Jose.
SB Traffic at SR87 - Bayshore on 04/03/12

Mainline VDS 401816 - Guapalupe Parkway

Current Location

Raw Data for Mainline 401816 - All Lanes
Mainline VDS 401816 - Guapalupe Parkway
Tue 04/03/2012 00:00:00 to Tue 04/03/2012 23:59:59

Occupancy (%)

401816 Lane 1 Occupancy

401816 Lane 2 Occupancy

Cr Off To FWD
Cr Off To Park
Cr On FWD

9.69 8.69 7.69 6.69 5.69
SB Traffic at SR87-Taylor on 04/03/12
SB Traffic at SR87-Taylor on 04/03/12
SB Traffic at SR87-Taylor on 04/03/12
SB Traffic at SR87- Julian on 04/03/12
SB Traffic at SR87 - Julian on 04/03/12

Mainline VDS 402057 - Julian St rm-s-dlag

Raw Data for Mainline 402057 - All Lanes
Mainline VDS 402057 - Julian St rm-s-dlag
Tue 04/03/2012 00:00:00 to Tue 04/03/2012 23:59:59

- 402057 Lane 1 Speed
- 402057 Lane 2 Speed
- 402057 Lane 3 Speed
- 402057 Lane 4 Speed

- SB ON FR GUARD PLY
- SE ON FR EB JUL
- SE ON FR AUGERA
- SE OFF TO LEMON
SB Traffic at SR87- Julian on 04/03/12
Higher Level Coordination Strategy: SR-87-Taylor

- Overall System Analysis
- Potential Performance Parameters
- Higher Level Control/Coordination Logistics
Overall System Analysis: Freeway Section

• Road Geometry

• Upstream traffic is moderate
• Downstream diverging
  – Lane/capacity increasing
  – Two close onramps with high demand may also cause traffic congestion
  – System partially isolated from freeway upstream & downstream in certain time period
Overall System Analysis: SR-87-Taylor

- Freeway SB off-ramp flow to intersection are low in PM peak
- Freeway NB off-ramp flow to intersection is medium-high but off-ramp length is long enough
- Intersection demand flow to NB onramp are low in PM peak
  - NB can be decoupled from SB from Intersection viewpoint
  - Off-ramp can be decoupled from the system at intersection
- Diamond exchange is simplified for PM peak:
  - Arterial (Taylor)
    - EB and WB through traffic
    - EB right turn and WB left turn traffic → feeding flows to (SR87-SB) onramp
    - Other movements are minor: always setting to minimum green-times
  - Freeway (SR87)
    - Main lane upstream/downstream flow
    - Onramp flow determined by RM rate
Potential Performance Parameters

- Freeway flow
- Total delay of intersection for all movements
- Onramp queue length (onramp delay)
- Onramp spillback probability
Higher Level Control/Coordination Logistics

- Low to Medium Traffic (Occ < 10% - critical occupancy): Keep freeway at its capacity flow as long as possible
  - Occupancy <5%:
    - Onramp:
      - Increase RM rate or RM off (to max onramp flow)
    - Intersection:
      - Feeding movements have higher priority s.t. onramp storage limit
  - 5% < Occupancy <10%:
    - Onramp:
      - Proportional RM strategy (ALINEA)
    - Intersection:
      - Balance the demand/supply ratio of all the movement s.t. onramp storage limit (implicitly using intersection storage)
Higher Level Control/Coordination Logistics

- Medium to High Traffic: If traffic congestion back-propagate from downstream (10% < Occ < 20%)
  - **Onramp:**
    - RM rate is proportional to mainline occupancy (ALINEA)
    - Fully use onramp storage
  - **Intersection:**
    - Green time distribution to balance the demand/supply ratio of all the movements s. t. onramp storage limit (implicitly using intersection storage)
Higher Level Control/Coordination Logistics

• High Demand Traffic:
  – $20\% < \text{Occupancy} < 30\%$
    ➢ Onramp:
      – RM rate is the lowest rate
      – Fully use the onramp storage
    ➢ Intersection:
      – Fill up the intersection storage first
      – Reduce green times of the movements to the onramps
      – Balance the demand/supply of other movements except the movements to onramp
      – Use extra cycle time for other movements
Higher Level Control/Coordination Logistics

- Saturated Traffic:
  - Occupancy > 30%
    - Onramp:
      - RM rate: needs more consideration
      - Fully use onramp storage
      - Onramp flow will depends on the acceptance of the mainline in merging area
    - Intersection:
      - Fully use intersection storage
      - Green time distribution to balance the demand/supply ratio of all the movement s. t. onramp storage limit (implicitly using intersection storage)
Traffic Modeling and Simulation

- Current Intersection and Onramp Traffic Timing Plan
- Traffic Analysis Based on Video Data
- Modeling, Calibration and Simulation
- Preliminary Coordination Strategy
Current Intersection Traffic Timing Plan

- Intersection: Actuated control, timing plan from D4
Current Ramp Metering Plan

- Metering plan from Caltrans District 4: Local Response based on Occupancy (proportional control)

**Taylor on-ramp HOV lane (15:00-19:00)**

<table>
<thead>
<tr>
<th>% occ</th>
<th>Meter rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>900</td>
</tr>
<tr>
<td>6</td>
<td>820</td>
</tr>
</tbody>
</table>

**Taylor on-ramp general lane (15:00-17:15)**

<table>
<thead>
<tr>
<th>% occ</th>
<th>Meter rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>900</td>
</tr>
<tr>
<td>6</td>
<td>800</td>
</tr>
<tr>
<td>9</td>
<td>720</td>
</tr>
</tbody>
</table>

**Taylor on-ramp general lane (17:15-17:45)**

<table>
<thead>
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<th>% occ</th>
<th>Meter rate</th>
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</thead>
<tbody>
<tr>
<td>4</td>
<td>900</td>
</tr>
<tr>
<td>6</td>
<td>800</td>
</tr>
<tr>
<td>9</td>
<td>660</td>
</tr>
</tbody>
</table>

**Taylor on-ramp general lane (17:45-19:00)**

<table>
<thead>
<tr>
<th>% occ</th>
<th>Meter rate</th>
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</thead>
<tbody>
<tr>
<td>4</td>
<td>900</td>
</tr>
<tr>
<td>6</td>
<td>800</td>
</tr>
<tr>
<td>9</td>
<td>660</td>
</tr>
<tr>
<td>10</td>
<td>600</td>
</tr>
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</table>
Traffic Analysis Based on Video Data

• Taylor St traffic flow, 5-6pm
Traffic Analysis Based on Video Data

- **Taylor St traffic flow, 5-6pm**

<table>
<thead>
<tr>
<th>Time</th>
<th>Taylor EB left</th>
<th>Taylor EB through</th>
<th>Taylor EB right</th>
<th>Taylor WB left</th>
<th>Taylor WB through</th>
<th>Taylor WB right</th>
<th>NB off-ramp left</th>
<th>NB off-ramp right</th>
<th>SB off-ramp left</th>
<th>SB off-ramp right</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:00-5:15</td>
<td>27</td>
<td>101</td>
<td>165</td>
<td>211</td>
<td>117</td>
<td>31</td>
<td>111</td>
<td>176</td>
<td>29</td>
<td>41</td>
</tr>
<tr>
<td>5:15-5:30</td>
<td>28</td>
<td>116</td>
<td>145</td>
<td>196</td>
<td>127</td>
<td>41</td>
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<td>189</td>
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<td>59</td>
</tr>
<tr>
<td>5:30-5:45</td>
<td>28</td>
<td>114</td>
<td>170</td>
<td>169</td>
<td>83</td>
<td>22</td>
<td>126</td>
<td>170</td>
<td>35</td>
<td>49</td>
</tr>
<tr>
<td>5:45-6:00</td>
<td>21</td>
<td>93</td>
<td>145</td>
<td>207</td>
<td>116</td>
<td>10</td>
<td>103</td>
<td>188</td>
<td>36</td>
<td>43</td>
</tr>
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<td>total</td>
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<td>424</td>
<td>625</td>
<td>783</td>
<td>443</td>
<td>104</td>
<td>446</td>
<td>723</td>
<td>131</td>
<td>192</td>
</tr>
</tbody>
</table>
Current Intersection Traffic Timing Plan

• What we observed from video
  – There was a long queue on the on-ramp sometimes, so the left-turn and right-turn vehicles on Taylor St could not get in. The left-turn vehicles could block the through vehicles on Taylor EB.
  – There was a queue at Taylor EB downstream section (connected to San Pedro), so vehicles traveling to Taylor EB could not get in.
Modeling, Calibration and Simulation

- Demand data: PeMS and video
- Control: real signal for intersection and metering plan
- PeMS mainline flow as reference
- Simulation of Current Traffic Situation
SB Traffic at SR87-Taylor on 04/03/12
SB Traffic at SR87-Taylor on 04/03/12
SB Traffic at SR87-Taylor on 04/03/12
Speed at Taylor
Occupancy at Taylor
SB Traffic at SR87- Julian on 04/03/12

Mainline VDS 402057 - Julian St rm-s-dlg

Raw Data for Mainline 402057 - All Lanes
Mainline VDS 402057 - Julian St rm-s-dlg
Tue 04/03/2012 06:00:00 to Tue 04/03/2012 23:59:59

Flow (veh/5 min)

04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03 04/03
00:00 02:00 04:00 06:00 08:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00

402057 Lane 1 Flow 402057 Lane 2 Flow 402057 Lane 3 Flow 402057 Lane 4 Flow

San Jose

Map data ©2012 Google

CALTRANS

PATH
Flow at Julian

Detector: 721 (Layer: freeway)

Flow DTA Experiment 310 (Replication 313)
Preliminary Control/Coordination Strategy

- Intersection Control Strategy
- Ramp Metering Strategy
- Coordination strategy for balancing the v/c ratio of each movement (technical details)
Intersection Control Strategy

- **Goal:** maximize intersection flow without sacrificing any movement
- **Balance the ratio between assigned green time and desired green time of each movement**
- **Restrictions:**
  - Minimum green
  - Ramp storage
  - Cycle length
  - Little waste of green time (the assigned green time doesn’t exceed the desired green time)
- **Quadratic Programming,** fast computation for real-time application
Intersection Control Strategy

Obj:
\[ \min \sum_{i \neq j} \left( g_i \left( \frac{q_i + d_i}{f_i} - g_j \frac{q_j + d_j}{f_j} \right) \right) \]

Subject to:
\[ \forall i, g_i \geq G_{\text{min},i} \]
\[ \sum_{r \in R} f_r \cdot \beta_r \cdot g_r \leq RA \]
\[ \sum_{i=1\sim4} g_i = C \]
\[ \text{or } i=5\sim8 \]
\[ \forall i, g_i \leq (q_i + d_i \cdot C) / f_i \]
Ramp Metering Strategy

- State-based control, based on measured occupancy.
- Maximize freeway flow
- ALINEA at current stage
- Change to a coordinated ramp metering strategy when we consider freeway corridor with multiple ramps
Next Step

- Further Model Calibration
- Developing Simulation with Control/Coordination
- Simulation Results Comparison with Selected Performance Measure
- Selection of Control/Coordination Strategy for Field Test
Discussion