hEART 2018

Freeway – Arterial Interactions: Strategies and Impacts

David Kan

Alexander Skabardonis

NTUA 1977, University of California, Berkeley

Athens, August 31, 2018

Outline & Conclusions

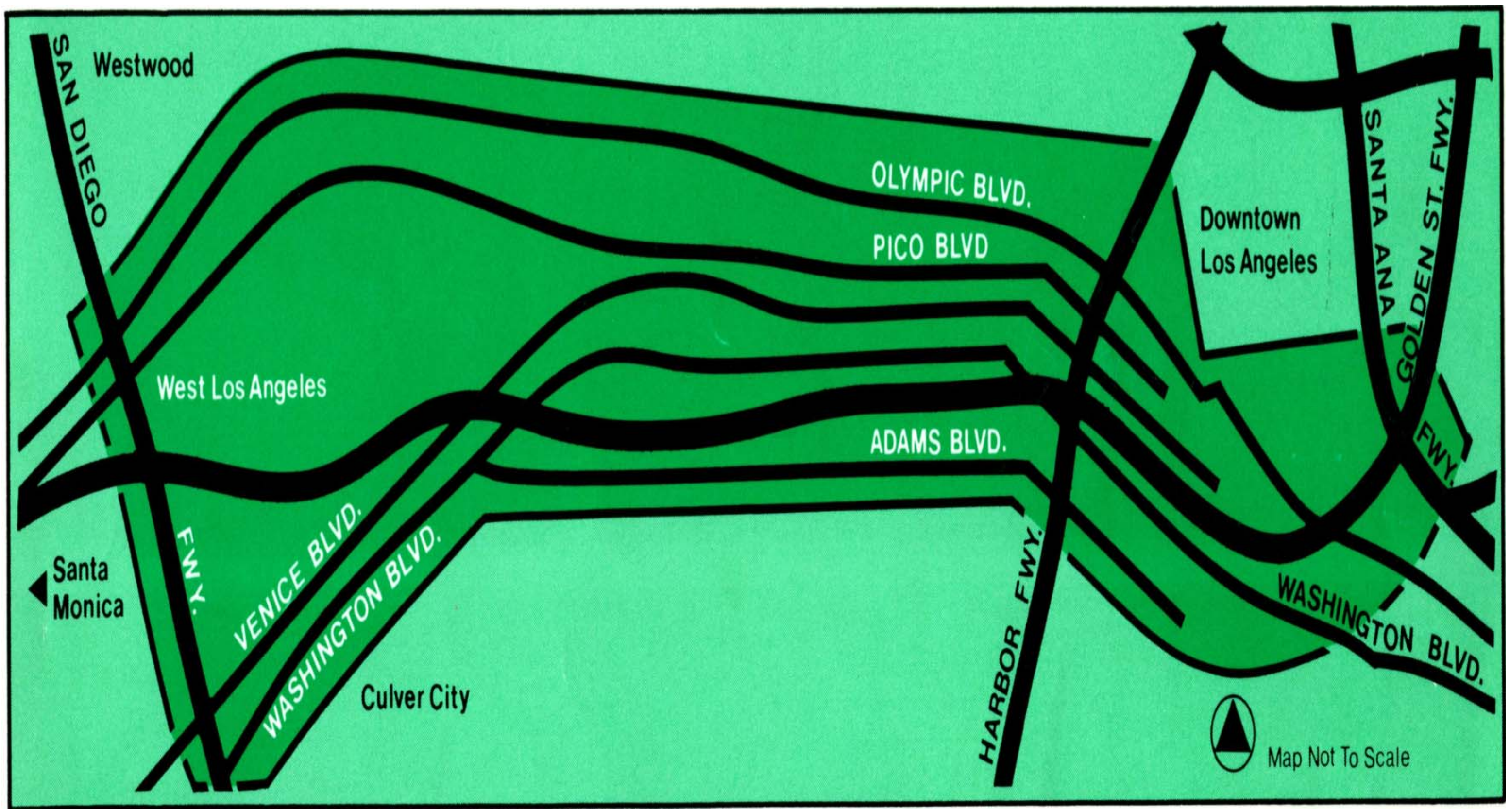
- Freeway Corridor Management
- Impacts of Ramp Metering
- Freeway-Arterial Coordination
  - Recurrent Congestion
  - Non-Recurrent Congestion

- Queue override causes 10% freeway capacity drop
- Improved arterial signal timing can reduce freeway delay and increase throughput
- Proposed simple methods for estimating potential diversion volumes

Background: Corridor Management (1)

Cooperative management of freeways and adjacent arterial networks

Los Angeles, Smart Corridor 1988

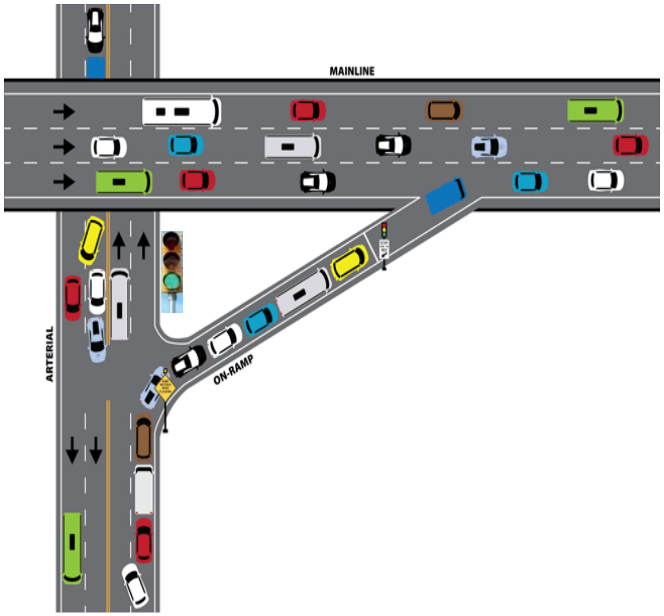


Background: Corridor Management (2)

Corridor Traffic Management & Information Vision

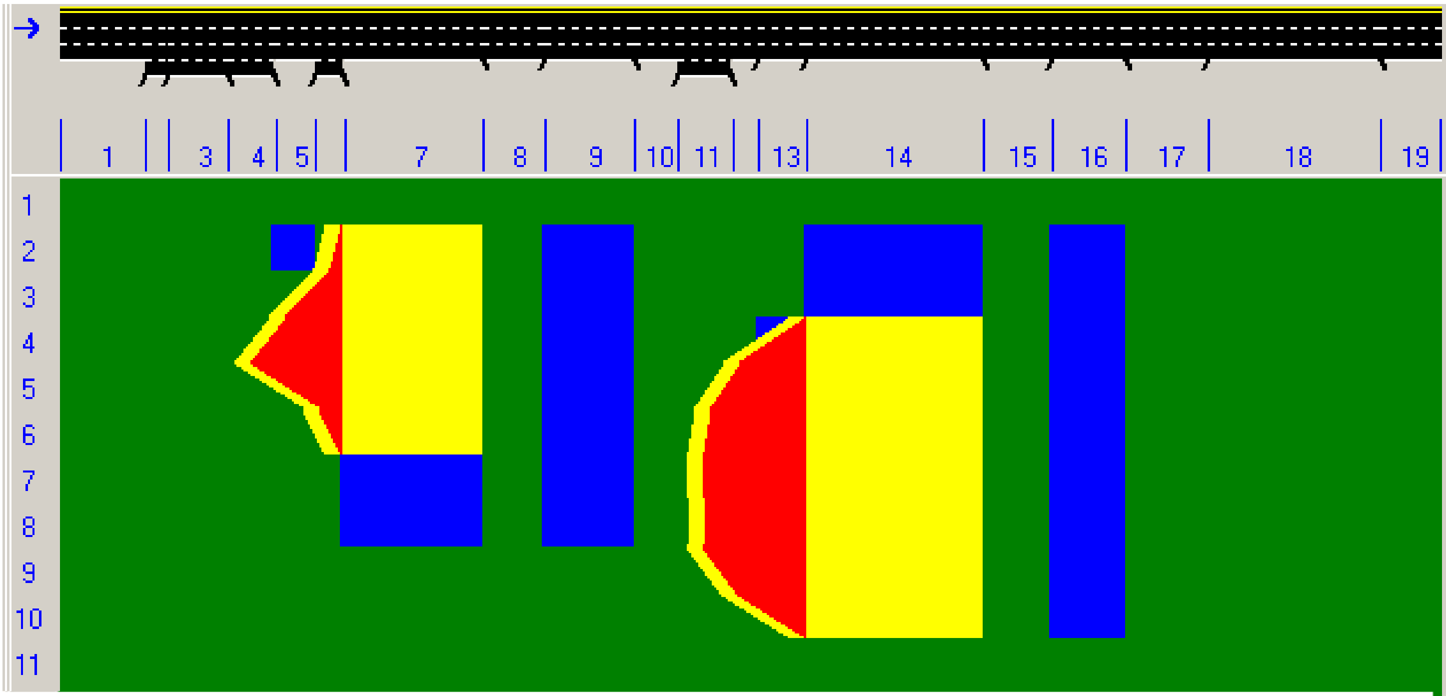
Freeway – Arterial Coordination

- **Existing coordination guidelines mostly address institutional issues (*example: FHWA Handbook*)**
- **Most approaches consist of scenarios with “flush” signal timing plans on arterials in case of freeway incidents**
- **Lack of Methodologies for Freeway-Arterial Interactions**
  - **Spillbacks to - from ramps**
  - **NCHRP 15-57 “HCM Methodologies for Freeway and Surface Street Corridors” (on going)**



Freeway Ramp Metering: Impacts (1)

Control on-ramp flows to preserve freeway capacity



$$MAX \sum_{i=1}^{N} X_i \qquad \sum_{i=1}^{N} a_{ij} X_i \leq c_j$$

X_i : input flow rate at on-ramp i , N : # on-ramps

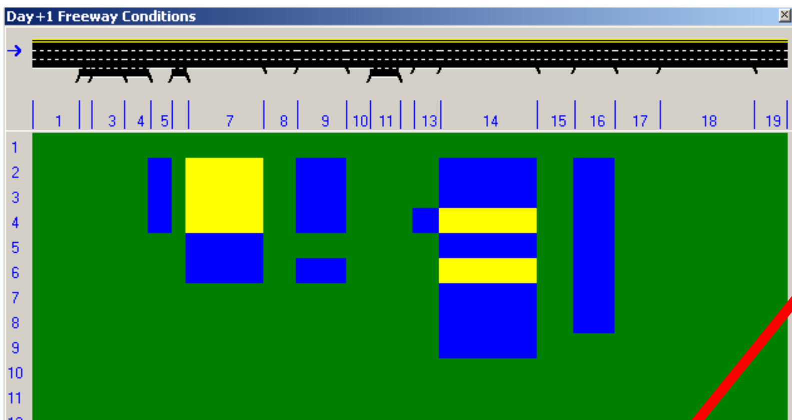
a_{ij} : proportion of traffic entering on-ramp i going through section j

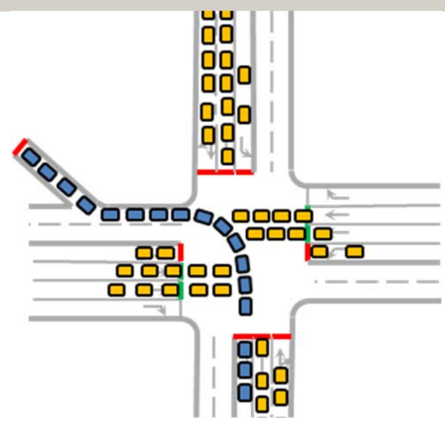
C_j : capacity of freeway segment j

Ramp Metering Impacts (2)

Freeway Mainline:
- **Maximize freeway throughput**
- **Minimize time spent**
- **Preserve freeway capacity**

On-Ramps:
- **Excessive delays to on-ramp veh**
- **Spillback to local streets**





Queue Override (*Suspend metering*)
- **Diminishes ramp metering benefits**
- **Capacity drop**

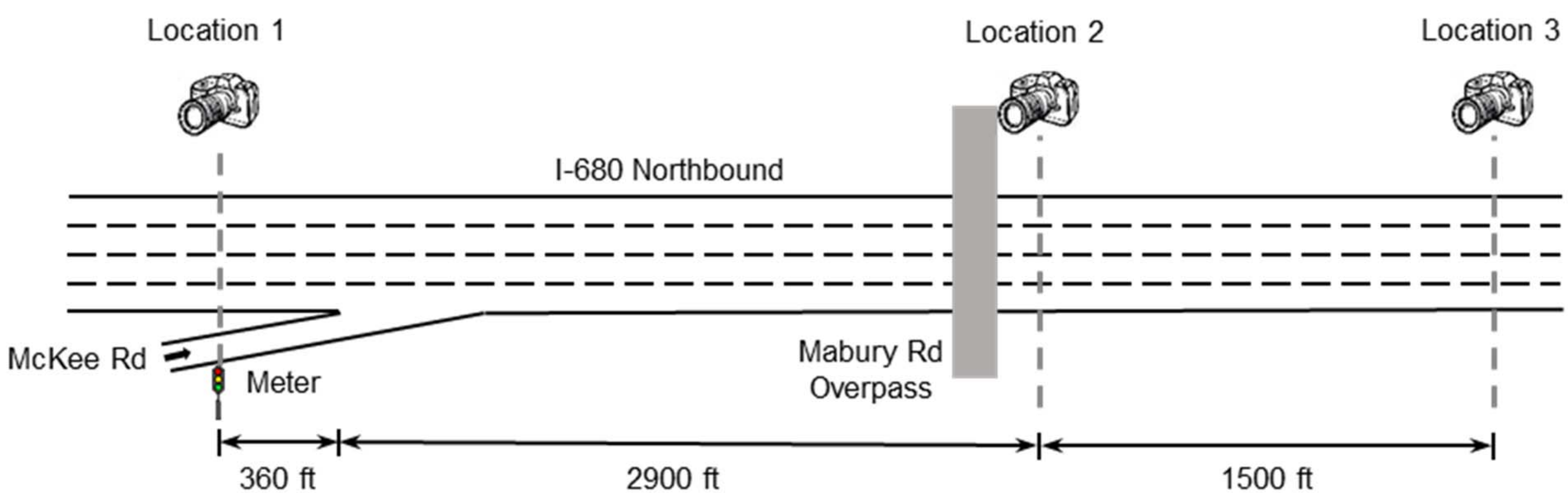
Field Study: Impacts of Queue Override (1)

Study Location:

- NB I-680, San Jose, CA
- McKee Rd, bottleneck

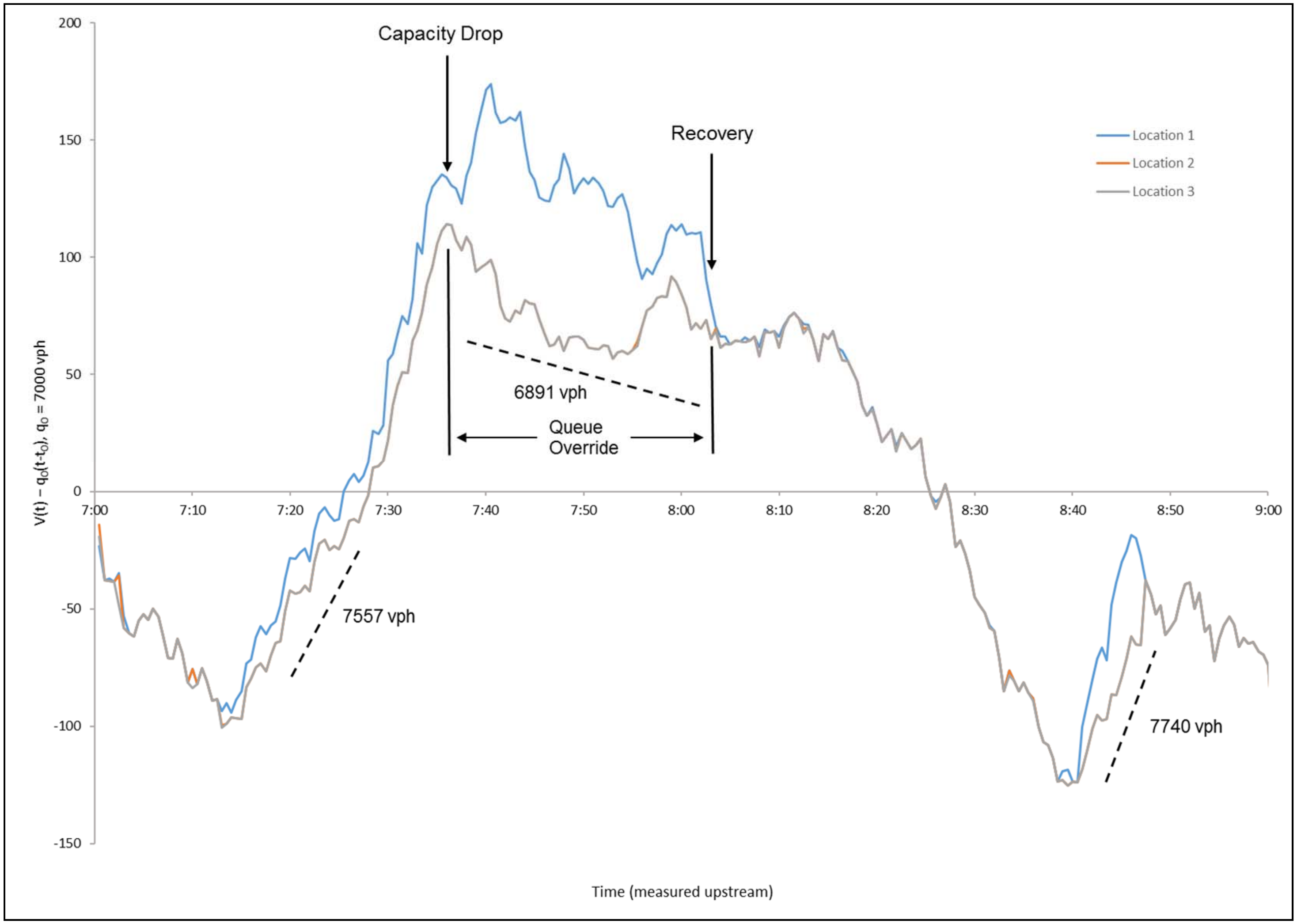
Time Period:

- Weekdays (May 9 – 20, 2015)
- AM Peak (7-10 am)



Field Study: Impacts of Queue Override (2)

- **Data Processing: Cumulative Curves (Example: 5/10/2015)**



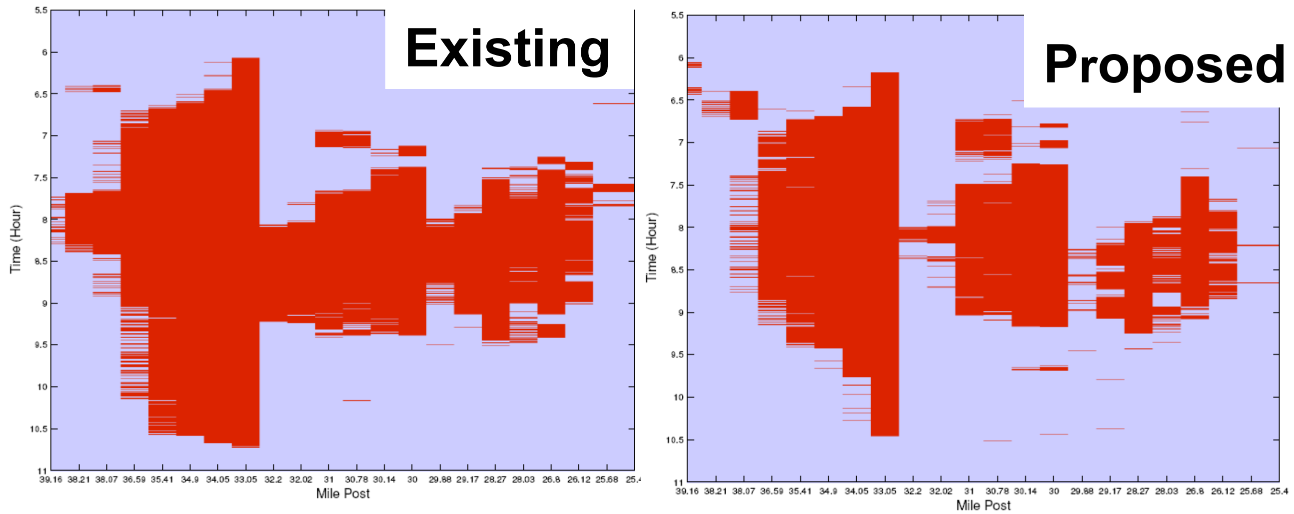
Field Study: Impacts of Queue Override (3)

	Total Outflow (Mainline and On-ramp)		
	Before Queue Override	**After Queue Override**	**% Difference**
Week 1			
May 9 (Monday)	**Not Activated**		**----**
May 10 (Tuesday)	**7847 vph**	**6891 vph**	**-12.81%**
May 11 (Wednesday)	**6752 vph**	**6058 vph**	**-10.28%**
May 12 (Thursday)	**Downstream spillback**		**----**
May 13 (Friday)	**Not Activated**		**----**
Week 2			
May 16 (Monday)	**Not Activated**		**----**
May 17 (Tuesday)	**7214 vph**	**6672 vph**	**-7.51%**
May 18 (Wednesday)	**7109 vph**	**6493 vph**	**-8.67%**
May 19 (Thursday)	**7532 vph**	**6612 vph**	**-12.21%**
May 20 (Friday)	**Not Activated**		**-----**
Overall	**----**		**-10.30%**

Strategy: Ramp Metering Algorithm

Incorporate an on-ramp queue control regulator

Application: Los Angeles I-210W



Improvements: 6% Travel Time/ 16% Delay Reduction

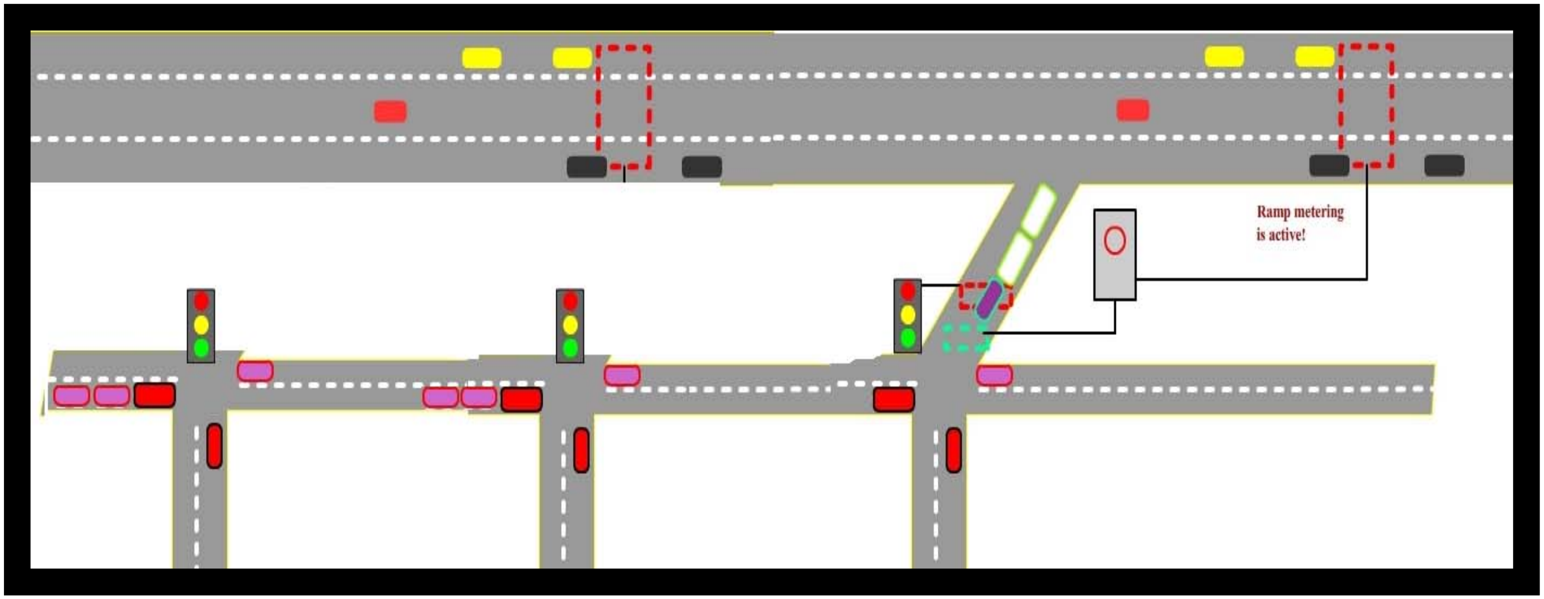
Challenge: Measuring On-Ramp Queue Length in Real-Time

"Design, Field Implementation and Evaluation of Adaptive Ramp Metering Strategies," PATH Research Report UCB-2005-2

"Analysis of Queue Estimation Methods Using Wireless Magnetic Sensors," TRR 2229

Strategy: On-Ramp Access Control

Determine the signal settings to avoid queue spillover from ramp metering that result in queue override



Constraints

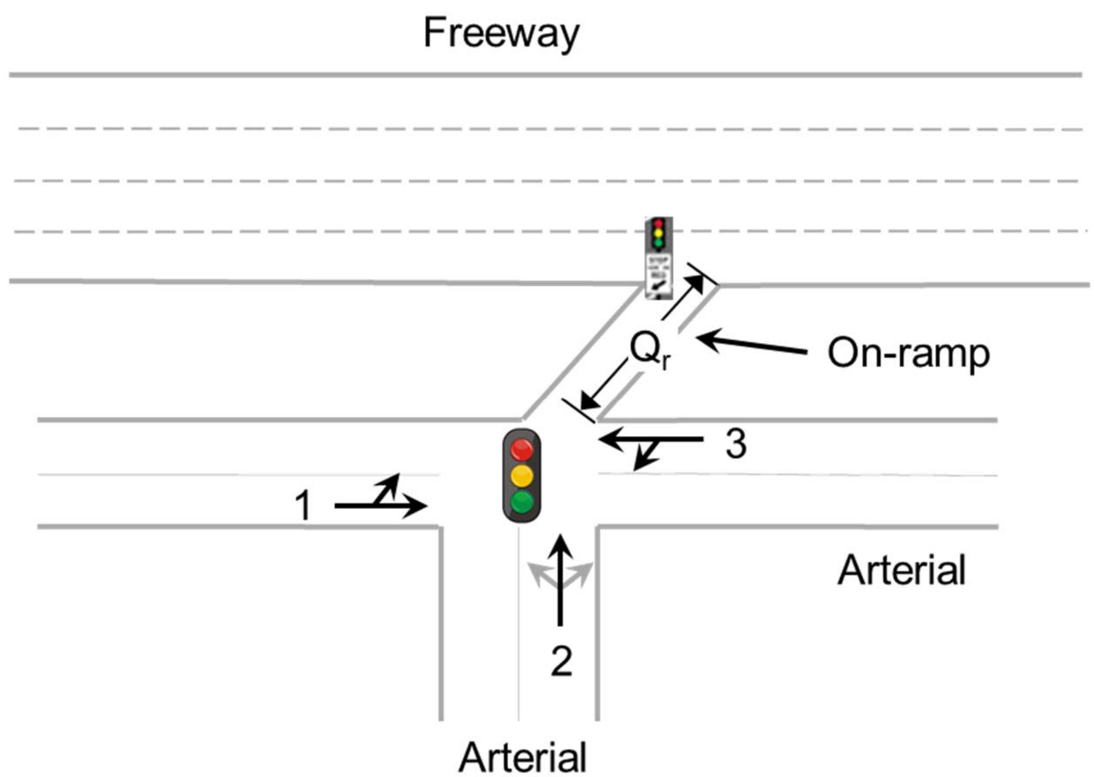
Serve the traffic demand on arterial phases

Arterial link storage (arterial spillback)

Minimum phase green times

Proposed on-Ramp Access Control (1)

- Ramp metering algorithm remains unchanged
- Example signalized intersection near freeway on-ramp



Proposed on-Ramp Access Control (2)

On-ramp excess accumulation

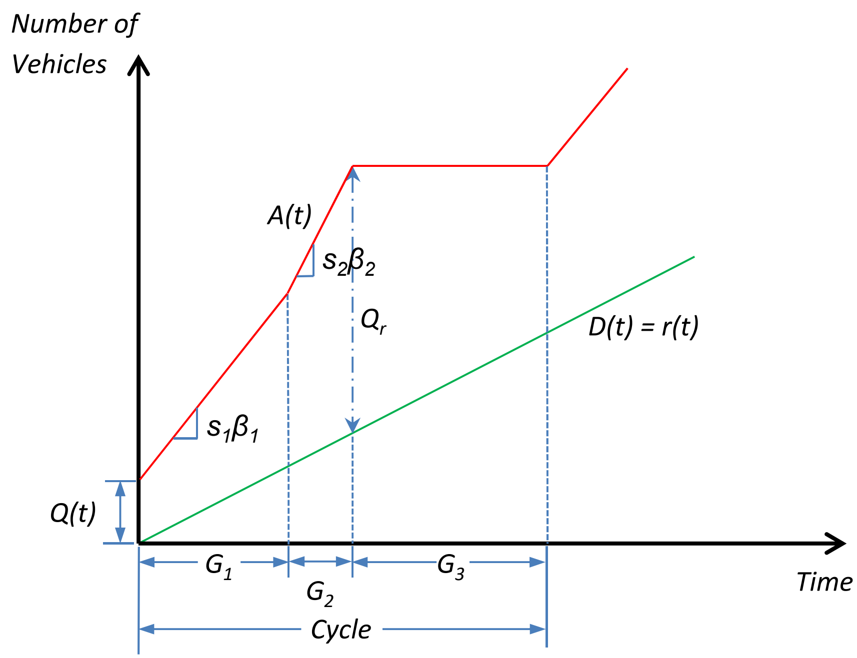
- $Q(t) + G_1 \cdot s_1 \cdot \beta_1 + G_2 \cdot s_2 \cdot \beta_2 - G_1 \cdot r(t) - G_2 \cdot r(t) \leq Q_r$

Residual on-ramp excess accumulation

Upstream arrival

Downstream departure

Available queue storage



Proposed Signal Control Strategy (3)

- On-ramp residual excess accumulation can be determined by tracking vehicles entering and leaving the on-ramp:

$$Q(t) = Q(t-1) + A(t) - D(t)$$

- Maintain the same green time distribution:

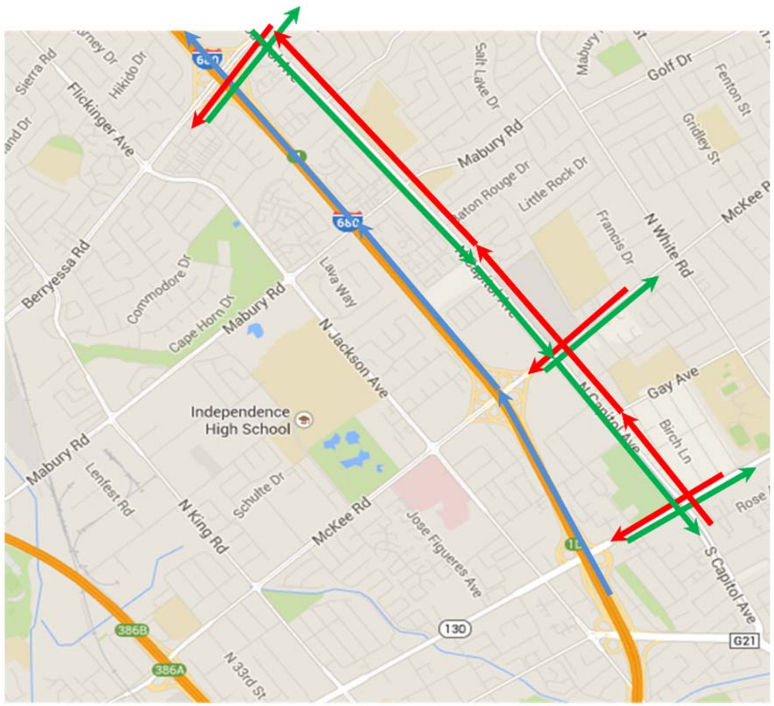
$$g_i = \frac{y_i}{Y} \cdot (C - L)$$

- Cycle length upper limit:

$$C \leq \frac{[Q_r - Q(t) + r(t) \cdot 2l] \cdot Y + 4l \cdot \left[\sum_{i=1,2} s_i \beta_i y_i - \sum_{i=1,2} r(t) y_i\right]}{\left[\sum_{i=1,2} s_i \beta_i y_i - \sum_{i=1,2} r(t) y_i\right]}$$

Simulation Test

- Test site: NB I-680/Capitol Ave Corridor, San Jose, CA
  - Recurrent bottleneck –AM peak (7:00 – 9:30 AM)
  - AIMSUN microscopic model
    - Enhanced driving behavior model [1]
  - Calibrated to replicate field data
  - **Before:** metering <u>with</u> queue override, <u>long</u> cycle lengths
  - **After:** metering <u>without</u> queue override, <u>short</u> cycle lengths
  - 20 replications



1 *Lu, X., Kan, X., Shladover, S.E., Wei, D., Ferlis, R.A., 2017. An enhanced microscopic traffic simulation model for application to connected automated vehicles. 96th TRB Annual Meeting, Washington, DC.*

Simulation Results

I. Freeway

	Before		After		% Difference	
Freeway Mainline						
	Total Delay (veh-hr)	Total Distance Traveled (veh-mile)	Total Delay (veh-hr)	Total Distance Traveled (veh-mile)	Change in Total Delay	Change in Total Distance Traveled
I-680 NB	833.41	43104.13	740.64	44792.95	**-11.13%**	**3.92%**

II. Arterial

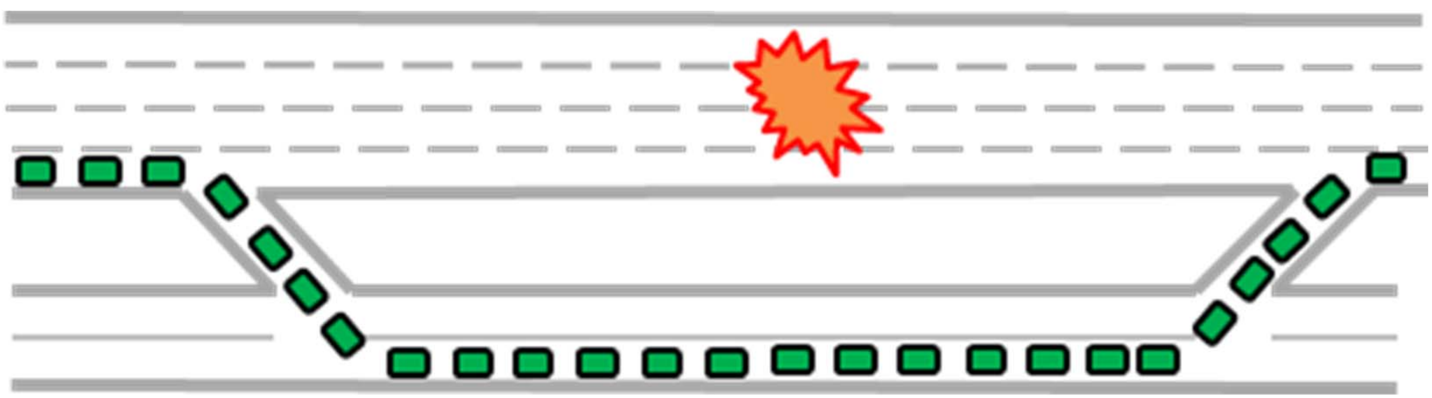
Average Delay on Main Parallel Arterial (min/veh)			
Capitol Ave NB	8.63	10.51	**21.84%**
Capitol Ave SB	5.72	5.91	**3.33%**
Average Delay of Cross Street (sec/veh)			
Alum Rock WB	48.05	47.33	-1.43%
Alum Rock EB	37.27	37.82	1.47%
McKee WB	56.76	52.34	**-7.79%**
McKee EB	28.92	16.51	**-42.91%**
Berryessa WB	47.27	39.26	**-16.73%**
Berryessa EB	50.50	37.55	**-34.48%**

III. Total System

	Total Delay (veh-hr)	Total Delay (veh-hr)	Change in Total Delay
Freeway & Arterial	2881.37	2727.19	**-5.65%**

Non-Recurrent Congestion: Diversion Strategies

- **Most freeway-arterial coordination studies**
- **Emphasis on Institutional Issues**
  - *e.g. FHWA Freeway-Arterial Coordination Handbook*
- **Several Site Specific studies**
- **Limited Technical Guidance at the Planning Level**

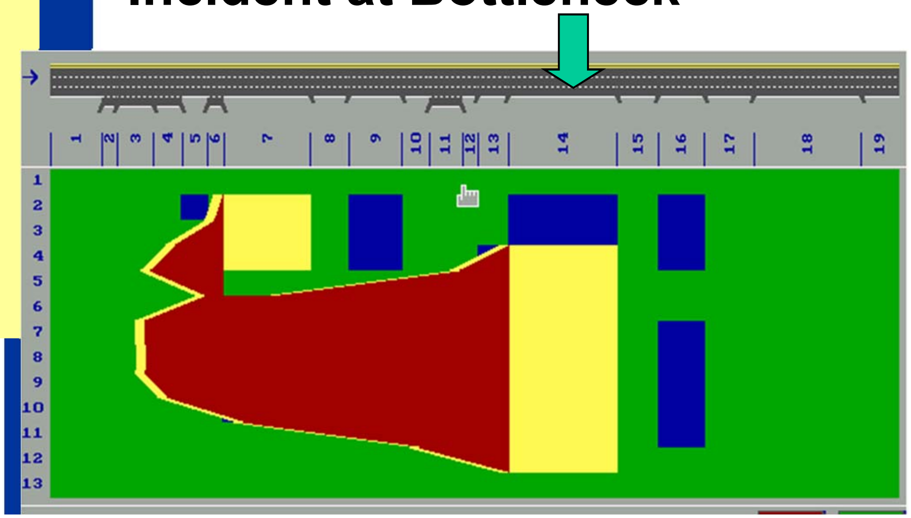


- ***Develop planning level guidance for freeway-arterial operational strategies under incident conditions***

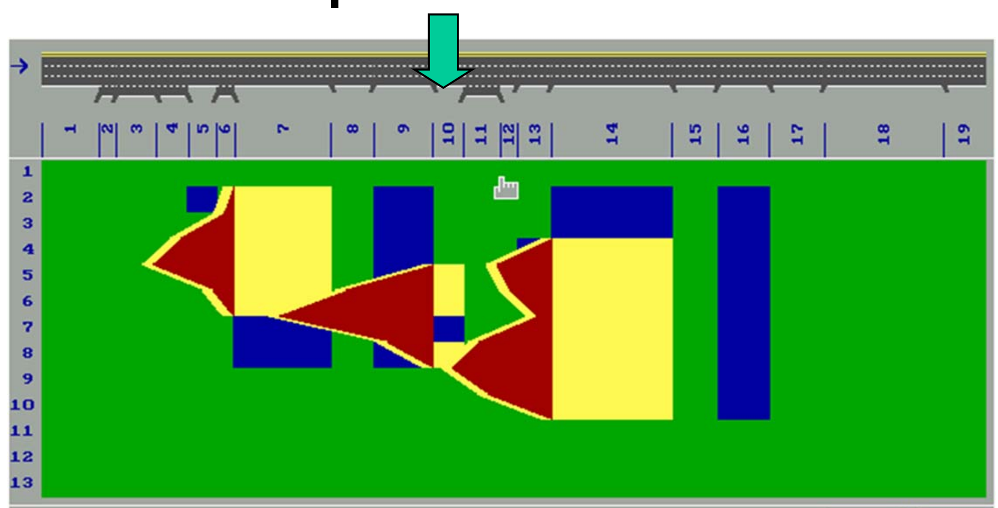
Non-Recurrent Congestion: Traffic Diversion

- **Key Issues:**
  - Freeway Operating conditions (congestion level)
  - Incident characteristics (location, severity)
  - Characteristics of freeway control & freeway surveillance
  - Characteristics of traveler information system
  - Characteristics of parallel arterial(s)

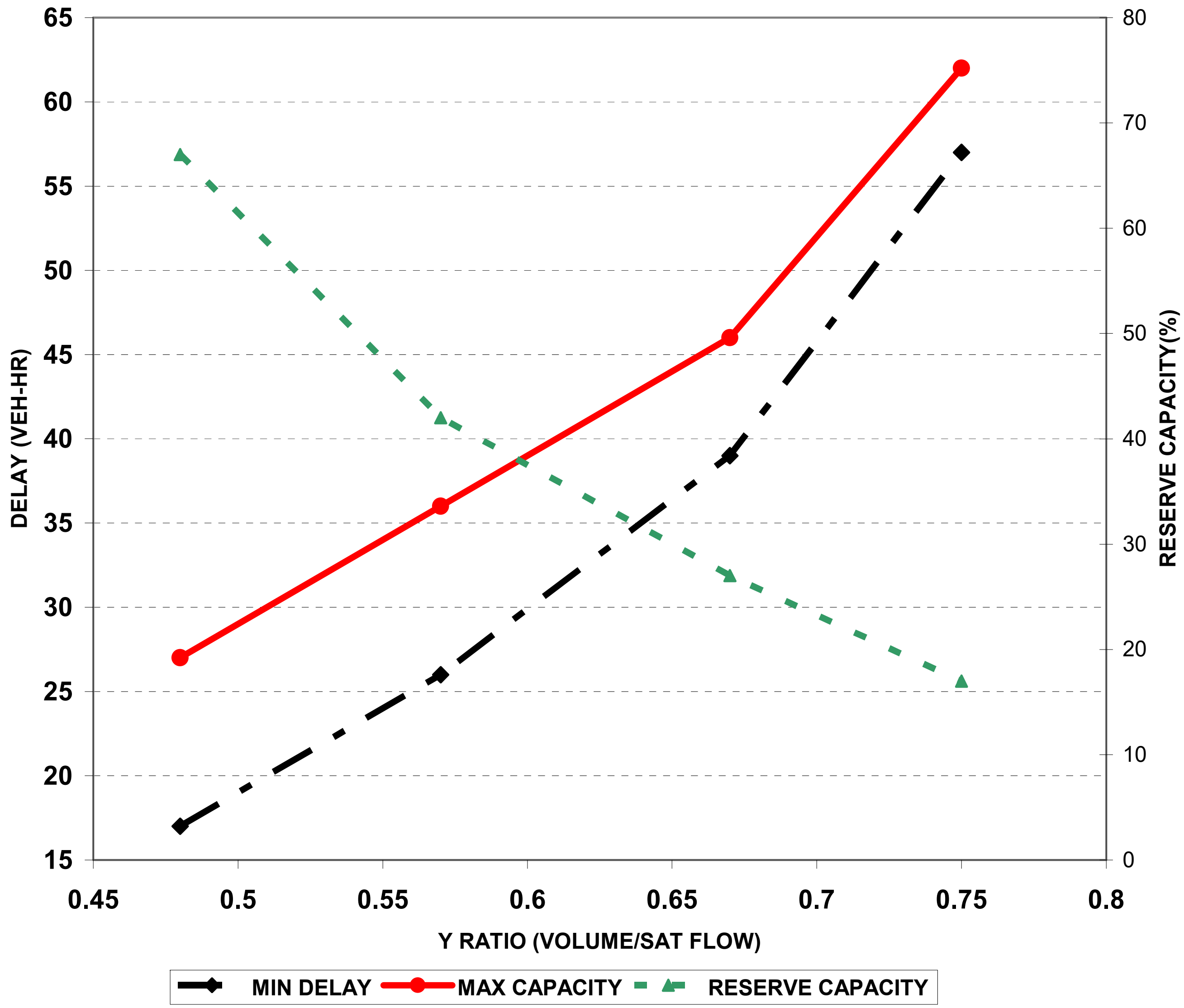
Incident at Bottleneck



Incident Upstream of Bottleneck

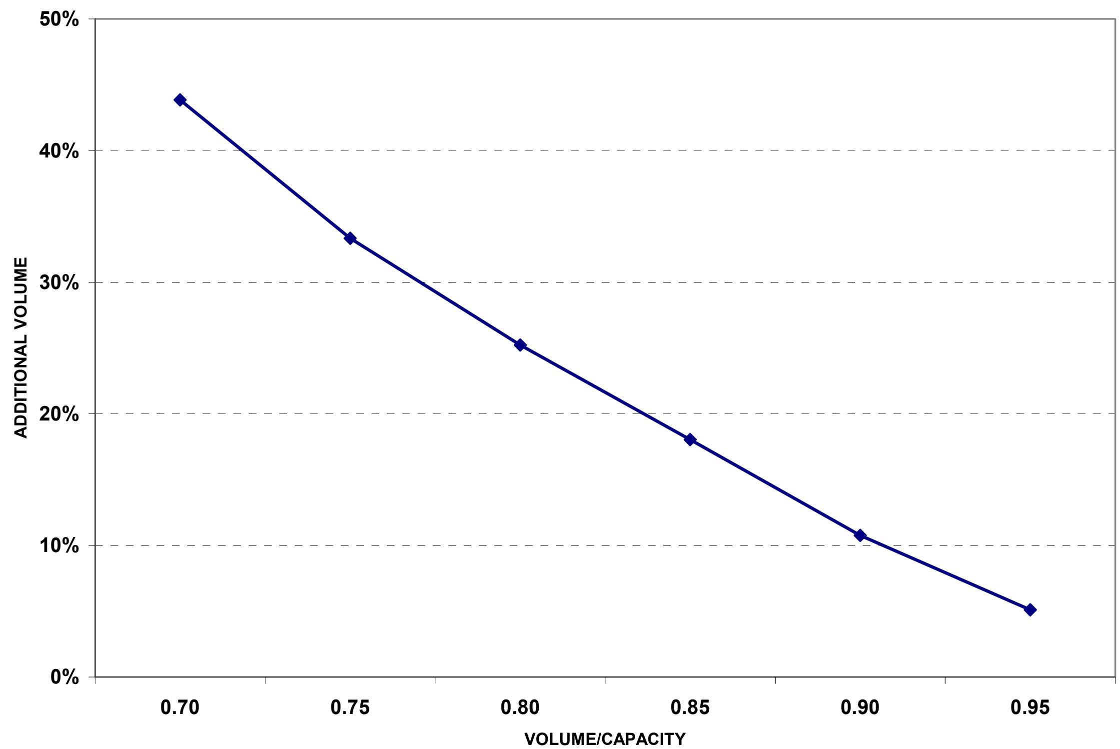


Signal Settings: Min Delay vs. Max Capacity



Diversion: Planning for Operations Approach (1)

Max Diverted Volume? = f(remaining capacity at critical intersection)



$$dV_i = \frac{RC_i}{X_i} \times 100$$

where:

- **DV_i** : additional traffic volume on approach *i* *(%)*
- **X_i** : volume/capacity (degree of saturation) on approach *i (%)*
- **RC_i** : reserve capacity on approach *i* = *1*- X_i

Diversion: Planning for Operations Approach (2)

Freeway Lost Capacity vs. Critical Intersection Remaining Capacity