Variable Speed Limit Control To Increase Discharge Rates At Freeway Incident Bottlenecks

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Background

- Variable Speed Limit (VSL)
  - Safety (harmonized speed, smooth queue transition)
  - Freeway efficiency (defer congestion onset, increase BN discharge rate).
VSL – efficiency focus

- SPECIALIST – resolve moving jams (implemented) (Hegyi et al., 2008; 2009).
- MTFC – prevent/defer congestion onset (simulation) (Carlson et al., 2010a, b).
- Chen et al. – resolve BN queue and then resume high discharge flow (analytical study) (2014).
Key characteristics of incident BNs

- Moderate to severe congestion
- Sharp transition at the tail of queue
- Significant capacity drop (Knoop et al., 2008; 2009a; 2009b)
  - Road blockage
  - Rubbernecking
  - Change in driving behavior
  - Disruptive LCs.
Key characteristics of incident BNs

- Moderate to severe congestion
- Sharp transition at the tail of queue
- Significant capacity drop
  - Road blockage
  - Rubbernecking
  - Change in driving behavior
  - Disruptive LCs. Potentials of discharge improvement
Background

Key characteristics of incident BNs

- Moderate to severe congestion → Need less restrictive speed limit
- Sharp transition at the tail of queue → Need smoother queue management
- Significant capacity drop
  - Road blockage
  - Rubbernecking
  - Change in driving behavior
  - Disruptive LCs. → Potentials of discharge improvement

New VSL
What our new VSL strategy will do?

- Reduce delay – by increasing BN discharge flow
- Enhance safety – by smoothing upstream queue transition
Baseline case

Basic VSL control
  - Procedure
  - Parameter analysis

VSL for re-emergent queue
  - Procedure
  - Parameter analysis

Conclusions
Baseline Case

- Traffic scenario
  - KW theory
  - Demand: $A$ (constant)
  - Breakdown state: $H$
Basic assumptions

- Lower FD: $u^{inc} < u$: rubbernecking + other effects
- Stable max state: $e$
  - $q_{BN} = q_e; q_E = q_G = q_e$
  - $q_H < q_{BN}$
Basic VSL Control Strategy

Procedure

- Step 1: control demand progressively to clear queue at BN.
- Step 2: regulate inflow at stable max flow.
Basic VSL Control Strategy

Step 1: control demand progressively to clear queue at BN

Demand in $A \rightarrow$ state $E: u \rightarrow V_1 \rightarrow V_2 \rightarrow V_3 \rightarrow v_E$
Basic VSL Control Strategy

- Step 1: control demand progressively to clear queue at BN

  1-1: Impose $VSL = V_1$ simultaneously over an extended segment upstream of queue
Basic VSL Control Strategy

- Step 1: control demand progressively to clear queue at BN
  1-2: Impose $V_2$, $V_3$, and $v_E$ in sequence.
Basic VSL Control Strategy

- Step 2: regulate inflow at stable max flow

  2-1: Deactivate $\nu_E$ to enable free-flow traffic at the acceleration zone
Basic VSL Control Strategy

- Step 2: regulate inflow at stable max flow

2-2: Impose $V_1$ at the rate of $s_{AA_1} (= s_{AE})$
Basic VSL Control Strategy

- Step 2: regulate inflow at stable max flow

2-2: Impose $V_2$, $V_3$, and $v_E$ in similar way. $v_E$ is extended to the entrance.

\[ q_{BN} = q_G = q_E = q_e \]
Step 2: regulate inflow at stable max flow

2-3: De-activate $V_1$, $V_2$, and $V_3$ along LVT to end VSL control.
Basic VSL Control Strategy

- Step 1: control demand progressively to clear queue at BN.
- Step 2: regulate inflow at stable max flow.
Basic VSL Control Strategy

- **Parameter analysis**
  - Delay saving $\Delta W_{VSL}^0$
    - Queue clearance time: shorter time $\rightarrow$ more saving
    - Capacity drop $(1 - q_H/q_M)$: larger drop $\rightarrow$ more saving
Basic VSL Control Strategy

- Parameter analysis
  - Delay saving $\Delta W_{VSL}^0$
    - $q_{BN}$: positive (moderate congestion)
Basic VSL Control Strategy

Parameter analysis

- Delay saving $\Delta W_{VSL}^0$
  - $q_{BN}$: positive (moderate congestion)
  - $q_{BN}$: positive $\rightarrow$ negative (severe congestion)

Higher $q_{BN} \rightarrow$ higher $v_E$ (less restrictive)
Potential cause: overestimated stable max flow

Control procedure
- Impose a restrictive VSL to clear new queue
- Regulate BN discharge rate at $q_{E^*}$
Re-emergent Queue

- Full image for traffic evolution
  - Impose a restrictive VSL ($v_H$) to clear new queue
  - Regulate BN discharge rate at $q_E^*$
Conclusions

- VSL control can achieve significant delay savings at freeway incident BNs and also smooth traffic transition at the tail of the queue.
- Re-emergent queue can be remedied. Delay saving will be smaller but still substantial.