Field Test of Combined VSL and CRM for Freeway Traffic Control

Project Meeting
Caltrans District 4

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Outline

- Combined VSL & CRM
- Technical Scheme
- Implementation Related Issues
- Why is Traffic Speed Estimation Required?
- Speed Estimation with Single Loop Event Data
- Site Selection
Combined VSL & CRM - Objectives

- Control Objectives:
  - Maximize bottleneck flow
  - Delay congestion start time if possible
  - Control density distribution
  - Achieve higher density (thus flow) for the same speed
  - Reduce total congestion time
  - Reduce shockwaves, including Stop & Go
  - Avoid off-ramp blocking and spill-back
  - Minimize VHT and Maximize VMT system wide
  - Byproduct: Improve safety and emissions
Combined VSL & CRM - Benefits

- **Coordinated Ramp Metering (CRM)**
  - Control density (or average density immediately downstream of the onramp) (mobility)
  - Balance demand and capacity at each onramp along the stretch, taking into account queue length limit (mobility & equity)

- **Benefits of CRM: Mitigating Local RM Problems**
  - Conflict with mainline flow which could aggravate the congestion at bottlenecks in peak hours
  - Storage capacity of onramps may not be fully used due to the demand flow and the length differences between onramps
  - Significant negative impact to traffic on arterials
Combined VSL & CRM - Benefits

- **Variable Speed Limits (VSL)**
  - Influence driver behavior ➔ reduce speed variance in the same lane and between lanes (safety and environment)
  - Avoid shock waves (mobility, safety and environment) ➔ to avoid primary and secondary collisions
  - Keep homogenous flow when density changes (mobility) ➔ same speed can be maintained for higher density
  - Smooth traffic when demands are too high, or RM has to be switched off due to ramp length limit (equity, mobility)

- **VSL and CRM are complementary in function**
  - RM only controls the demand into the freeway; it has to be switched off if demand from local streets is too high
  - VSL affects the mainline driver behavior (traffic flow)
  - Enforced VSL could help regulate the flow as desired to maximize the bottleneck flow
Technical Scheme – VSL Only

- **Caltrans PeMS 30s Real-time Data Server** connected to **Internet**
- **PATH Control Computer**
- **VSL Stand Alone for Freeway Corridor Traffic Control**
- **TMC Computer**
- **Wireless 3G modem**
- **Onsite Server Computer**
- **FreeWave**
- **Traffic detector**
- **Speed 35 For Max Flow**
Technical Scheme – CRM Only, Scheme 1

CRM Stand Alone for Freeway Corridor Traffic Control

Caltrans PeMS 30s Real-time Data Server

Internet

RT data

RM rate

PATH Control Computer

TMC Computer

Cabinet 1

170/2070 Controller

Cabinet 2

170/2070 Controller

Cabinet 3

170/2070 Controller

Cabinet N

170/2070 Controller

Traffic detector
Technical Scheme – CRM Only, Scheme 2

CRM Stand Alone for Freeway Corridor Traffic Control

PATH Control Computer

RT data

TMC Computer

RM rate

RM Rate

Cabinet 1

170/2670 Controller

Cabinet 2

170/2970 Controller

Cabinet 3

170/2070 Controller

Cabinet N

170/2070 Controller

Traffic detector
Technical Scheme – Combined VSL & CRM, Scheme 2

Combined VSL & CRM for Freeway Corridor Traffic Control, Scheme 2

- PATH Control Computer 2
- PATH Control Computer
- TMC Computer
- Traffic detector
- Cabinet 1: 170/2070 Controller
- Cabinet 2: 170/2070 Controller
- Cabinet 3: 170/2070 Controller
- Cabinet N: 170/2070 Controller
- 3G modem or Internet
- Wireless 3G modem
- RM Rate
- Onsite Server Computer
- FreeWave
- Speed 35
- For Max Flow
Technical Scheme – CRM Only, Scheme 3

CRM Stand Alone for Freeway Corridor Traffic Control

TMC Computer

Cabinet 1: 170/2970 Controller
Cabinet 2: 170/2070 Controller
Cabinet 3: 170/2070 Controller
Cabinet N: 170/2070 Controller

Traffic Detector
Implementation Related Issues

- VSL and CRM can be implemented independently
- When implementing CRM alone, the speed in the model just uses the real time estimated traffic speed
- Critical to the success of field test → Data Health
- Traffic state parameter estimation based on RT data
- Proper feedback to the driver for better acceptance
  - Good visibility and advance in time/location
  - Appropriate location of VMS
  - Simple message to avoid driver distraction
  - VMS message update at a reasonable frequency
  - Convincing reason to adopt the advised speed
Implementation Related Issues

- Critical Factors for VSL Implementation
  - Higher level control logics for switch VSL according to the traffic
    - Demand below bottleneck capacity
    - Demand close to bottleneck capacity
    - Demand over bottleneck capacity
  - Road geometry and bottleneck type
    - Lane reduction or virtual lane reduction
    - Weaving
    - Upstream storage section
  - VSL advisory using portable VMS
  - Suitable advisory messages and VMS locations
  - Traffic state parameter estimation (data health)
Implementation Related Issues

- Critical factors for implementation of CRM
  - Higher level control logics for switch CRM according to the traffic
    - Demand below bottleneck capacity
    - Demand close to bottleneck capacity
    - Demand over bottleneck capacity
  - Ramp storage capacity and demand: long enough to store most vehicles from arterials ➔ no need to coordinate with arterials
  - Onramp queue detection to improve performance
  - Traffic state parameter estimation (data health)
    - Non-model based
    - Model based
Implementation Related Issues

- Critical factors for implementation of CRM
  - Most situations impossible due to
    - High demands
    - Uneven distribution of demands
    - Road geometry limit
  - Coordination with arterial traffic control would be necessary
    - If road geometry permit
      - Traffic signal control in favor of certain movements in peak hours
      - Routing using VMS
  - An example of necessity for coordination
SR101 SB Corridor from Mathilda Ave to De La Cruz: 5.3 miles
SR101 SB Corridor from Mathilda Ave to De La Cruz: 5.3 miles
SR101 SB Corridor from Mathilda Ave to De La Cruz: 5.3 miles

- A combined strategy would be necessary to maximize the bottleneck flow
  - Fully using storage capacity of upstream onramp and freeway interchange, but not exceeding it
  - Combined with VSL
  - Reducing the feeding flow to downstream by diverging traffic from
    - E. Arques Ave and Scott Blvd
    - Lawrence Expressway
  - Control strategy for arterials:
    - Integrated traffic signal control
    - Routing with VMS
Why is Speed Estimation Required?

- HERO (also ALINEA) project recommended measurements downstream of onramp to determine RM rate instead of upstream
Why is Speed Estimation Required?

Measure $q_{\text{in}}$ to determine $q_r$
Outcome at bottleneck is not measured $q_{\text{cap}}$
This method results in very poor operations
Why is Speed Estimation Required?

Measure $q_{\text{cap}}$ to determine $q_r$

Outcome at bottleneck is measured $q_{\text{cap}}$

This method results in good operations
Why is Speed Estimation Required?

Measure $q_{\text{cap}}$ to determine $q_r$

Outcome at bottleneck is measured $q_{\text{cap}}$

This method results in good operations
Why is Speed Estimation Required?

- Reasons: measurements downstream of onramp can
  - Include flow rate from onramp
  - Account sooner for congestion back-propagation
  - Measurements upstream do not offer those advantages in-time
Why is Speed Estimation Required?

- Benefits with traffic speed estimation
  - Simple first order model (CTM) can be linearized
  - Linearized model for traffic flow estimation and prediction along the corridor at any point, in principle, due to speed availability
  - Sensor located upstream or downstream of the onramp does not matter much for CRM
  - Sensor spacing can be flexible: 200 ft ~ 700 ft
  - Avoid infrastructure changes: maximally use current infrastructure for VSL and CRM to optimize traffic flow to the extent possible
- It is also required for VSL control
Why is Speed Estimation Required?

- Speed estimation using loop detectors
  - Single loop gives vehicle count and occupancy
  - From Occupancy to speed, one needs vehicle length;
  - From 30 s aggregated g-factor method using assumed vehicle length (which is usually fixed)
    ➔ speed estimation is bad in traffic transition phases and in congestion
Why is Speed Estimation Required?

- Speed estimation using loop detectors
  - Dual loop direct speed estimation needs event (60 Hz) data; dual loop aggregated (over 30 s) does not offer much advantage, only redundancy;
  - Speed estimation using single loop event data can have similar accuracy as from dual loop event data;
Speed Estimation with Single Loop Event Data

- **Algorithm**

\[ v(t) = g(t) \times \frac{c(t)}{o(t) \times T} \quad \Leftrightarrow \quad v(t) = \frac{g_m(t)}{o_m(t) \times T} \quad \Rightarrow \quad v(t) = \eta \frac{g_m(t)}{dur(t)} \]

- \( T \) – polling time interval; \( v(t) \) - space mean speed; \( g(t) \) - **effective vehicle length** plus loop length; \( c(t) \) - vehicle count during time interval \( T \), for event data \( T=1 \); \( o(t) \) - occupancy; \( g_m(t) = 21[ft] \) - **mode vehicle length** plus loop length; \( o_m(t) \) - **mode occupancy**; \( dur(t) \) - mode dwell time; \( \eta = [0.9, 1.0] \) loop sensitivity parameter.
Speed Estimation with Single Loop Event Data

• **Basic Concepts**
  - *Dwell time (duration)* of individual vehicle over a loop: available if the data has 60 Hz information;
  - *Moving Window*: traffic changes analyzed within a moving window up to current time interval.
  - *Mode Duration*: (a) deposit all the dwell times of individual vehicles within the moving window into evenly distributed bins; (b) choose the bin with the largest deposits, the *mode bin*; and (c) average the dwell times of all the deposits in the mode bin to produce the mode duration;
  - Mode Occupancy: ratio of *mode dwell time and sample time interval*, ~ 1 [s] for most BHL data.
Speed Estimation with Single Loop Event Data

- Mode duration extraction

![Diagram showing mode duration extraction](image)
Speed Estimation with Single Loop Event Data

- **To Extract Mode Occupancy**
  - Variable Length Moving Window: defined as having ~200 vehicles passed the loop detector: adaptive to traffic flow, suitable for traffic from low to high volume;
  - Exception: For heavily congested (stop & go) traffic identified as very high occupancy and very low flow, use Fixed Time Length Moving Window until traffic begins to recover
  - Number of bins in the moving window: 10 ~ 20
Speed Estimation with Single Loop Event Data

- Speed Estimation from Dual Loop Stations
  - used as baseline for comparison;
  - sensitivity level does not affect results if U-loop and D-loop has the same level
Speed Estimation with Single Loop Event Data

- BHL data on 04/13/2005, St-7 WB Lane 1 (HOV) D-loop: mode duration extracted
Speed Estimation with Single Loop Event Data

- BHL data on 04/13/2005, St-7 WB Lane 1 (HOV): estimated speed comparison
Speed Estimation with Single Loop Event Data

- BHL data on 04/13/2005, St-7 WB Lane 3 U-loop: number of samples in first 4 Bins
Speed Estimation with Single Loop Event Data

- BHL data on 04/13/2005, St-7 WB Lane 3 D-loop: number of samples in first 4 Bins

![Graphs showing number of samples in first 4 bins for downstream loop](image)
Speed Estimation with Single Loop Event Data

- BHL data on 04/13/2005, St-7 WB Lane 3 D-loop: mode duration extracted
Speed Estimation with Single Loop Event Data

- BHL data on 04/13/2005, St-7 WB Lane 3: estimated speed comparison
Speed Estimation with Single Loop Event Data

- RMSE in Table 1 is used to quantify the discrepancy w. r. t. both U-loop and D-loop;
- Data analysis has been conducted for 4 stations in both E-Bound and W-Bound over 24 hours;
- RMSE is between 1.73~5.39 mph. However, in most stations/lanes are about 2~4 mph;

<table>
<thead>
<tr>
<th>Data Set and Station</th>
<th>Dir</th>
<th>$\eta$</th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Lane 4</th>
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<tr>
<td></td>
<td></td>
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<td>D</td>
<td>U</td>
<td>D</td>
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<td>2.51</td>
<td>2.70</td>
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<td></td>
<td>W</td>
<td>0.95</td>
<td>4.14</td>
<td>3.77</td>
<td>Bad data</td>
<td>3.15</td>
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<tr>
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</table>
Length Based Classification with Single Loop Event Data

1. Raw single loop event data – occupancy: individual vehicle activated data

2. Vehicle length estimation

3. Traffic speed in similar time resolution

4. Vehicle length based classification

5. Moving window process

6. Mode occupancy

7. Revised g-factor method
Consideration of Site Selection

- Site Selection Criteria for Combined VSL & CRM
- Some Candidate Sites
  - I-880 Nimitz Freeway
  - I-280 Near Saratoga Ave.
  - SR85-Camden, NB AM Peak
  - I-80 WB PM Peak
Site Selection Criteria for Combined VSL & CRM

- Mainly for CRM
  - Road geometry and traffic situation
  - Onramps are close enough; otherwise not need for coordination
  - All onramps are metered along the corridor, otherwise, the one without meter will cause problems
  - Mainline sensor density is adequate
  - Onramp flow & queue detection is critical to CRM
  - Avoiding off-ramp blockage (protecting accessibility)
  - Hardware setup would allow CRM control (D4 TMC)
  - Coordinate with arterial if road geometry permit
    - Routing with VMS
    - Traffic signal control
Site Selection Criteria for Combine VSL & CRM

- Mainly for VSL
  - Traffic demand is high to over-saturated in peak hours
  - The corridor has a recurrent bottleneck downstream
  - The most downstream (main) bottleneck has the minimum capacity or largest v/c ratio
  - Congestion cause is lane reduction or virtual lane reduction
  - Upstream of the main bottleneck has adequate storage section without off-ramp or has a separated off-lane
  - Detection at critical locations:
    - at the start of the bottleneck and 500 m upstream;
    - each section has detectors 300~500 m apart;
    - sensor health is important for good performance
Speed 35 For Max Flow