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

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Outlines

- Project Overview
- Where We Are
- Simulation Development
- Algorithm Development
- System Interface and Integration
- Next Step
Project Review: 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 Review: 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.
Where We Are

- Task 1: Develop a Project Team and Charter
- Task 2: Technical Literature Review
- Task 3: Developing Work Plan and Finalizing the ConOps
- Task 4: Site Selection, Data Collection and Modeling
- Task 5: Selecting/Developing Feasible Coordination Strategies
- Task 6: Preliminary Field Implementation of the ConOps
- Task 7: System Integration and Field Test
- Task 8: Demonstration and Preliminary Evaluation after Study
- Task 9: Preparing Study Report and Final Report
Simulation Development

- Model Calibration
- Previous Calibration Result (Intersection)
- Current Calibration Result (Intersection)
- Calibration Result (Freeway)
Simulation Development

• Calibration
  – Focus on the intersection flows.
  – Fine tuning of parameters.

• Result
  – Flow: more than 85% of flows satisfied.
  – Speed: 10% error.
  – Occupancy: 7% error.
Simulation Development - Model Calibration

• Flow
  – Compute the percentage of acceptable simulated flow
  – Aggregated flow in 10min
  – Freeway: detector at upstream of Taylor SB on-ramp, 1 lane available
  – Intersection: 8 movements
  – Criteria
    ➢ Link flow quantity
      – $700\text{vph} < \text{Flow} < 2700\text{vph}$, within 15%;
      – Flow < 700vph, within 100vph;
      – Flow > 2700vph, within 400vph;
    ➢ Link flow GEH
      \[
      GEH = \sqrt{\frac{2(M-C)^2}{M+C}}
      \]
• Occupancy and Speed
  – Mean Square Root Error
  – Aggregated over 10min
## Previous Calibration Result (Intersection)

<table>
<thead>
<tr>
<th></th>
<th>EB Left</th>
<th>EB Through</th>
<th>EB Right</th>
<th>WB Left</th>
<th>WB Through</th>
<th>SB Left</th>
<th>NB Left</th>
<th>NB Right</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean acceptable case</strong></td>
<td>100%</td>
<td>86.9%</td>
<td>65%</td>
<td>74.4%</td>
<td>92.5%</td>
<td>100%</td>
<td>100%</td>
<td>95.6%</td>
</tr>
<tr>
<td><strong>GEH&lt;5</strong></td>
<td>96.9%</td>
<td>86.9%</td>
<td>74.4%</td>
<td>79.4%</td>
<td>93.1%</td>
<td>98.8%</td>
<td>100%</td>
<td>99.4%</td>
</tr>
<tr>
<td><strong>Best acceptable case</strong></td>
<td>100%</td>
<td>93.8%</td>
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<td>87.5%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Worst acceptable case</strong></td>
<td>100%</td>
<td>75%</td>
<td>50%</td>
<td>62.5%</td>
<td>87.5%</td>
<td>100%</td>
<td>100%</td>
<td>87.5%</td>
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</tbody>
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<td>100%</td>
<td>93.8%</td>
</tr>
</tbody>
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## Simulation Development - Calibration Result (Freeway)

<table>
<thead>
<tr>
<th></th>
<th>Flow</th>
<th>Occupancy</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean acceptable case</td>
<td>95.6%</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Worst acceptable case</td>
<td>93.8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Square Root Error</td>
<td></td>
<td>6.9%</td>
<td>10.4%</td>
</tr>
<tr>
<td>Smallest Error</td>
<td></td>
<td>6.7%</td>
<td>9.8%</td>
</tr>
<tr>
<td>Largest Error</td>
<td></td>
<td>7.1%</td>
<td>11.4%</td>
</tr>
</tbody>
</table>
Algorithm Development

- Intersection Control Algorithm Development
- Separated EB Right-turn
- Practical Feasibility
- Performance Evaluation with Separated EB Right-turn
- Not Separated Right-turn
- Performance Evaluation with Not Separated EB Right-turn
Algorithm Development - Intersection Control

• Basic idea
  – assign green times to phases based on what they need.
  – Avoid queue spillover.

• Object function

\[
\max \sum \mu_i g_i - \sum v_i \left( \frac{q_i + d_i \cdot C}{f_{sat,i}} - g_i \right) \left( \frac{q_j + d_j \cdot C}{f_{sat,j}} \right)^2
\]

• Constraints

\[
\forall i, g_i \geq G_{min,i}
\]

\[
\sum_{i \in R} f_{sat,i} \cdot \beta_i \cdot g_i \leq RA
\]

\[
\sum_{i=1\text{ or } i=5\text{–}8} g_i = C
\]

\[
g_1 + g_2 = g_5 + g_6
\]

\[
\forall i, g_i \leq (q_i + d_i \cdot C) / f_{sat,i}
\]

\(g_i\): the green length assigned to phase \(i\).
\(G_{min,i}\): minimum green length of phase \(i\).
\(f_{sat,i}\): saturation flow of phase \(i\).
\(R\): set of phase indices, phases in this set contain flows directing to SB on-ramp.
\(\beta_i\): turning proportion to the SB onramp of phase \(i\).
\(RA\): the number of vehicles the SB onramp can accommodate.
\(C\): cycle length.
\(q_i\): queue length of phase \(i\).
\(d_i\): demand of phase \(i\).
\(\mu_i, v_i\): tuning parameters.
Algorithm Development - Separated EB Right-turn

• Why do we separate?
  – Direct control of right-turn flow.
  – Leave on-ramp space to WB left-turn, preventing blockage at Taylor St & San Pedro St and on-ramp queue spillover.
  – Right-turn has a large storage and a separate light.

• Modified control
  – Activate when on-ramp is near full.
  – First find the green times of WB left-turn and EB right-turn based on on-ramp space.
  – Second find the green times of other movements.
Algorithm Development – Practical Feasibility

- RT overlap with Phase 6 and Phase 7
- Difficult to make it independently controlled
## Algorithm Development – Performance Evaluation

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<tr>
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<th>EB Left</th>
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<th>All Movements (10 movements in total)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total number of vehicles</strong></td>
<td>243</td>
<td>1110</td>
<td>1703</td>
<td>2018</td>
<td>1052</td>
<td>227</td>
<td>1210</td>
<td>1757</td>
<td>10028</td>
</tr>
<tr>
<td><strong>Average delay in current control (veh/s)</strong></td>
<td>35.56</td>
<td>32.86</td>
<td>31.62</td>
<td>55.72</td>
<td>16.36</td>
<td>34.21</td>
<td>29.16</td>
<td>15.16</td>
<td>30.20</td>
</tr>
<tr>
<td><strong>Delay change in proposed control (negative number means improved)</strong></td>
<td>Mean</td>
<td>33.14%</td>
<td>3.10%</td>
<td>44.22%</td>
<td>-27.64%</td>
<td>-16.45%</td>
<td>28.81%</td>
<td>-0.11%</td>
<td>-12.04% -3.12%</td>
</tr>
<tr>
<td></td>
<td>Best case</td>
<td>19.88%</td>
<td>-6.75%</td>
<td>-16.20%</td>
<td>-50.42%</td>
<td>-26.51%</td>
<td>11.78%</td>
<td>-6.75%</td>
<td>-19.92% -25.22%</td>
</tr>
<tr>
<td></td>
<td>Worst case</td>
<td>42.26%</td>
<td>11.63%</td>
<td>108.96%</td>
<td>10.58%</td>
<td>-7.53%</td>
<td>39.98%</td>
<td>8.50%</td>
<td>-0.15% 18.78%</td>
</tr>
</tbody>
</table>
Algorithm Development – Not Separated Right-turn

- Keep the current configuration of phases.
- Cannot avoid on-ramp queue spillover.
- Green time distribution among WB left, EB through, and NB right.
### Algorithm Development – Performance Evaluation

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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>39.23%</td>
<td>0.89%</td>
<td>-39.51%</td>
<td>8.41%</td>
<td>6.48%</td>
<td>56.91%</td>
<td>2.16%</td>
<td>-0.43%</td>
<td>-1.51%</td>
</tr>
<tr>
<td>Best case</td>
<td>4.67%</td>
<td>-5.24%</td>
<td>-61.00%</td>
<td>-29.69%</td>
<td>-20.41%</td>
<td>34.24%</td>
<td>-5.19%</td>
<td>-11.70%</td>
<td>-16.43%</td>
</tr>
<tr>
<td>Worst case</td>
<td>56.92%</td>
<td>7.05%</td>
<td>14.68%</td>
<td>50.66%</td>
<td>36.03%</td>
<td>78.86%</td>
<td>6.85%</td>
<td>6.59%</td>
<td>6.18%</td>
</tr>
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</table>
General Conclusion Of Control Algorithm

• The performance is sensitive to the offset between Taylor & SR87 and Taylor & San Pedro.
• If we can separate the EB right-turn, the delay and queue of the WB left-turn can be reduced. Queue spillover at the left-turn bay is avoided. WB through also get benefit. But the queue at the EB right-turn may increase, and it has a large variation among different simulation runs.
• If we cannot separate the EB right-turn, WB left-turn is hard to get improved without harming EB through and NB left-turn too much. On-ramp queue spillover and left-turn queue spillover cannot be avoided at the same time.
System Interface and Integration

- System Architecture Schematic
- Arterial and Ramp Meter Control (ac_rm_algo)
- Arterial Coordination – ab3418comm
- Ramp Metering – urmscomm
- Integration with Control Algorithm
System Interface and Integration - Architecture Schematic

Arterial Coordination laptop

ac_rm_algo

ab3418comm

Arterial 2070

Phases 1-8 Overlap B

Ramp metering laptop

urmscomm

Ramp Metering 2070

Ramp Meter
System Interface and Integration - Arterial and Ramp Meter Control (ac_rm_algo)

- Reads status data from publish/subscribe database (db_slv)
- Calculates optimum green times for all phases
- Calculates ramp metering rate
- Writes green times and metering rate into database, thus triggering arterial and ramp metering communication processes to send these changes to their respective 2070 controllers
System Interface and Integration - Arterial Coordination – ab3418comm

- Monitoring and control of 2070 controller using AB3418/AB3418E protocol via serial port 1
- Communicates with TSCP version 2.16 daemon running on arterial coordination 2070
- Three messages used in active control: GetLongStatus8, GetControllerTimingData, and SetControllerTimingData
- SetTime used at startup to synchronize laptop and controller system times
- Polls controller status using GetLongStatus8
  - Controller responds with message containing active phase status, detector status, overlap status, controller alarm status, current plan number, and volume and occupancy data for system detectors
- Sends timing changes using SetControllerTimingData
  - Can change maximum and minimum green times, yellow, all-red, extension, max and min gap
  - On the “Overlap Assignment” page, can set the “No Start” setting, but not the “Parent” nor the “Omit” or “Not” settings (we need to be able to set the “Parent” setting to control the overlap dynamically)
System Interface and Integration - Arterial Coordination – ab3418comm

- Uses publish/subscribe database (db_slv) to communicate to other processes (programs) running on laptop, especially control algorithm (ac_rm_algo)
System Interface and Integration - Ramp Metering - urmscomm

- Ramp metering controller running URMS (Universal Ramp Metering System) version 12.09
- Monitoring and control is done using the URMS protocol via an Ethernet port
- Two messages are used for communication with the ramp meter controller, a status request and a control command
- The urms daemon responds to the status request with the station ID, occupancy, volume, and speed of all monitored lanes
- urmscomm polls ramp metering 2070 status. URMS responds with status, volume, and occupancy of mainline and opposite lanes; demand and passage status, volume, and violations of the metered lanes; release rate of the metered lanes
- urmscomm writes status to database
- ac_rm_algo triggers a release rate change by writing a new release rate to the database. urmscomm picks up this new rate and writes it to the RM 2070
System Interface and Integration- Integration with Control Algorithm

- Read raw loop data from 2070 controller
- Write data to database
- Input raw data to control algorithm
- Control algorithm to generate green times for each phase
- Write those green distributions to database
- Activate those controls using AB3418 protocol
- Test run has been conducted on traffic signal tester
Next Step

- Control and coordination algorithm further fine-tuning
- Performance evaluation by simulation to select final version
- Closely work with D4 freeway and intersection traffic engineers
- Caltrans D4; change 170 Controller to 2070 Controller at Taylor
- Caltrans D4: need to change RM controller to 2070
- Interfacing with two field 2070 controllers
- Build wireless communication for system integration
- Get real-time intersection and freeway data
- Develop traffic data processing modules
Next Step

- Traffic State Parameter and Queue Estimation
  - Check measurement accuracy
  - Estimate on-ramp queue and intersection queues.
  - Use on-ramp exit detector or ramp metering rate for exit flow
  - Use intersection stop-bar detectors
    - Traffic counts
    - Occupancy during green time