Control Strategies for Corridor Management  
Agreement 65A0329 TO008  
Quarterly Progress Report (First Quarter FY 2015-16) Version 1  
Reporting Period: July 1st 2015 to September 30, 2015.

**Brief Project Description**

Considerable attention has been given to new approaches for improving the transportation system because of limited funding and environmental concerns for constructing new highway facilities. One promising approach is integrated management of travel corridors comprising of freeways and adjacent arterial streets controlled by traffic signals. However, the implementation and effectiveness of corridor management strategies is limited because of the lack of information on traffic conditions on arterials. Recently the availability of High-resolution (HR) data at signalized intersections consisting of time-stamped records of every event involving vehicles, together with the signal phase provides significant opportunities for assessing the performance of existing control and developing new control strategies. We propose to analyze real-time and archived HR data from real-world test sites and calculate performance measures. We will next utilize the HR data to develop improved control strategies for signalized arterials, and to propose and test corridor management control strategies for both recurrent and non-recurrent (incident related) congestion.

**Work Completed This Quarter**

The contract was executed in late March 2015. Authorization to proceed was received on April 2, 2015. The kick-off meeting for the project took place on June 11, 2015 at the Caltrans Division of Research & Innovation and Systems Information (DRISI) offices in Sacramento.

This quarter the following activities were performed:

**Task 1. High Resolution Data Collection and Estimation of Performance Measures**

Task 1 of the project is concerned with the collection and analysis of HR data at signalized intersections, and the calculation of performance measures. We obtained a data set from a multiphase intersection in Beaumont, South Carolina.

We developed and applied methodologies to process the data and calculate a number of basic quantities (traffic flows per movement and saturation flows), and derived performance measures such as volume/capacity (V/C) ratio and delay (sec/veh) for each movement. These measures are used to determine the Highway Capacity manual (HCM) level of service LOS for each movement.

**Task 2. Development and Testing of Signal Control Strategies**

The scope of work in Task 2 involves the development and evaluation of signal control algorithms on signalized arterials. We will extend and refine the “max pressure” algorithm and simulate its performance using a mesoscopic simulation model called .Q. Both the control algorithm and the simulation model were developed at UC Berkeley.
This period we applied the .Q model in a real-world test site: San Pablo Avenue in Berkeley. The selected test section consists of ten signalized intersections. We also applied the SYNCHRO software (which is used by Caltrans stuff) to the site. We compare the performance of the two analysis tools in terms of travel times for the arterial through traffic and queue lengths at the approaches of the critical intersections. Preliminary findings indicate that the .Q model predictions are in reasonable agreement with SYNCHRO.

**Task 3. Freeway/Arterial Coordination**

The scope of work in Task 3 involves the development and evaluation of control algorithms for coordination of ramp meters and traffic signals on adjacent signalized arterials. This quarter we developed and tested a control strategy that restricts the entry of vehicles to the on-ramp from arterial phases to avoid queue spillover on the metered on-ramp. The strategy was tested with the AIMSUN microscopic simulation model on a real-world freeway section of I-680 in San Jose and a parallel arterial. The simulation results indicate that the proposed algorithm improved the freeway performance without significant negative impacts on the arterial.

**Meetings/Presentations**

A project progress meeting was held at the Caltrans DRISI offices on October 13, 2015. The meeting participants and their contact information are listed below:

<table>
<thead>
<tr>
<th>Participants</th>
<th>Organization</th>
<th>Phone</th>
<th>E-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicholas Compin</td>
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</tr>
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</tr>
</tbody>
</table>

The project team presented the work performed in each project task and future work. Discussions focused on the results to-date, and next steps of the project.

Appendix A includes the presentation at the meeting by the research team.

**Work Planned Next Quarter**

**Task 1. High Resolution Data Collection and Estimation of Performance Measures**

We will complete the work in this task by a) developing procedures for estimating queue lengths from the HR data, investigating the possibility of using the HR data for safety (red light running), and c) developing procedures for generating robust timing plans.
Task 2. Development and Testing of Signal Control Strategies
We will complete the evaluation of the .Q model at the selected test site and assess its strengths and limitations in simulation analyses. We will then apply the “max pressure” and evaluate its effectiveness in improving the performance at the selected site.

Task 3. Freeway-Arterial Coordination
We will refine the proposed algorithm and test it through simulation for a range of operating conditions. We will also propose approaches for freeway-arterial coordination under incident conditions.

Problems/Issues Encountered This Quarter
There are no problems to report.

Project Budget Summary
The award amount is $114,222 for agreement number 65A0529 TO008. The agreement ends on February 29, 2016.

Projected expenditures for the fourth Quarter of FY 14/14 covering the months of July, August and September 2015 are shown below. These are draft estimates and will be refined when the financial statements will be made available by the University.

<table>
<thead>
<tr>
<th>Month</th>
<th>Projected Expenditure ($)</th>
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<tr>
<td>April</td>
<td>6,000</td>
</tr>
<tr>
<td>May</td>
<td>6,500</td>
</tr>
<tr>
<td>June</td>
<td>9,000</td>
</tr>
</tbody>
</table>

Project Management References
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Appendix A.

Presentation at the Progress Meeting – October 13, 2015.
Agreement 65A0529

Control Strategies for Corridor Management

Zahra Amini
Yu-Chieh Lo
Alex Skabardonis
Pravin Varaiya

UC Berkeley

Progress Meeting
Sacramento, CA
October 13, 2015
Background: Project Objectives / Expected Results

- Collect and Analyze High Resolution (HR) at traffic signals to calculate performance measures
- Develop and Test Improved Control Strategies for Signalized Arterials
- Propose and Test Freeway-Arterial Coordination Strategies

- A Database of HR data
- Methodology for estimating performance measures
- Analysis Tools & Control Strategies for Traffic Signals
- Freeway/Arterial Coordination Strategies
Task 1. HR Data Collection and Estimation of Performance Measures at Traffic Signals

- Traffic data
  
  Detector data for each movement
  
  stop bar detectors
  
  advance detectors
  
  detectors on departure lanes
  
  A basic HR system collects the location (lane) and speed of every vehicle as it enters and leaves the intersection, together with the signal phase.

- Signal data

  Phase & Timing

- Test Site: Beaufort, SC
Selected Test Site: Beaufort, SC

<table>
<thead>
<tr>
<th>Phase</th>
<th>Movement</th>
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<tbody>
<tr>
<td>1</td>
<td>Leg 2 left turn only</td>
</tr>
<tr>
<td>2</td>
<td>Leg 1 left, through, right</td>
</tr>
<tr>
<td>4</td>
<td>Leg 3 left, through, right</td>
</tr>
<tr>
<td>5</td>
<td>Leg 1 left turn only</td>
</tr>
<tr>
<td>6</td>
<td>Leg 2 left, through, right</td>
</tr>
<tr>
<td>8</td>
<td>Leg 4 left, through, right</td>
</tr>
</tbody>
</table>

Selected Time Period:
February 18, 2015  7am - 8 pm
### Existing Signal Settings

#### Weekdays Plan Patterns

<table>
<thead>
<tr>
<th>Week days</th>
<th>Plan</th>
<th>Patterns</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
<td>2,3,6,1</td>
<td>0600; 9:00; 14:00; 19:00; 22:00</td>
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<tr>
<td>Friday</td>
<td>4</td>
<td>4</td>
<td>9:00; 18:00</td>
</tr>
<tr>
<td>Saturday</td>
<td>2</td>
<td>5</td>
<td>11:00; 18:00</td>
</tr>
<tr>
<td>Sunday</td>
<td>3</td>
<td>2,3,7,6,1</td>
<td>6:00; 9:00; 14:30; 16:00; 19:00; 22:00</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Pattern</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<tr>
<td>Cycle</td>
<td>90</td>
<td>110</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>130</td>
<td>160</td>
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<tr>
<td>Offset</td>
<td>84</td>
<td>11</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>68</td>
<td>54</td>
</tr>
<tr>
<td>Split</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
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</table>

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
<th>Phase 5</th>
<th>Phase 6</th>
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<th>Phase 8</th>
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<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>42</td>
<td>N/A</td>
<td>18</td>
<td>15</td>
<td>42</td>
<td>N/A</td>
<td>15</td>
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<tr>
<td>2</td>
<td>15</td>
<td>40</td>
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<td>39</td>
<td>15</td>
<td>40</td>
<td>N/A</td>
<td>16</td>
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<tr>
<td>3</td>
<td>17</td>
<td>53</td>
<td>N/A</td>
<td>33</td>
<td>25</td>
<td>45</td>
<td>N/A</td>
<td>17</td>
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<tr>
<td>4</td>
<td>17</td>
<td>53</td>
<td>N/A</td>
<td>33</td>
<td>25</td>
<td>45</td>
<td>N/A</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>53</td>
<td>N/A</td>
<td>33</td>
<td>25</td>
<td>45</td>
<td>N/A</td>
<td>17</td>
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<tr>
<td>6</td>
<td>15</td>
<td>62</td>
<td>N/A</td>
<td>33</td>
<td>37</td>
<td>40</td>
<td>N/A</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>80</td>
<td>N/A</td>
<td>40</td>
<td>45</td>
<td>55</td>
<td>N/A</td>
<td>20</td>
</tr>
<tr>
<td>Min</td>
<td>6</td>
<td>15</td>
<td>N/A</td>
<td>8</td>
<td>6</td>
<td>15</td>
<td>N/A</td>
<td>6</td>
</tr>
<tr>
<td>Max</td>
<td>15</td>
<td>50</td>
<td>N/A</td>
<td>28</td>
<td>30</td>
<td>50</td>
<td>N/A</td>
<td>40</td>
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</tbody>
</table>

- **PM Off-Peak**
- **AM Peak**
- **Mid Day**
- **Saturday**
- **Sunday**
- **PM Peak**
- **Saturation**
Daily Variation: Cycle Length and Intersection Volume

Cycle length 7AM to 8PM  Total volume (veh/cycle): 7AM to 8PM
Peak Period 4-7 pm: Intersection Volume

Total volume (veh/cycle)

Total volume (veh/15 minutes)
Peak Period 4-7 pm: Approach Volumes

Approach Volume (veh/cycle)

Approach Volume (veh/15 min)
Peak Period 4-7 pm: Turning Movements

Leg 1

Leg 2

Leg 3

Leg 4
Signal Control Data

Green Times per Phase

MAIN STREET: Phases 1, 2, 5, 6

CROSS STREETS: Phases 4, 8
Data Processing (2): Signal Control Data

Wasted Green time at phase 4

Maximum waiting time at phase 4
Data Analysis (1): Saturation Flow

• Saturation flow is determined by measuring the time of discharge (i.e. the event time) between the third and the last vehicle in the queue at an intersection.

• For the 4PM saturation flow, we used the average saturation flow over 24 hour.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Movement</th>
<th>Saturation Flow (veh/hour/lane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Through</td>
<td>1727</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>1798</td>
</tr>
<tr>
<td>2</td>
<td>Through</td>
<td>1728</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>2217</td>
</tr>
<tr>
<td>3</td>
<td>Through</td>
<td>1723</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>1828</td>
</tr>
<tr>
<td>4</td>
<td>Through</td>
<td>2219</td>
</tr>
</tbody>
</table>
Data Analysis (2): $V/C$ Ratio

Through movement, Leg 1

Through movement, Leg 2

$\left( \frac{V}{C} \right) = \frac{V \times C}{g \times s}$

- $s$: Saturation flow (veh/hr.)
- $V$: Traffic volume (veh./hr)
- $C$: Cycle length (sec.)
- $g$: Green time (sec.)
- $V/c$: Volume to capacity ratio
Performance: Average Delay (sec/veh)
HCM Level of Service (LOS)

Through movement, Leg 1

Through movement, Leg 2

Left turn movement, Leg 1

Right turn movement, Leg 2
Performance: Delay (Analytical solution)

Leg 2 through movement

\[ d = \frac{C(1 - \frac{g}{C})^2}{2\left(1 - \frac{g}{C} \times \frac{V}{c}\right)} \]

- \( d \) : Delay (sec/veh)
- \( C \) : Cycle length
- \( g \) : green time
- \( V/c \) : Volume to capacity ratio
Performance: % Vehicles arriving on Green

- Calculated by dividing the number of vehicle arrived during the green interval over the total number of vehicle that arrived per cycle.
OnGoing and Future Work

- Estimating queue length
- Clustering the intra-day data
  - Determine the time periods with significantly different traffic.
- Purdue coordination diagram (PCD) vs. Progression
  - Measures the quality of traffic progression at the intersection.
- Develop Methodologies for Robust Timing Plans
- Safety
  - Using HR data to assess moving violation
Task 2. Development and Testing of Signal Control Strategies based on HR Data

- **Control Algorithm**
  - “Max Pressure” algorithm
    - Distribution of green times based on the size of conflicting queues
    - Extend and refine the algorithm

- **Evaluation**
  - .Q model
    - Individual vehicles
    - Macroscopic modeling of traffic dynamics

This time period:
- Evaluation of the .Q model
- Application to a real data set
- Comparison with SYNCHRO

RESULTS
PRELIMINARY
WORK IN PROGRESS
Selected Test Site

San Pablo Ave, Berkeley

Fixed Time Plans

Time Period: 4-5 pm
San Pablo Avenue

Sample Intersection Data
San Pablo Ave: Travel Times on Arterial
San Pablo Ave: Max Queue Lengths

![Queue Lengths Diagram](image)

- **DW LT**: Queue length of 2 vehicles.
- **DW TH**: Queue length of 12 vehicles.
- **UN LT**: Queue length of 2 vehicles.
- **UN TH**: Queue length of 8 vehicles.
- **GL LT**: Queue length of 2 vehicles.
- **GL TH**: Queue length of 4 vehicles.

Graph shows the comparison between Synchro and .q queue lengths for different approaches and movements.
Task 3. Development and Testing of Freeway/Arterial coordination Strategies

- Objective:
  Develop & test control strategies for selected operating scenarios

- This Time Period
  Evaluation of the control strategy that prevents on-ramp queue overflow by restricting the green times of phases feeding the on-ramp at the adjacent intersections
Background: Control Strategy (1)

Arterial with \( k \) intersections
Each intersection has \( i \) phases
Desired green time = minimum green time to serve the demand

Arterial: Minimize the ratio of actual and desired green times
Background: Control Strategy (2)

Constraints

- Minimum green time constraint: \( g_{ik}(t) \geq G_{ik,\text{min}} \)
- Cycle length constraint: \( \sum_i g_{ik}(t) = C \)
- On-ramp storage constraint:
  \[
  \sum_{i \in \mathcal{R}} f_{\text{sat},ik} \cdot g_{ik}(t) \leq R A_r
  \]
Background: Control Strategy (3)

Constraint: Arterial link storage

\[
\begin{align*}
\text{Flow into downstream link} & = f_{sat,ik} \cdot [o_{ik}(t) + l_{acc}] \\
\text{Available queue storage space} & \leq s_L - \sum_{i \in L} q_{i,k+1}(t)
\end{align*}
\]
Application of Proposed Strategy

Test Site: I-680, San Jose CA

- AIMSUN Microscopic Simulator
- API

<table>
<thead>
<tr>
<th>Arterial Performance</th>
<th>Before</th>
<th>After</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Delay on Parallel Arterial (min/veh)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capitol Ave NB</td>
<td>7.55</td>
<td>7.4</td>
<td>-1.95%</td>
</tr>
<tr>
<td>Capitol Ave SB</td>
<td>2.05</td>
<td>1.79</td>
<td>-12.73%</td>
</tr>
<tr>
<td>Arterial--Average Delay on Cross Street (sec/veh)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alum Rock WB</td>
<td>34.96</td>
<td>36.57</td>
<td>4.62%</td>
</tr>
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<td>9.52</td>
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<td>Berryessa WB</td>
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<td>12.86%</td>
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<td>Berryessa EB</td>
<td>7.71</td>
<td>6.71</td>
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<tr>
<td>Freeway Performance --VMT</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>I-680 NB**</td>
<td>13749.1</td>
<td>14220</td>
<td>3.4</td>
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