Field Test of Combined VSL and CRM for Freeway Traffic Control

Project Meeting
Caltrans District 3

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Outline

- VSL and CRM for Freeway Traffic Control
- Combined VSL & CRM Strategy
- Progressive Project Plan for 4 Years
- Overall System Structure
- Implementation Related Issues
- Why Traffic Speed Estimation Required?
- Site Selection Consideration
- Discussion
VSL and CRM for Freeway Traffic Control

- Combined VSL & CRM - Backbone of ATM
- International and US Practices
- Combined VSL and CRM Strategy
- Control Objectives and Benefits
- Overall System Structure
Combined VSL & CRM - Backbone of ATM

Pre-Trip planning & mode use selection

Traffic assignment for individual veh. routing

Demand Management

Capacity Management

Combined VSL & CRM for integrated mainstream and arterial traffic control

Bottleneck detection and management

Traffic Control Assistance Measures

Driver advice or mandate on: lane use limit; merge/lane-change assistance/limit; dynamic shoulder use; dynamic use of HOV/HOT lane; gap advice
International and US Practices

  - Increase in average throughput for congested periods of 3 to 7 percent;
  - Increase in overall capacity of 3 to 22 percent;
  - Decrease in primary incidents of 3 to 30 percent;
  - Decrease in secondary incidents of 40 to 50 percent;
  - Overall harmonization of speeds during congested periods;
  - Decreased headways and more uniform driver behavior;
  - Increase in trip reliability; and
  - Ability to delay onset of freeway breakdown
International and US Practices

- European Traffic Management Strategies (England, The Netherlands, New Zealand, Australia, …)
  - Speed Harmonization/Lane Control
  - Queue Warning
  - Dynamic Use of Hard Shoulder
  - Junction Control
  - Dynamic Re-routing
  - Traveler Information for pre-trip and in-route decisions
  - Coordinated Ramp Metering (HERO in Australia)
  - VSL (UK, the Netherlands, …)
International and US Practices

- US Traffic Management Strategies
  - Ramp Metering
  - Lane Management (or Managed Lane)
  - VSL and Managed Lanes (WSDOT)
  - Shoulder Use (TOD, Transit)
  - Pricing (HOT)
  - Traveler Information
Control Objectives and Benefits

- **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
Control Objectives and 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
Control Objectives and 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
Why is Bottleneck flow below capacity if its upstream is congested?
Answer: Feeding flow into the bottleneck is low – even if the speed in the bottleneck is increasing, the density is decreasing.
Bottleneck Flow Maximization

- Control strategy: to maximize bottleneck flow;
- Applicable bottleneck type: (virtual) lane drop and weaving
- How: (1) create a discharge section before the bottleneck; (2) regulate the discharge section flow to bottleneck capacity flow
- Example: flow of 3-lane discharge section could be made closer to (a 2-lane) bottleneck capacity flow
Overall System Structure

- CRM Stand Alone
- Combine VSL & CRM
CRM Stand Alone for Freeway Corridor Traffic Control

PATH Control Computer

TMC Computer

Cabinet 1
2070 Controller

Cabinet 2
2070 Controller

Cabinet 3
2070 Controller

Cabinet N
2070 Controller

RT data

RM rate

RM Rate

Traffic detector
Combined VSL & CRM for Freeway Corridor Traffic Control

PATH Control Computer 2
PATH Control Computer

3G modem or Internet

Wireless 3G modem

RM traffic data
RM Rate

TMC Computer

Cabinet 1
2070 Controller

Cabinet 2
2070 Controller

Cabinet 3
2070 Controller

Cabinet N
2070 Controller

Onsite Server Computer

FreeWave

Traffic detector

Speed 35 For Max Flow

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Traffic detector

Speed 35 For Max Flow
Combined VSL & CRM for Freeway Corridor Traffic Control

PATH Control Computer

RM traffic data
RM Rate

3G modem

RM Rate

Cabinet 1
2070 Controller

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2070 Controller

Cabinet 3
2070 Controller

Cabinet N
2070 Controller

Onsite Server Computer

FreeWave

Traffic detector

Speed 35
For Max Flow

Combined VSL & CRM for Freeway Corridor Traffic Control
CRM Stand Alone for Freeway Corridor Traffic Control

TMC Computer

Cabinet 1
170/2070 Controller

Cabinet 2
170/2070 Controller

Cabinet 3
170/2070 Controller

Cabinet N
170/2070 Controller

Traffic detector
Progressive Project Plan for 4 Years

- Phase 1: Preparations for Field Testing of Combined VSL & CRM
- Phase 2: Field Experiment of CRM
- Phase 3: Field Experiment of VSL
- Phase 4: Field Test Combining VSL & CRM
Phase 1: Preparations for Field Testing of Combined VSL & CRM (15 Months)

- **Objectives:**
  - To prepare for future field testing of Variable Speed Advisory (VSL) and Coordinated Ramp Metering (CRM).

- **SOW:**
  - Finalize site selection criteria and select proper site
  - Extensive literature review on VSL and CRM
  - Preparations for control computers and VMS at RFS
  - Define performance parameters for evaluation
  - Data collection and modeling of selected site
  - Validation of the VSL and CRM algorithms with simulation for the selected site
  - Preparations for use of 30 s real-time data from PeMS for supporting later stage tests
  - Preparing final report
Phase 2: Field Experiment of CRM (12 Months)

- Objectives:
  - Determine the technical feasibility, implement coordinated CRM and evaluate its effectiveness in improving corridor traffic flow.

- SOW:
  - Refine traffic state parameter estimation
  - Calibrate and refine traffic simulation for selected site
  - PATH computer to
    - interface with the TMC host computer
    - get real-time traffic data
    - send generated RM rate for selected freeway corridor
  - Evaluate effectiveness of CRM algorithm
  - Write Phase 2 report to document findings
Phase 3: Field Experiment of VSL (12 Months)

- **Objectives:**
  - Implement and test VSL at selected site for traffic flow and safety improvement

- **SOW:**
  - Retrieve real-time 30 s data from Caltrans PeMS
  - Use a PATH computer to control the display of VSL on portable VMS
  - Progressively switch on VSL displays for short time periods
  - Modify algorithms and tune the system based on observed effects on traffic flow and driver compliance
  - Collect data before and after VSL and analyze data for performance evaluation
  - Write Phase 3 report describing results
Phase 4: Field Test Combining VSL and CRM (12 Months)

- Objectives:
  - Test combined VSL & CRM and evaluate effectiveness

- SOW:
  - Improve algorithms based on previous tests
  - Implement combined VSL & CRM for selected site
  - Collect data before/after the control system activation
  - Systematic test of the combined algorithm
  - Analyze the data for evaluation of the performance
  - Assess merits and limitations of control algorithms, leading to implementation recommendations
  - Prepare Final Report to document all findings and recommendations
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
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 $q_{in}$ to determine $q_r$
Outcome at bottleneck is not measured $q_{cap}$
This method results in very poor operations
Why is Speed Estimation Required?

Measure $q_{cap}$ to determine $q_r$
Outcome at bottleneck is measured $q_{cap}$
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;
Site Selection Consideration

- Site Selection Criteria
- Some Candidate Sites
  - SR99-Mack Road:
    - NB AM
    - SB PM: Lane Reduction Bottleneck
  - SR51- Exposition Blvd:
    - SB PM: Lane Reduction Bottleneck
Site Selection Criteria

- 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 and spill-back
  - Hardware setup would allow CRM control (D4 TMC)
  - Coordinate with arterial if road geometry permit
    - Routing with VMS
    - Traffic signal control
Site Selection Criteria

- 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
SR99-Mack Road, SB PM Peak
SR99-Mack Road, SB PM Peak

- SB PM peak traffic demand is high along the corridor
- Congestion: both flow & speed drop
- A lane reduction bottleneck
- A storage section upstream (about 1 mile) is available
- Onramp in the bottleneck has metering
- Good RM infrastructure
- Sensor density, locations and some data are not available
- Parallel arterial exists for re-routing
- Queue detection for onramps (unknown)
- Possible candidate for combined VSL and CRM
SR51SB - Exposition Blvd and Arden Way
Road Geometry and VDS
SR51SB - Exposition Blvd and Arden Way
Road Geometry and VDS
SR51 SB - Exposition Blvd, PM Peak

- A lane reduction recurrent bottleneck
- SB PM peak traffic demand is high along the corridor
- Congestion between 3:00~7:00pm:
  - both flow & speed drop
- Congestion back propagation to north of Arden Way
- A storage section upstream (about 2 mile) is available with 2 off-ramps
- Onramps no metering from Google map
- Sensor density and locations are OK; VDS314157 (north of Arden Way) has no data
- No parallel arterial for re-routing
Discussion

- Recent practice in Australia (Steven Shladover)
- Site selection: Freeway section with Lane Reduction or virtual Lane Reduction or Weaving Bottleneck
  - SR99-Mack Road: NB AM and SB PM
  - SR51- Exposition Blvd: SB PM ?
  - Other recurrent bottlenecks?
- Mainline sensor density and detection health:
- Onramp queue length detection: Onramp upstream detector data availability
- How data are processed in D3 control system
  - Raw data retrieving – update rate
  - Aggregation: controller level of TMC computer level
Discussion

- Traffic state parameter estimation
  - Inside of RM Control Software
  - Outside of RM Control Software
- TMC RM Computer configuration and interface
- Data routing
  - Directly Using TMC Data
  - PeMS – data use for simulation and algorithm validation
- Traffic controller types at onramps: all are 2070 Controller
- Current RM metering strategy:
  - Traffic responsive if detector is healthy
  - Return to default, time-of-day strategy, in case of detector/data fault
Speed
35
For Max Flow