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

End of Project Presentation

XY Lu, PATH, Project Manager and Principal Researcher
Dongyan Su, GSR
John Spring, Software, PATH

Alex Skabardonis, Project PI

PATH, U. C. Berkeley
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Outlines

• Site Selection
• Data Collection for Modeling
• Modeling and Simulation
• Freeway Onramp Metering
• Intersection Signal Control
• Coordination Strategy
• System Integration
• Test Results
• Next Phase of the Project
Site Selection

- Site Selection criteria development
  - Road geometry, traffic situation, sensor detection
  - Data system
  - Communication systems
  - Traffic controllers (freeway & arterial), 170 ➔ 2070
  - Traffic control software and interface capability
  - Institutional issues
  - Small and relatively independent

- Data collection for site selection
  - 5 sites considered: I280-Saratoga, SR87-Taylor, SR85-Camden, I280-Lawrence, SR101-DeLaCruz
  - SR87-Taylor was selected with the project panel
Data Collection for Modeling

- 3 Miovision VCU systems + 3 Video cameras
Intersection Traffic Situation

• The Problem
  - EB RT \text{green} = \text{Phase 6 Thru green} + \text{Phase 7 green} \Rightarrow \text{too high priority to access onramp all the time}
  - EB Phase 5 LT has large demand, but less priority to access onramp in PM Peak \Rightarrow \text{queue spills over to San Pedros}
Modeling and Simulation - Model Calibration
Modeling and Simulation - Model Calibration

• Data:
  – Aggregated over 10min

• Flow
  – Compute the percentage of acceptable simulated flow (within acceptable error)
  – Aggregated flow in 10min
  – Freeway: detector at upstream of Taylor SB on-ramp, 1 lane available
  – Intersection: 8 movements
  – FHWA recommended flow calibration criteria

• Speed
  – Compute the percentage of acceptable simulated speed (speed error less than 5mph)
Calibration Results

- Intersection:
  - EB RT Movement
    - Percent of flow values within acceptable error: mean 92.1%, deviation 6.2%
    - Percent of flow values with GEH<5: mean 97.1%, deviation 3.9%
  - WB LT Movement
    - Percent of flow values within acceptable error: mean 89.2%, deviation 5.8%
    - Percent of flow values with GEH<5: mean 92.1%, deviation 4.2%

- Freeway Mainline:
  - Flow
    - Percent of flow values within acceptable error: mean 93.4%, deviation 1.4%
    - Percent of flow values with GEH<5: mean 90.3%, deviation 3.1%
  - Speed
    - Percent of speed values with error<5mph: mean 89.7%, 3.1%
Freeway Onramp Metering

• Ramp metering algorithm
  – ALINEA, control based on occupancy
  – Requiring detectors installed at merging area

• Simulated and Implemented UP ALINEA
  – Modified ALINEA
  – Need to estimate occupancy from upstream measurement.
Intersection Signal Control

Only controls green time of phase 3
Intersection Signal Control

• Initial development:
  – Optimization for balancing demand and supplies of all major movements and onramp

• Simplified Strategy for Field Implementation and Test
  – Keep the current control strategy: actuated control.
  – Limit EB RT Green to give more space at onramp to WB LT
  – Give more spaces at onramp to WB LT to improve throughput and to avoid queue spillovers
    ➢ Change the overlap of EB right-turn, connect EB RT to phase 3 (over lap 6&7 ⇒ 6&3).
    ➢ Regulate maximum green of phase 3 to indirectly change green length of EB RT.
    ➢ Regulation algorithm is a queue-overwrite-like design based on occupancy instead of direct queue estimation
Coordination Strategy

- Coordination logistics (dependencies)

  Based on freeway traffic situation (occupancy measurement) determines RM rate (RM algorithm)

  ➔ estimate the condition of onramp queue

  ➔ how to distribute the available space between Right Turn (overlap with Phase 6&3) and Phase 5 Left turn (intersection traffic control algorithm)
Pulling detector data
Receiving RM rate command from TMC computer
Communicating with PATH computer through AB3418(E)
Activating RM signal

Receiving detector data
Calculating RM rate
Sending RM rate to onramp
Monitor PATH RM rate
Stop PATH RM rate in case necessary

Secured Wireless Connection

Communicating with 2070 controller through AB3418
Polling and Retrieving detector and signal data from 2070
Communicating with PATH computer in RM cabinet with secured network
Calculate phase 3 maximum green
Send 3 max green to 2070

Serial Interface

Communicating with 2070 controller through AB3418
Polling and Retrieving detector and signal data from 2070
Communicating with PATH computer in RM cabinet with secured network
Calculate RM rate
Executing coordination strategy
Sending RM rate to RM controller
Data Flow Diagram

Intersection Traffic Control Cabinet
Running TSCP

- 2070 Traffic Controller
  - Offset
  - Cycle length
  - Max/Min Green
- Traffic detector

PATH Computer: As Master at intersection cabinet

- Traffic signal control algorithm
- Traffic data processing
- DSRC

TMC Ramp Meter Computer

- Ramp metering rate
- Traffic data server

Local RM Cabinet

- 2070 Running URMS
  - Ramp metering rate
- Traffic Detector

- Ramp metering rate

PATH Computer in RM cabinet

- Ramp meter algorithm
- Coordination algorithm
- Traffic data processing
- DSRC

Intersection Signal

Ramp Signal

Serial Interface

Secured Wireless Connection

PATH Computer in RM cabinet

PATH Computer: As Master at intersection cabinet
Test Results – Compare “before” & “after”

- Relevant Detector Locations
- Data Validation
- Focusing on WB LT and EB RT, Onramp and Freeway
- Data Analysis (10 min aggregation)
- Flow Comparison at WB LT Stop Line
- Vehicle Counts of EB RT & WB LT A-Loop
- Occupancy of EB RT & WB LT A-Loop
- Compare Average Across all Effective Days
- Net Benefit at Taylor Intersection
  - Net flow increase
  - Net time delay decrease
- Benefit at Onramp: Accumulated Passage detector Flow
- Affect to Freeway Upstream
Relevant Detector Locations
Test Results

- Data Validation: Test dates of PATH controller at SR87 Onramp and Taylor Intersection:
  - PATH control on date: 10/29/13 - 11/08/13 (Green)
  - Control, Loop & Overlap changed on date: 11/12/13 (12:30pm)
  - PATH control off for data collection: 11/09/13 – 11/18/13 (Red)
  - Health check conducted; weekend were dropped (Yellow)

<table>
<thead>
<tr>
<th>PATH Control on date</th>
<th>Control on date</th>
<th>Data Collection Date</th>
<th>Day of the Week</th>
<th>Comments</th>
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<tbody>
<tr>
<td>10/29</td>
<td>11/05</td>
<td>11/12</td>
<td>Tue</td>
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<td>11/06</td>
<td>11/13</td>
<td>Wed</td>
<td></td>
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<td>10/31</td>
<td>11/07</td>
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<td>Thu</td>
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<td>11/01</td>
<td>11/08</td>
<td>11/15</td>
<td>Fri</td>
<td></td>
</tr>
<tr>
<td>11/02</td>
<td></td>
<td>11/16</td>
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<td>Weekend dropped</td>
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<td>11/17</td>
<td>Sun</td>
<td>Weekend dropped</td>
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<tr>
<td>11/04</td>
<td></td>
<td>11/18</td>
<td>Mon</td>
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</table>
Test Results

- **Data Analysis Using: Vehicle Counts & Occupancy**
  - **Taylor intersection**
    - Phase 5 (WB) LT Stop-line
    - Phase 5 (WB) LT Advance loop (A-loop)
    - Phase 6 (EB) RT A-loop
  - **Onramp**
    - Passage detector
    - Queue detector
  - **Freeway SR87 mainlines immediate upstream**
    - HOV, GPL 1, and GPL 2
  - **Aggregation**
    - Accumulated value for each day 2:15-8:00pm
    - Average of Accumulated value overall effective days
WB LT: Vehicle Count at Stop Line (Phase 5)

After 

Before
Net Benefit at Taylor Intersection (EB RT & WB LT) at Advance Loop

<table>
<thead>
<tr>
<th>Time interval for evaluation</th>
<th>4:00-6:00pm</th>
<th>4:00-6:30pm</th>
<th>4:00-7:00pm</th>
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</thead>
<tbody>
<tr>
<td>Total Flow of WB RT &amp; EB LT increased</td>
<td>6.98%</td>
<td>7.64%</td>
<td>8.18%</td>
</tr>
<tr>
<td>Time delay reduced</td>
<td>7.15%</td>
<td>5.24%</td>
<td>3.06%</td>
</tr>
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</table>
### Onramp Benefit: Accumulated Flow

<table>
<thead>
<tr>
<th>Time interval for evaluation</th>
<th>4:00-6:00pm</th>
<th>4:00-6:30pm</th>
<th>4:00-7:00pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passage detector flow change (after meter)</td>
<td>0.73%</td>
<td>1.2%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Queue detector flow change</td>
<td>11.01%</td>
<td>11.12%</td>
<td>11.28%</td>
</tr>
</tbody>
</table>
Effect on Freeway Upstream Traffic Flow

- Freeway mainline throughput unchanged
- To improve freeway traffic, it is necessary to consider a freeway corridor and relevant arterial(s) in next project phase
Performance Improvement Summary

- Intersection
  - WB RT flow significantly increased by 7% in PM Peak
  - Total delay reduced by 7% in PM Peak

- Onramp
  - Passage detector flow increased about 1%
  - Queue flow increased by 11% ➔ better use of onramp storage in PM Peak

- Freeway mainline upstream
  - End even, not affected in PM Peak
Next Phase of the Project

• To consider a freeway corridor with relevant arterial(s)
• Coordinated ramp metering (developed in another project)
• Coordinated arterial intersection signal control
• For both freeway RM and arterial intersections
  – Centralized data systems
  – Centralized signal control
  – PATH computer interface with TMC computer
• Systematic coordination of the two subsystems
• Secured communication between two PATH computers running a special OS to avoid virus
• Objective: to achieve system-wide performance improvement
Questions and Comments?

• Please Contact:

XY LU
PATH, U. C. Berkeley

Tel: 510-665-3644
Cell: 925-246-4493
email: xiaoyun.lu@berkeley.edu
Technical Details: UP ALINEA

- Estimate downstream occupancy from upstream measurement.

\[
\tilde{o}_{out} = \alpha o_{in} \left(1 + \frac{q_r}{q_{in}}\right) \frac{\lambda_{in}}{\lambda_{out}}, \text{ if } o_{in} \leq o_{cr}
\]

\[
\tilde{o}'_{out} = o_{in} \frac{\lambda_{in}}{\lambda_{out}} + 100 \frac{L}{w_{\lambda_{out}}} q_r, \quad \tilde{o}_{out}(k) = \gamma \tilde{o}'_{out}(k) + (1 - \gamma) \tilde{o}'_{out}(k - 1), \text{ else.}
\]
Technical Details: Intersection design

- EB right-turn is connected to phase 3. (phase 3 still has SB left-turn, no conflict between them.)
- Design and set max green of phase 3 every cycle, indirectly change EB right-turn green.
- Detectors associated with EB right-turn are assigned to phase 3, so they can actuate phase 3.
- Queue overwrite like design
  - When the onramp queue is estimated to be, activate the regulation.
    - if onramp queue or the WB left-turn queue grows, reduce max green of phase 3 by 2sec per cycle to limit the discharge of EB right-turn.
    - Otherwise, increase max green of phase 3 by 2sec to allow more vehicles to get into onramp.
    - Release EB right-turn when its queue exceeds a limit.
    - Lower bound and upper bound of the max green.
  - Deactivate.
Technical Details: Intersection design (cont.)

• range of the max green
  – Max green is within 15~24sec.
  – Original max extension is 15sec, min initial is 4sec.
  – Max extension of phase 7 is 20sec, min initial is 4sec.
  – By choosing 24sec, phase 3 and phase 7 are possible to terminate at the same time (yellow and red clear are different).
  – By choosing 15sec, phase 3 vehicles can be discharged (phase 3 has a very low demand).
  – Phase 3 use max green every 4 cycle to release Phase 6 RT queue
Modeling and Simulation - Model Calibration

• Data: Aggregated over 10min

• 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
      – 700vph < Flow < 2700vph, within 15%;
      – Flow < 700vph, within 100vph;
      – Flow > 2700vph, within 400vph;
    ➢ Link flow GEH
      – \( GEH = \sqrt{\frac{2(M-C)^2}{M+C}} \)

• Speed
  – Compute the percentage of acceptable simulated speed (error<5mph)
Delay Estimation

• Assuming an average queue release speed
• Estimate queue length based on occupancy of single loop detector
• \(\Rightarrow\) Determine density from flow measurement
• \(\Rightarrow\) Determine the number of vehicles in the queue
• \(\Rightarrow\) Accumulate per cycle to get total delay
• \(\Rightarrow\) Apply to WB RT and EB LT to get total delay
• \(\Rightarrow\) Apply this method to both “before” and “after” situation