# FIU Seminar

## Control of Freeway Corridors: Strategies and Impacts



**Alex Skabardonis**
**University of California, Berkeley**

**Miami, FL**
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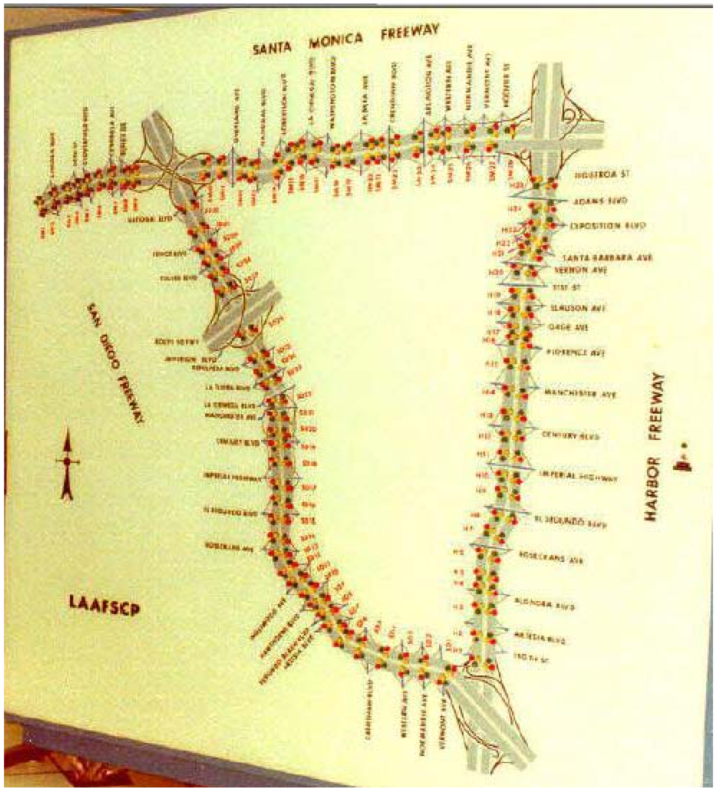
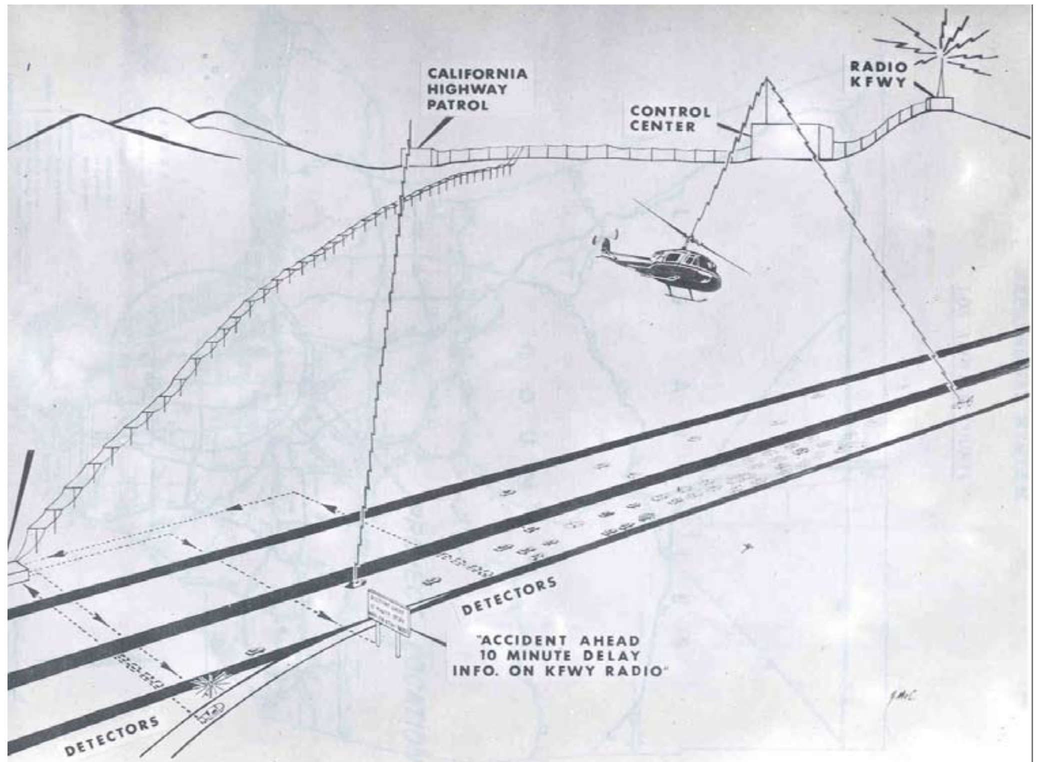
# Outline

- Freeway Corridor management
  - Background/Problem Statement
  - National Programs: ICM
- Freeway-Arterial Coordination
  - Recurent Congestion
  - Non-Recurrent Congestion
- Looking Ahead

# Background: Freeway Management

**1971 Los Angeles – 42 mile loop**

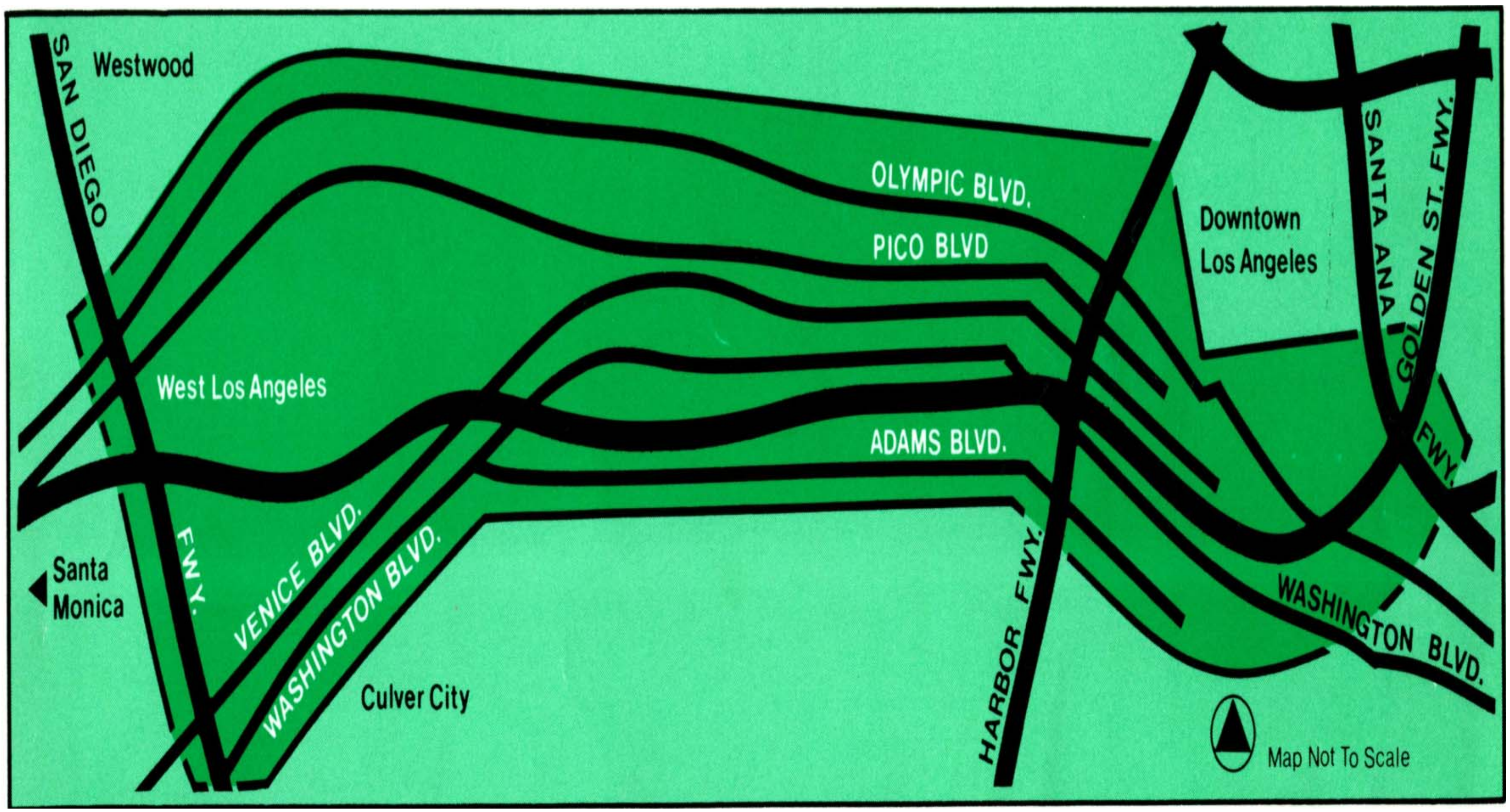


# Background: Corridor Management

**Cooperative management of freeways and adjacent arterial networks**

**Los Angeles, Smart Corridor 1988**



# Integrated Corridor Management (ICM)

## Corridor Traffic Management & Information Vision

# The I-10 Smart Corridor Goal/ConOps

Improve traffic efficiency and reliability through the coordinated use of management measures utilizing advanced technology.

Link different TMCs currently operating independently by Caltrans (freeway), Los Angeles (ATSAC - traffic signals), Highway Patrol (freeway), and SCRTD (buses).

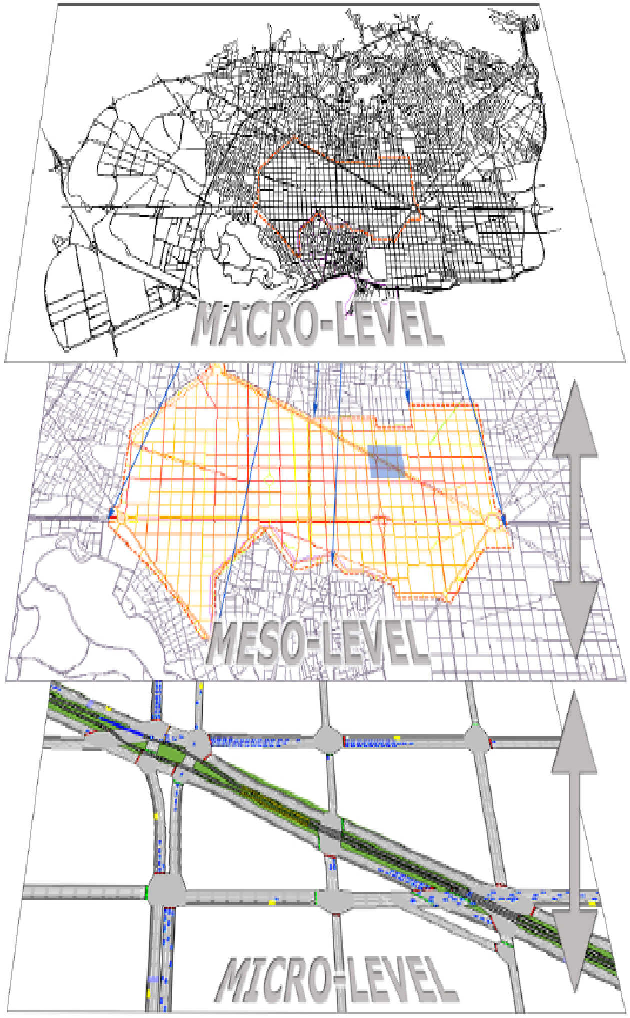
Full detection on freeway and city streets within the corridor.

Information systems: CMS,  HAR, telephone response, cable TV, in-vehicle navigation system, and computer bulletin boards.

Traffic management strategies will provide drivers with suggested alternate routes to avoid congestion and traffic incidents.

Expert system technology will assist TMC operators in the selection of appropriate management strategies

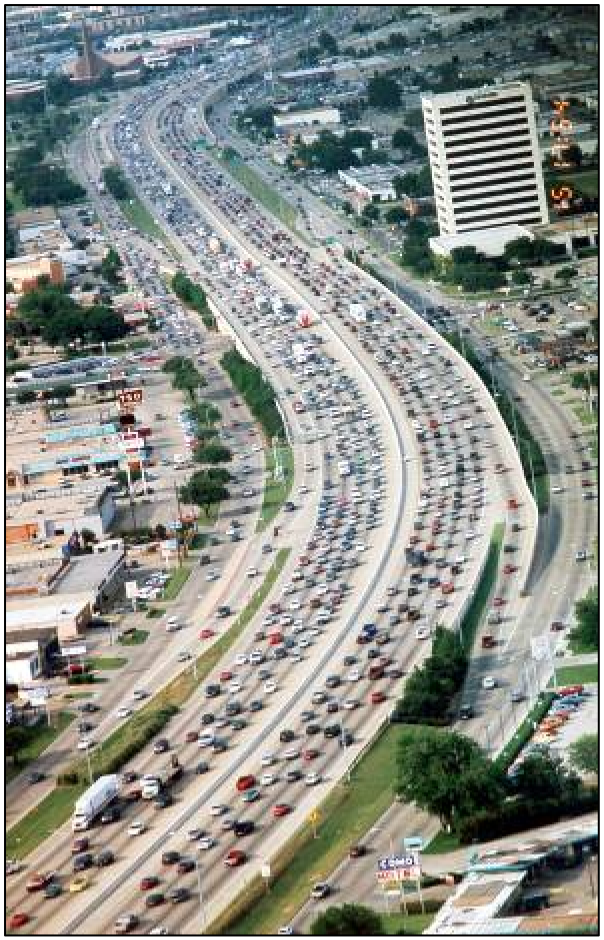
# USDOT ICM Program (1)

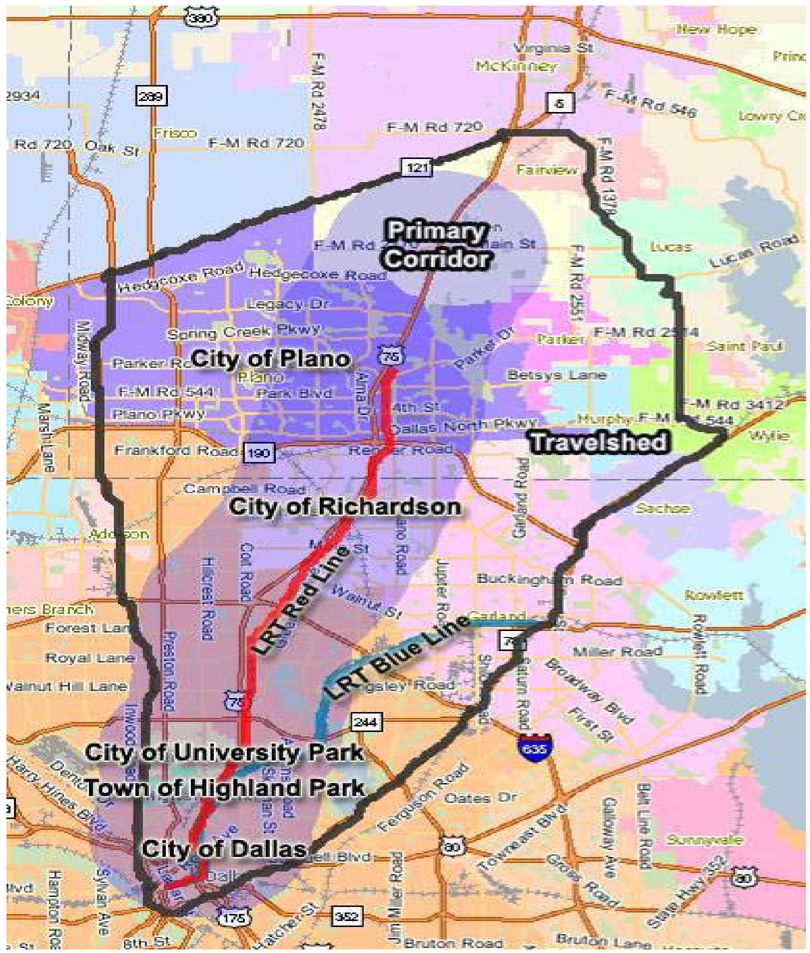



- Multimodal operations
- Complex modeling approaches
- Operational procedures/plans
- Institutional constraints
- Decision support systems
- Limited field evaluation
- Limited research

# USDOT ICM Program (2)

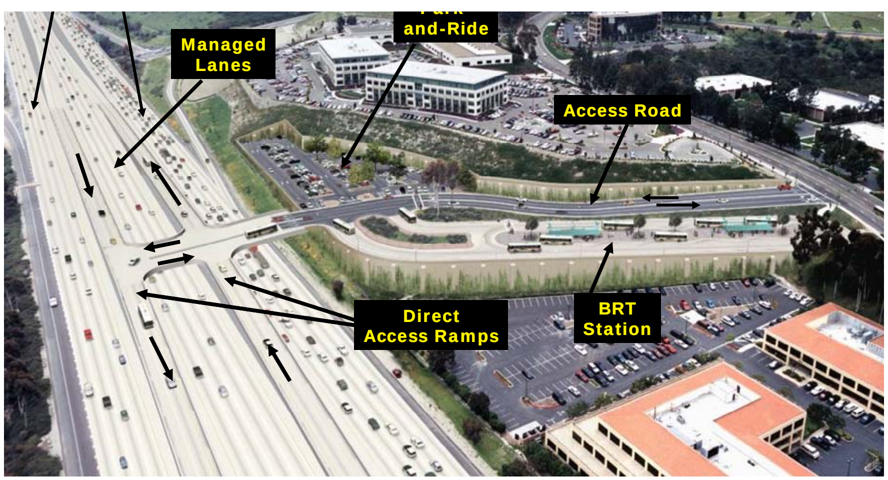
## US-75 ICM Corridor, Dallas, TX

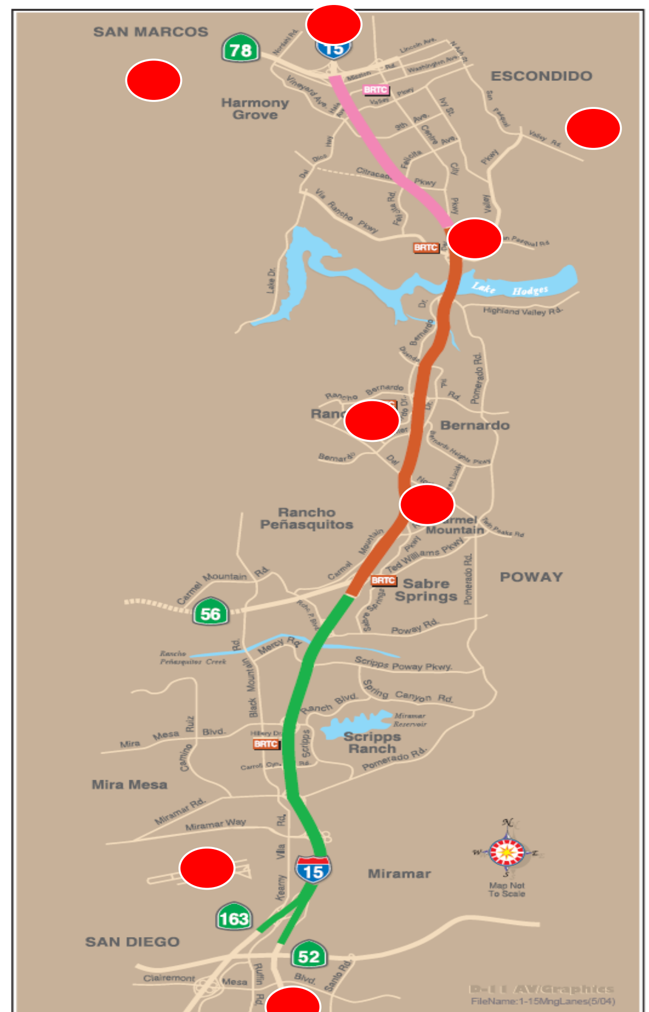




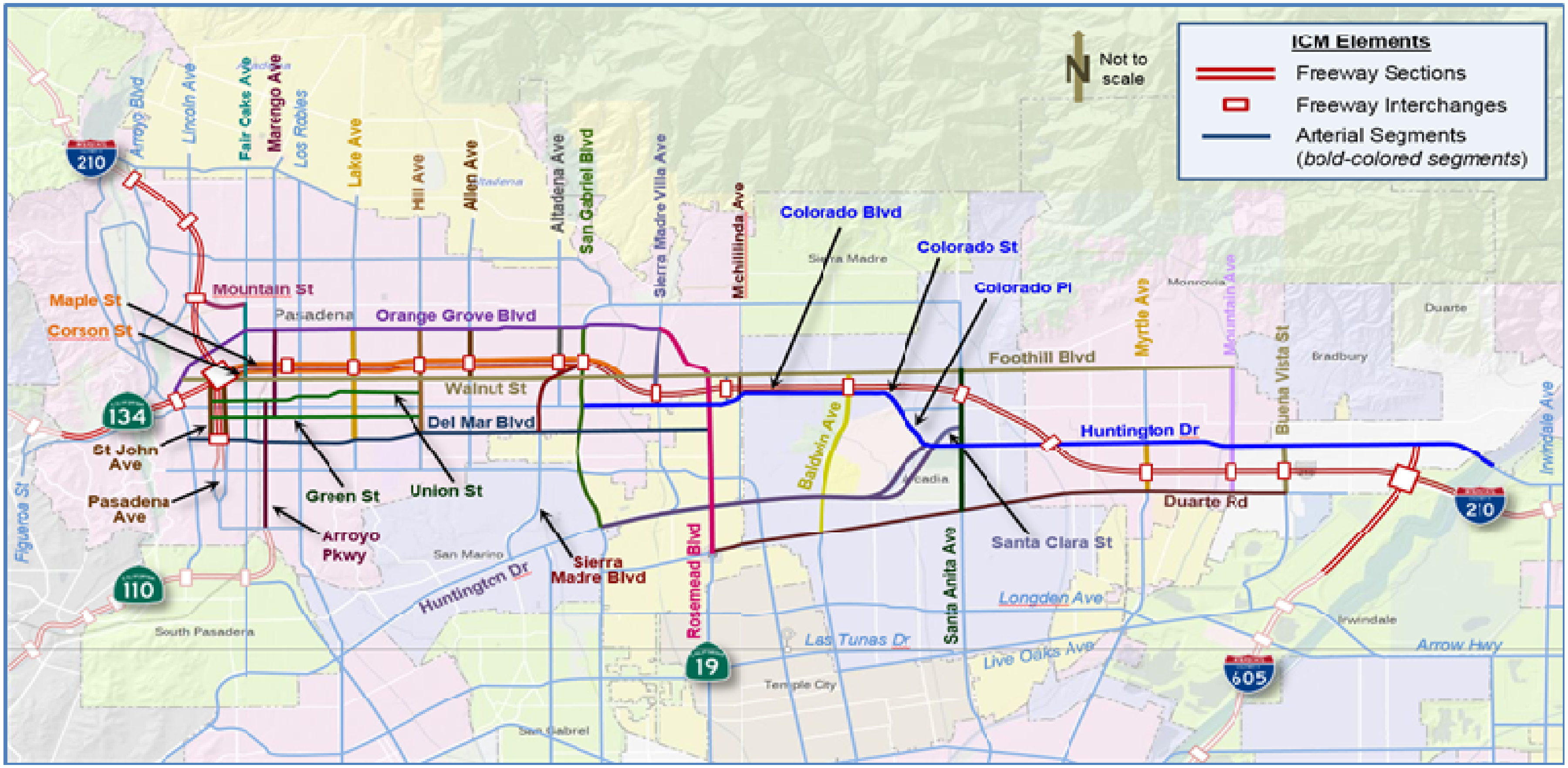
# USDOT ICM Program (3)

## I-15 ICM Corridor, San Diego, CA



# I-210 ICM Corridor – Los Angeles

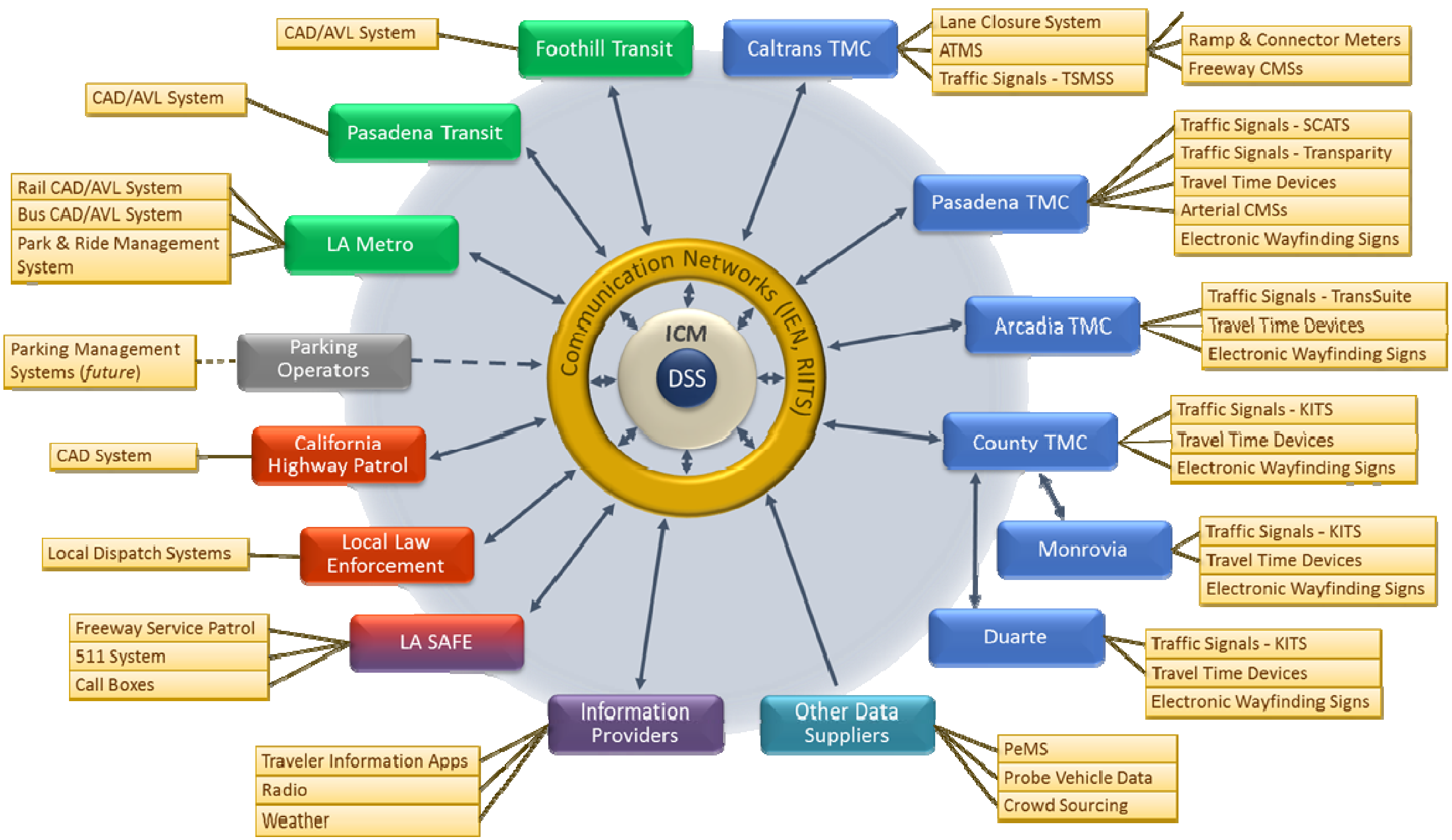



**14 fwy miles-62 metered ramps**

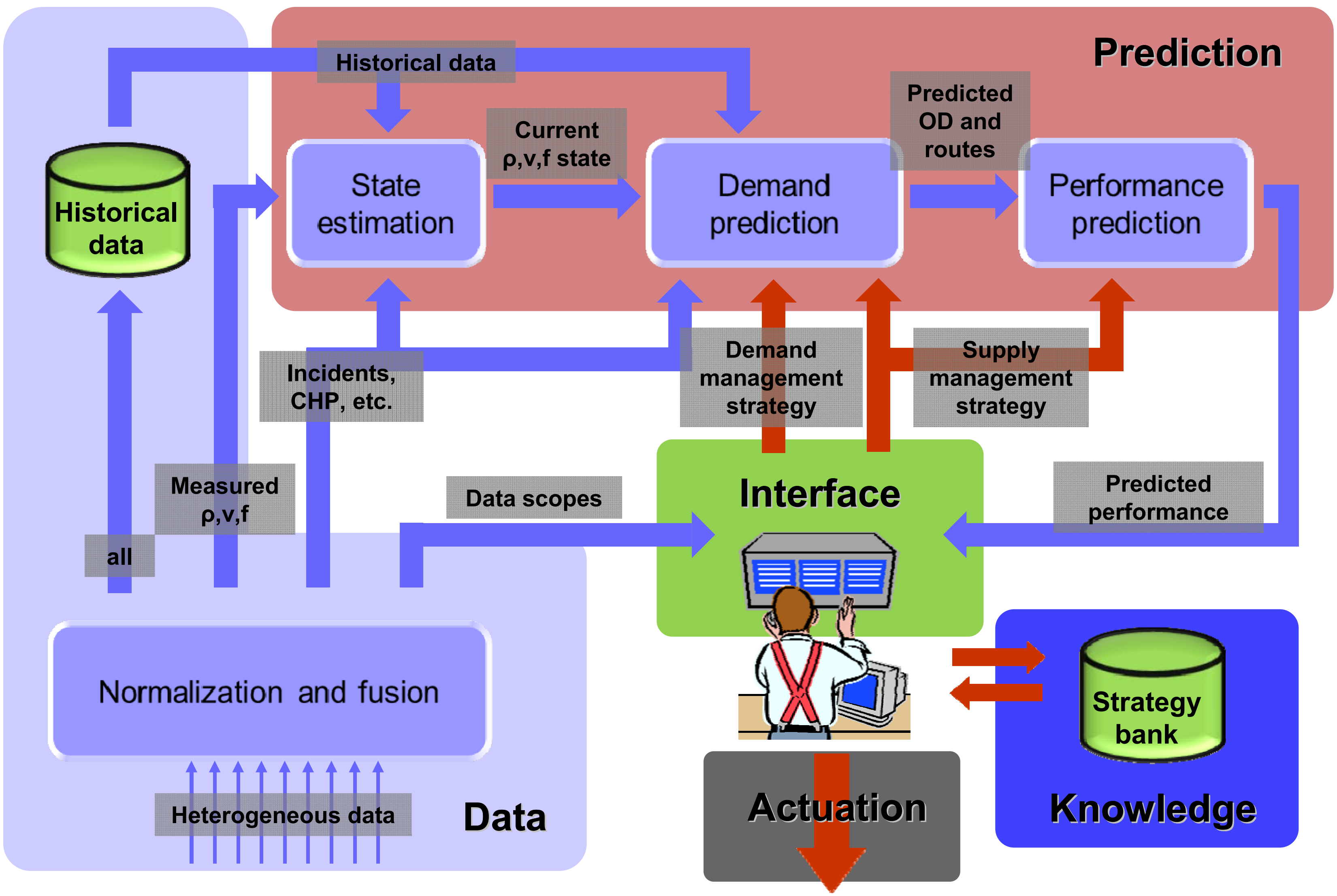
**450 signals**

**Multimodal: Light rail line + 35 bus lines**

# I-210 ICM: Data Sources

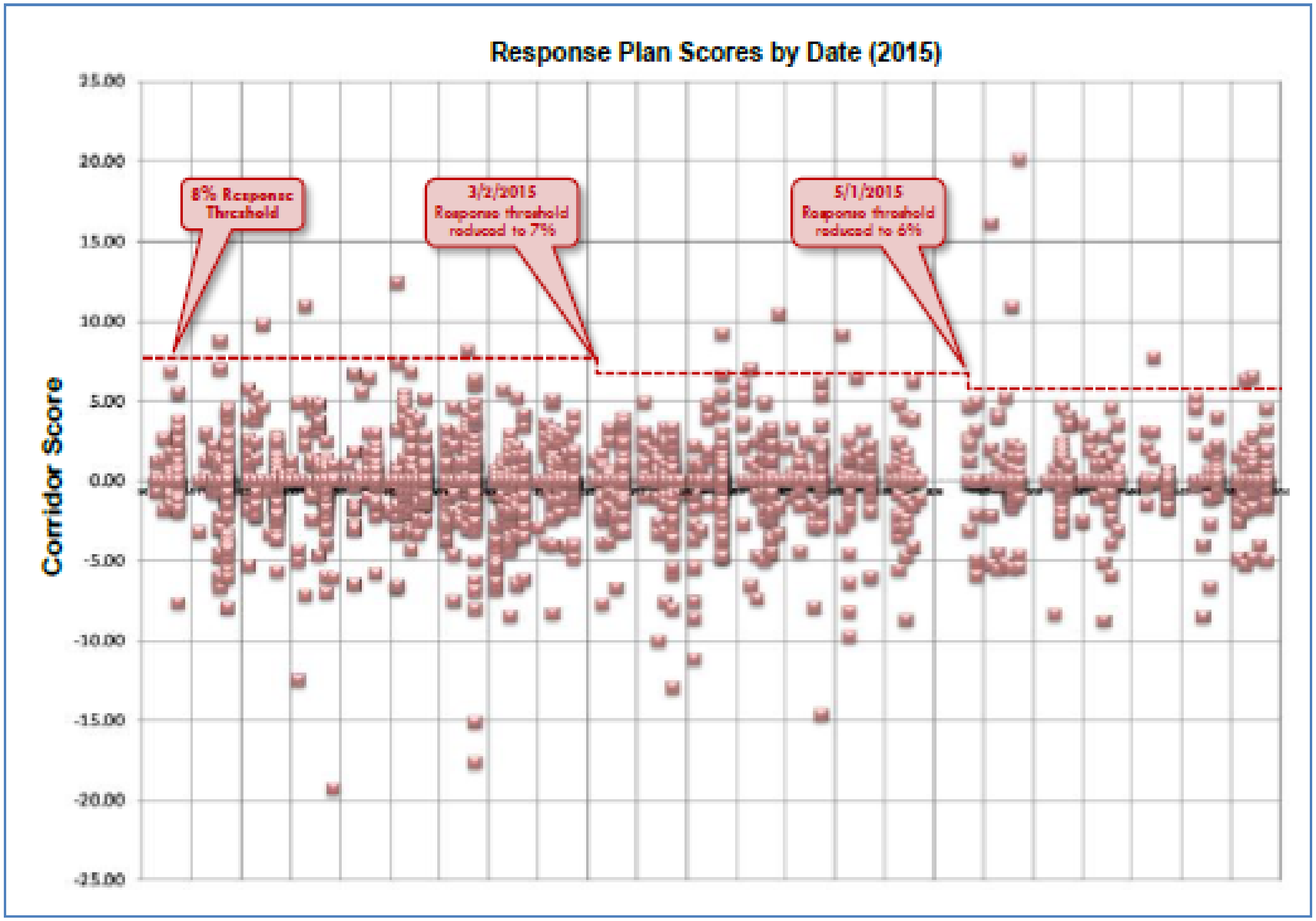


# CA CC I-210: Decision Support



# Example: San Diego DSS

**Example: Activate Response Plan when *predicted* travel time increase > x %**

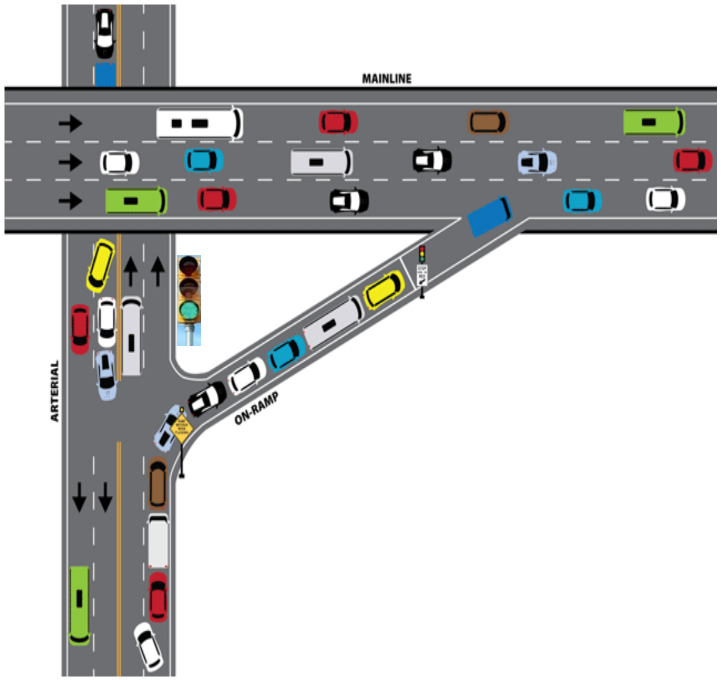


# ICM Programs: Lessons Learned

- Multimodal operations
  - Coordination gaps (real-time)
- Agencies Cooperation
  - Institutional constraints
  - Sharing information vs. sharing control
- Data
  - Data Sources/Types
  - Data Processing/Integration
- Impacts
  - Limited Field Tests
  - Benefits Reporting
  - Assessment of Corridor Component Strategies

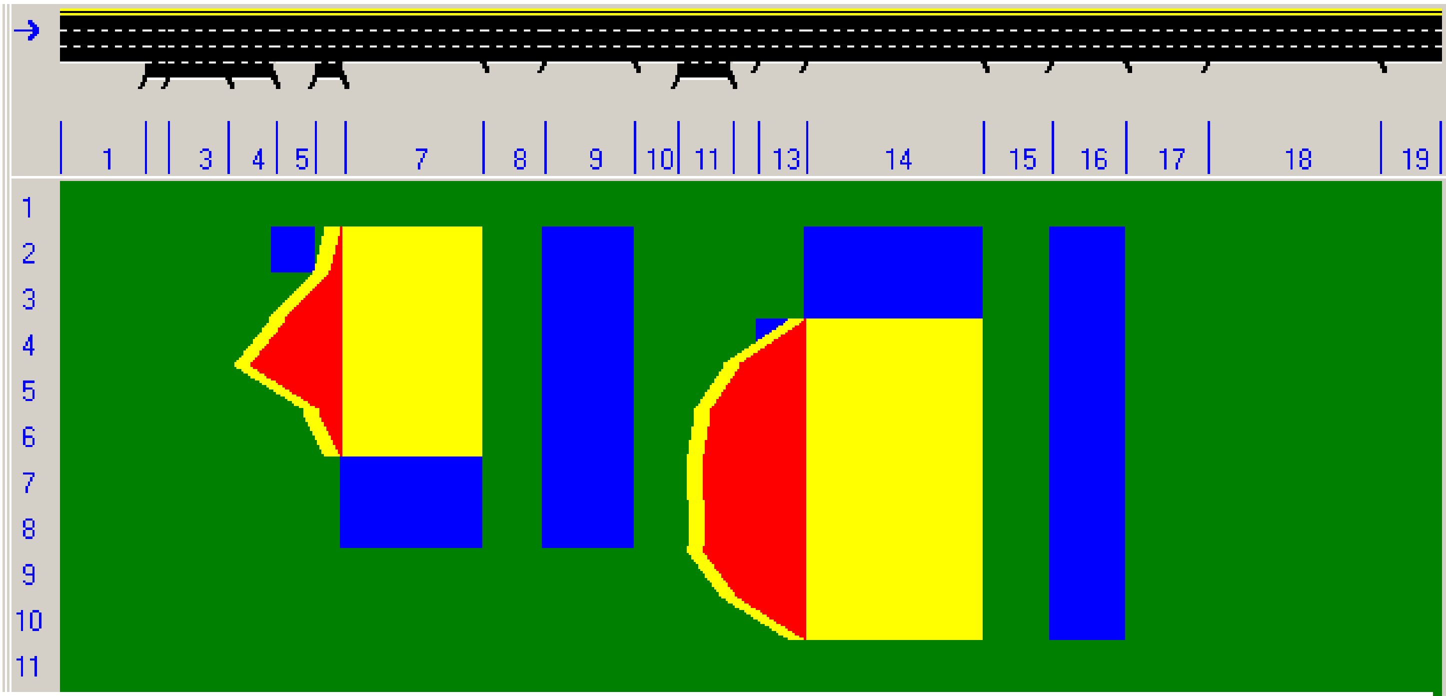
# Freeway – Arterial Coordination

- 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”



# Background: Freeway Ramp Metering

## 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**

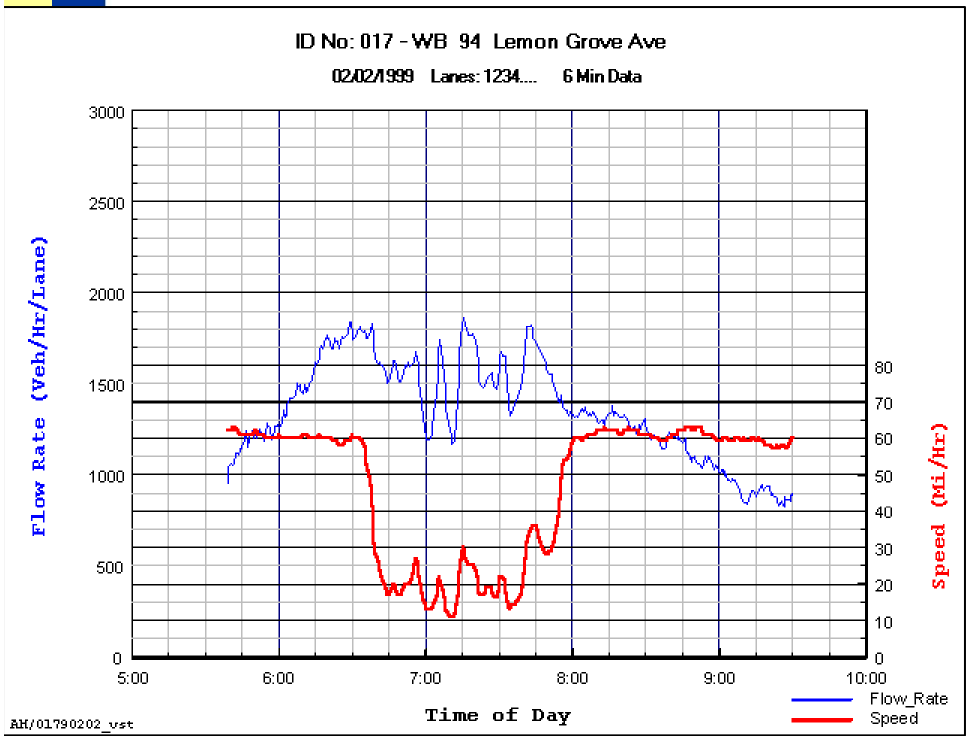
**$C_j$ : capacity of freeway segment j**

# Ramp Metering Impacts (1)

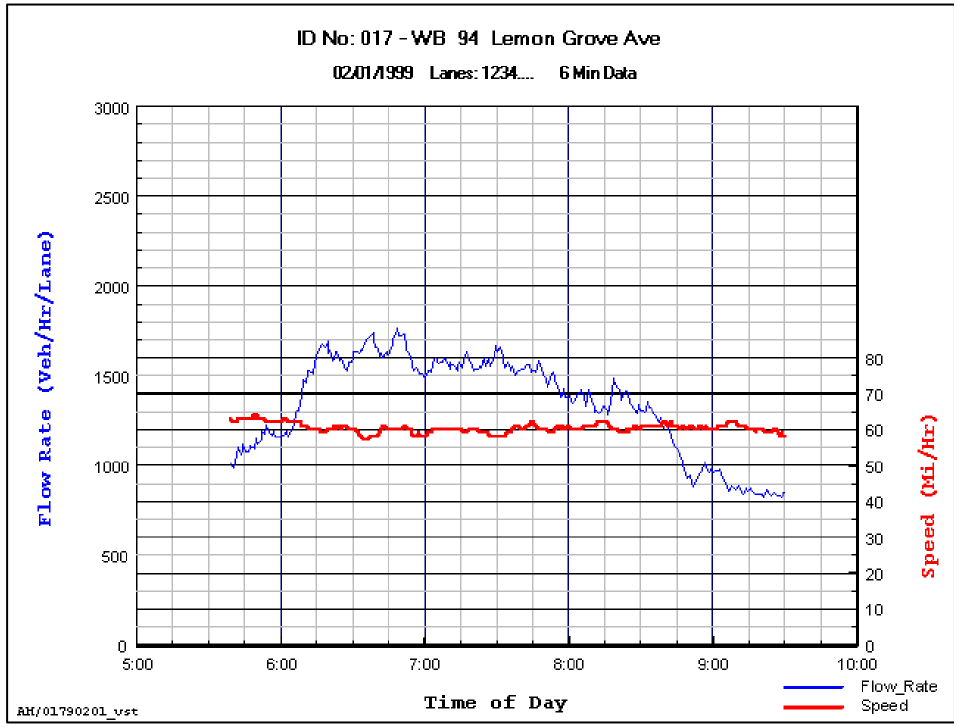
**Freeway:**

- **Maximize freeway throughput**
- **Minimize time spent**
- **Preserve freeway capacity**

## Fwy mainline: no metering




## Fwy mainline: metering

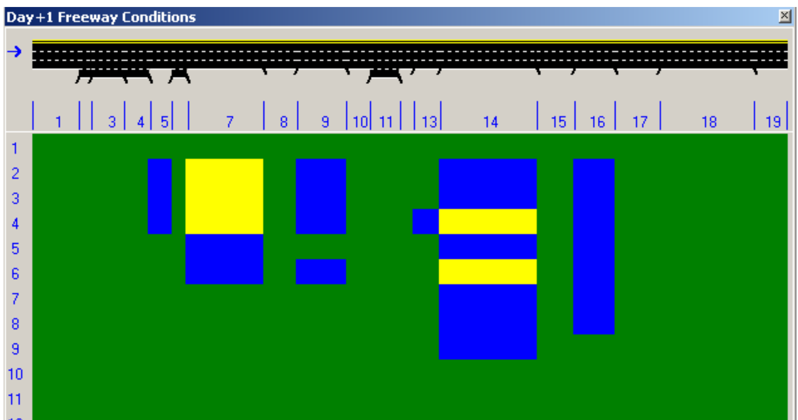


# Ramp Metering Impacts (2)

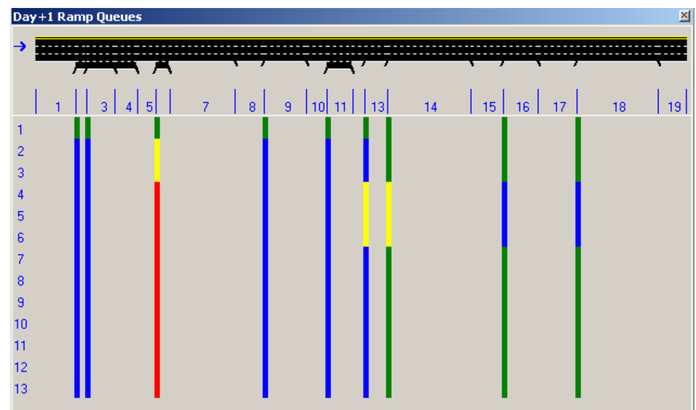
**On-Ramps:**

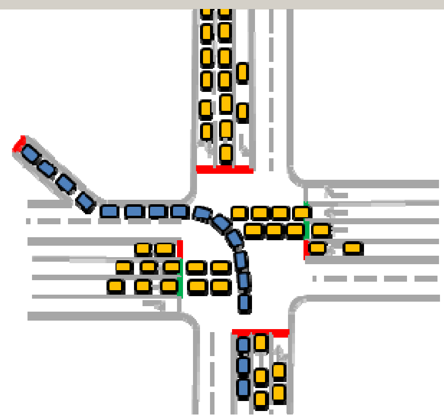
- **Excessive delays to on-ramp vehicles**
- **Spillback to local streets**

## Freeway Mainline




## On Ramp Queues



**Queue Override (*Suspend metering*)**

- **Diminishes ramp metering benefits**
- **Capacity drop**

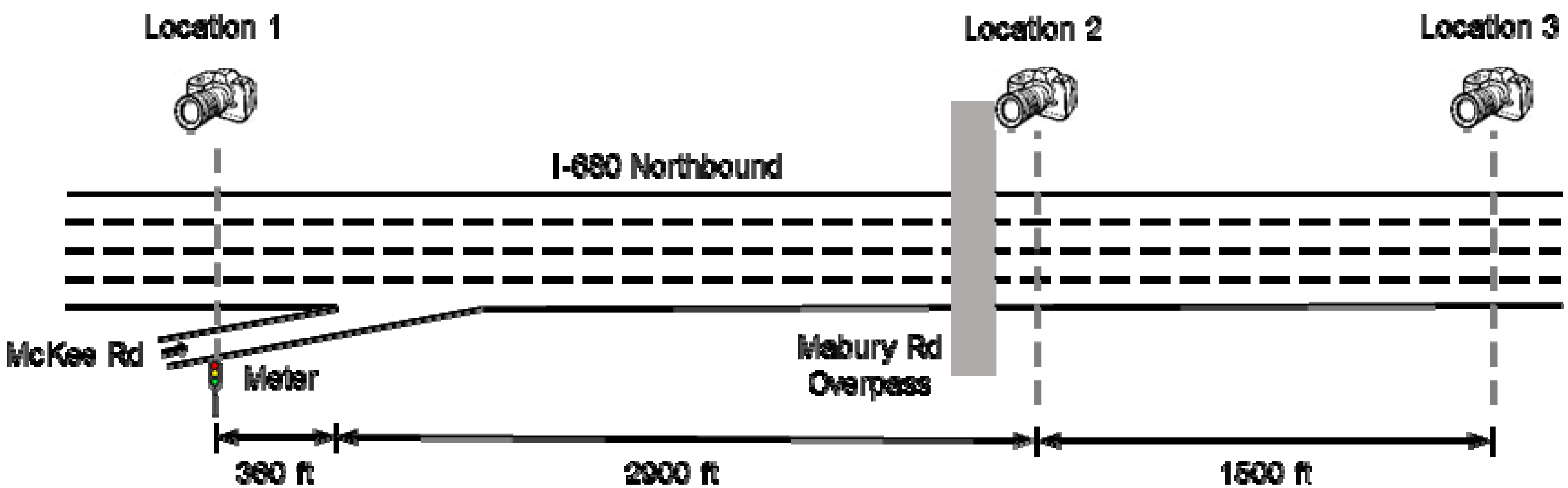
# Field Study: Impacts of Queue Override (1)

## Study Location:

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

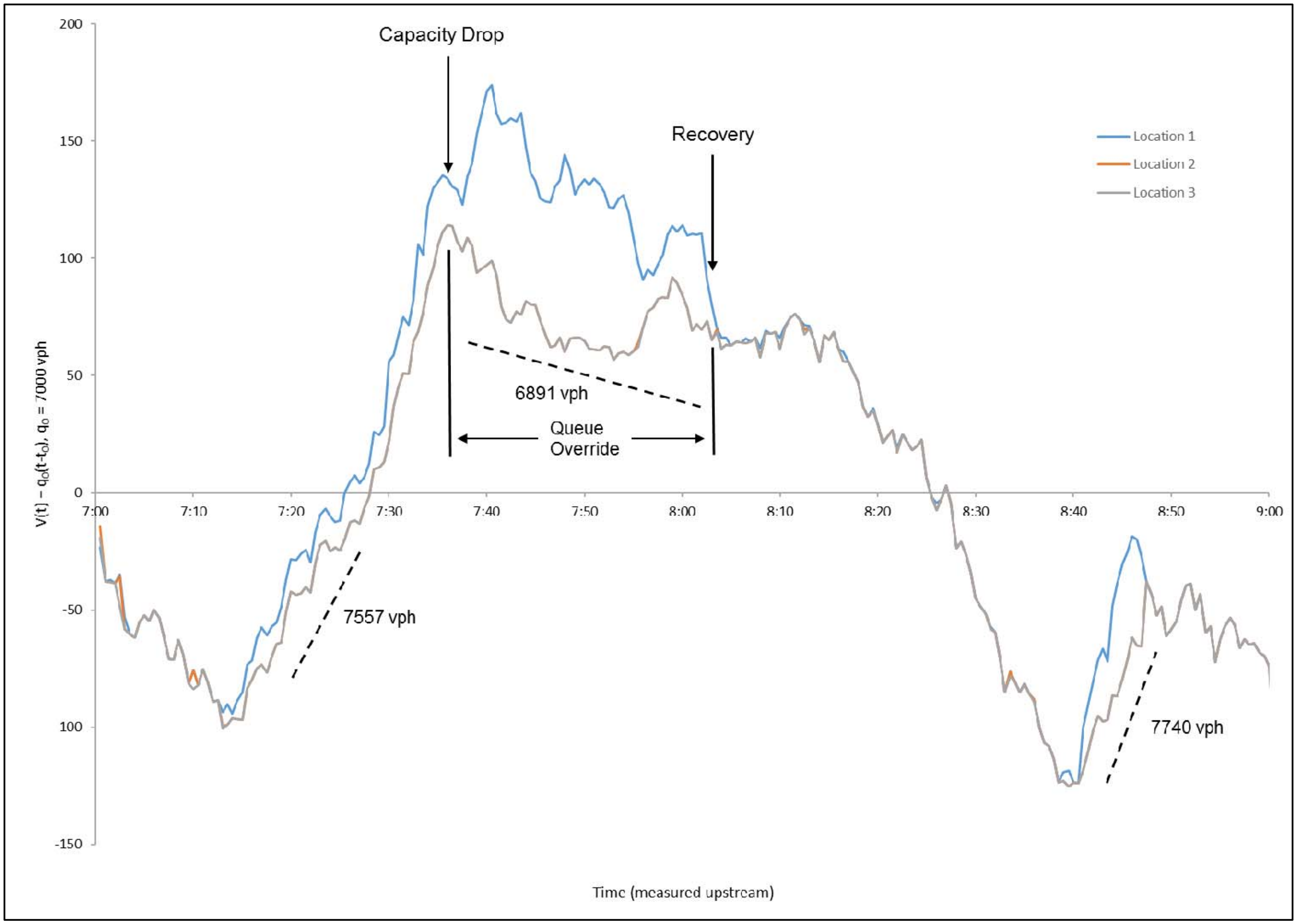
## Time Period:

- Weekdays (May 9 – My 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)

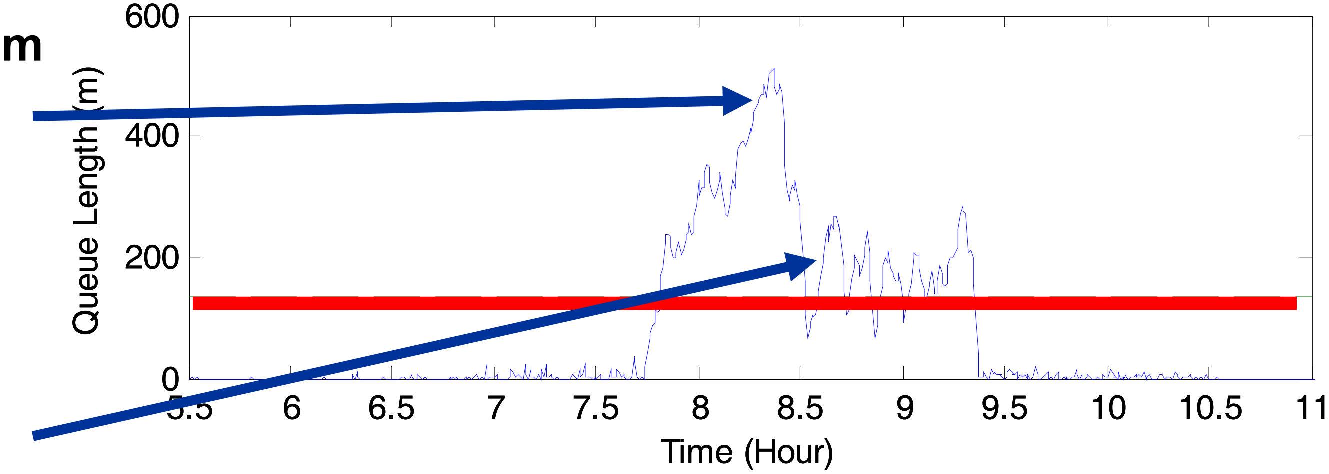
| | Total Outflow (Mainline and On-ramp) | | |
|---|---|---|---|
| | **Before Queue Override** | **After Queue Override** | **% Difference** |
| Week 1 | | | |
| May 9 (Monday) | **Not Activated** | | **----** |
| May 10 (Tuesday) | **7847 vph** | **6891 vph** | **-12.81%** |
| May 11 (Wednesday) | **6752 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%** |

# On-Ramp Queue Control Regulator

**Existing RM Algorithm**

- **failed to limit the queue within the limits**
- **large variation in queue length**

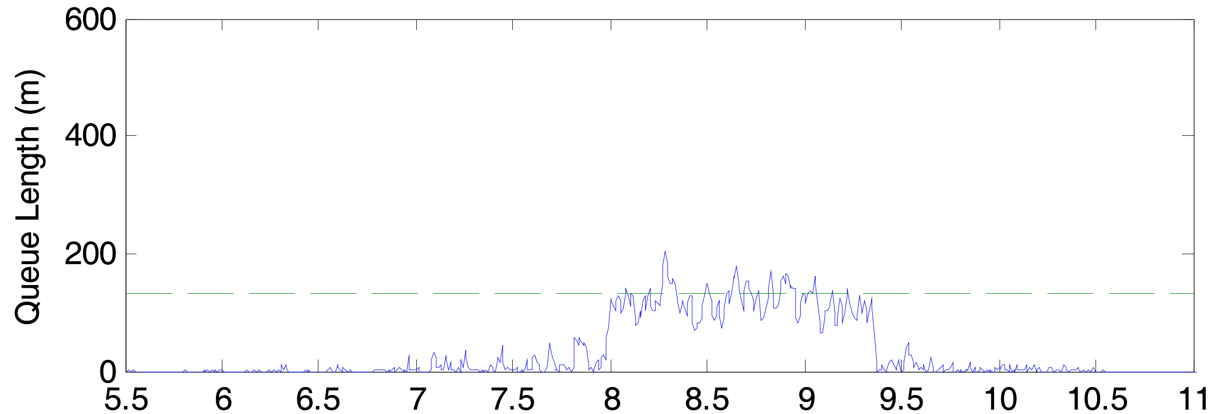
## Queue Override



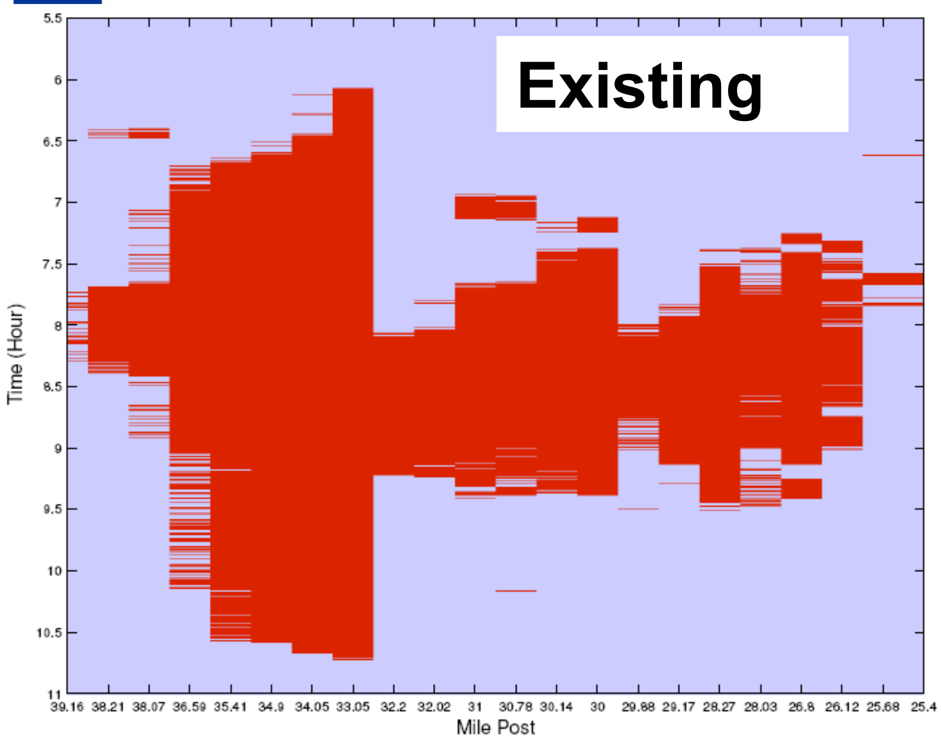

**Proposed RM Algorithm**

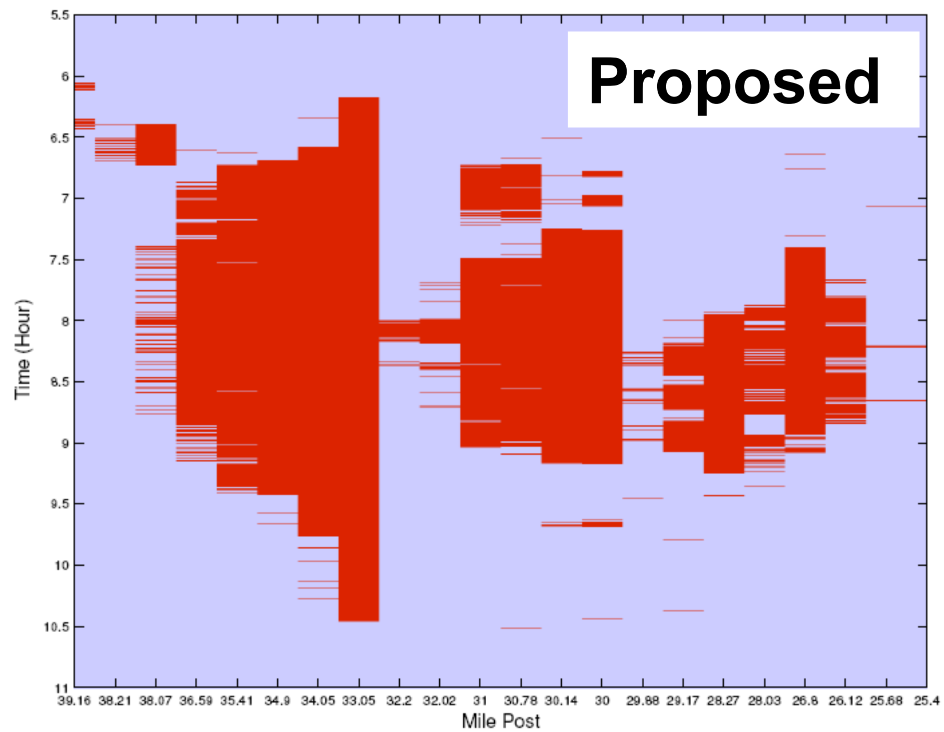
- **RM rate considers on-ramp queue length (measured in real time)**

## Queue Estimation & Control



# Application: Los Angeles I-210W



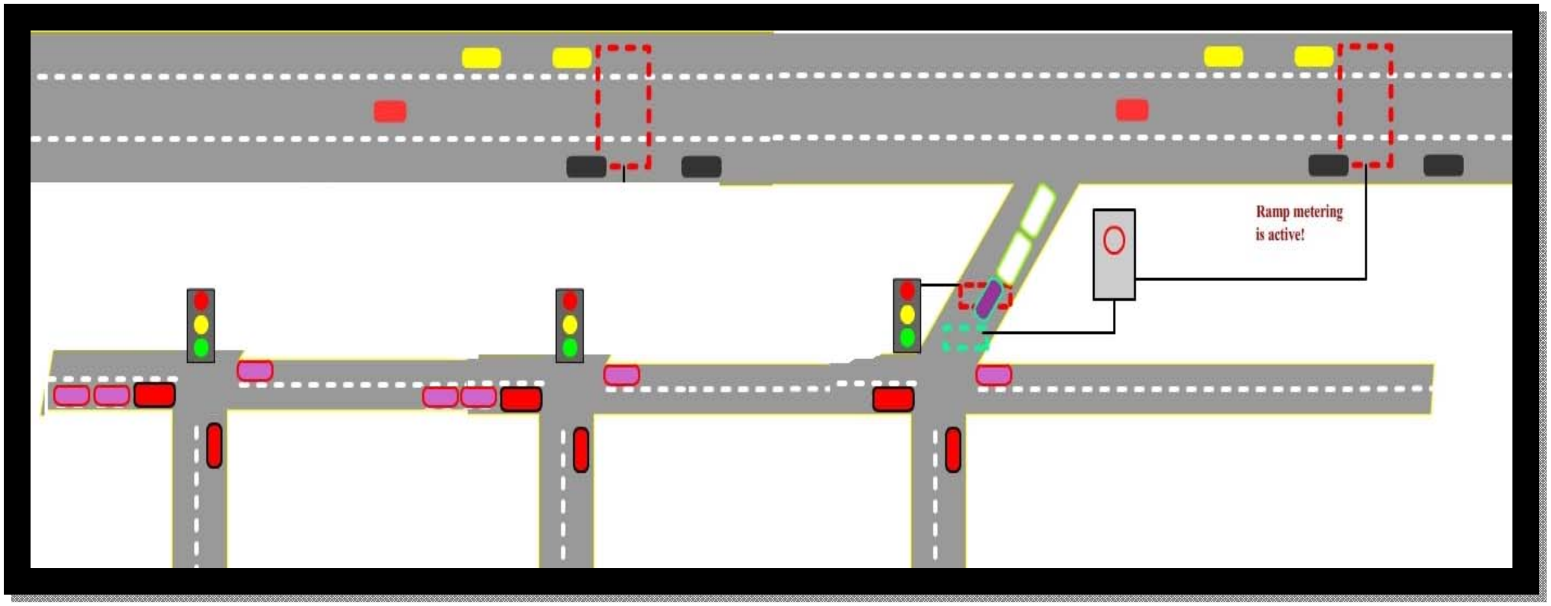

**Improvements:** **6% Travel Time/ 16% Delay Reduction**

***"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, 2011**

# Proposed on-Ramp Access Control (1)

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




## Constraints

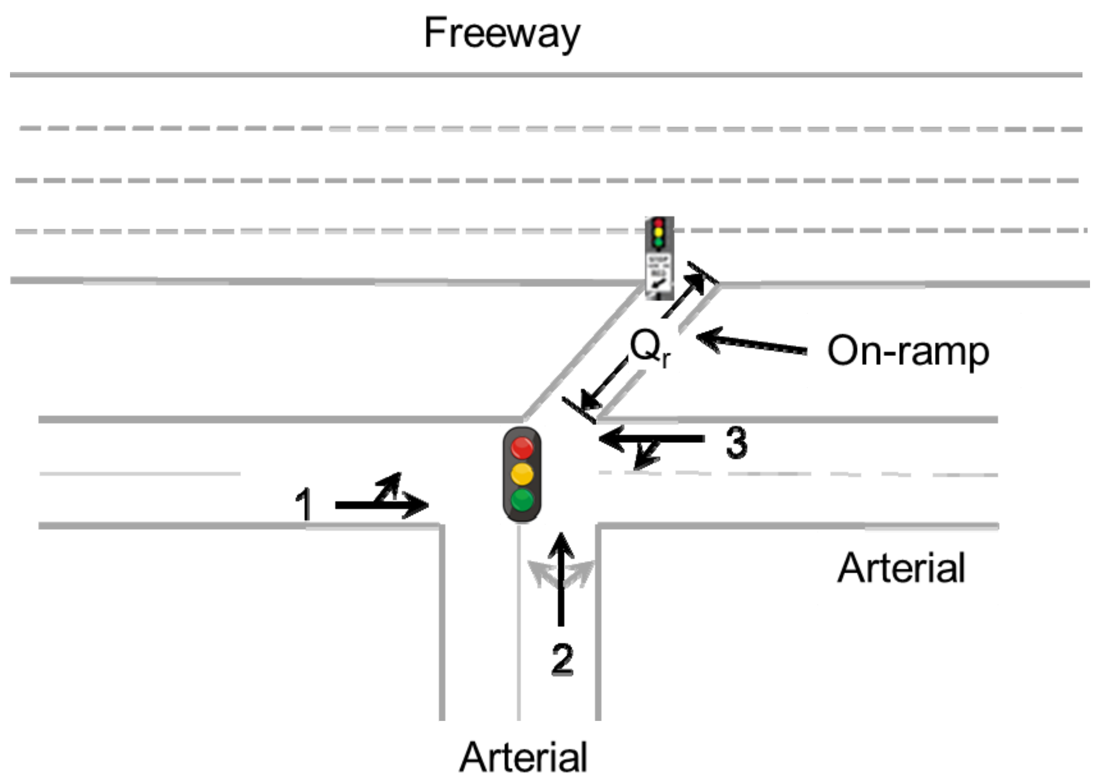
**Serve the traffic demand on arterial phases**

**Arterial link storage (arterial spillback)**

**Minimum phase green times**

# Proposed on-Ramp Access Control (2)

- Mitigate both on-ramp and arterial spillback
- Example signalized intersection near freeway on-ramp



# Proposed on-Ramp Access Control (3)

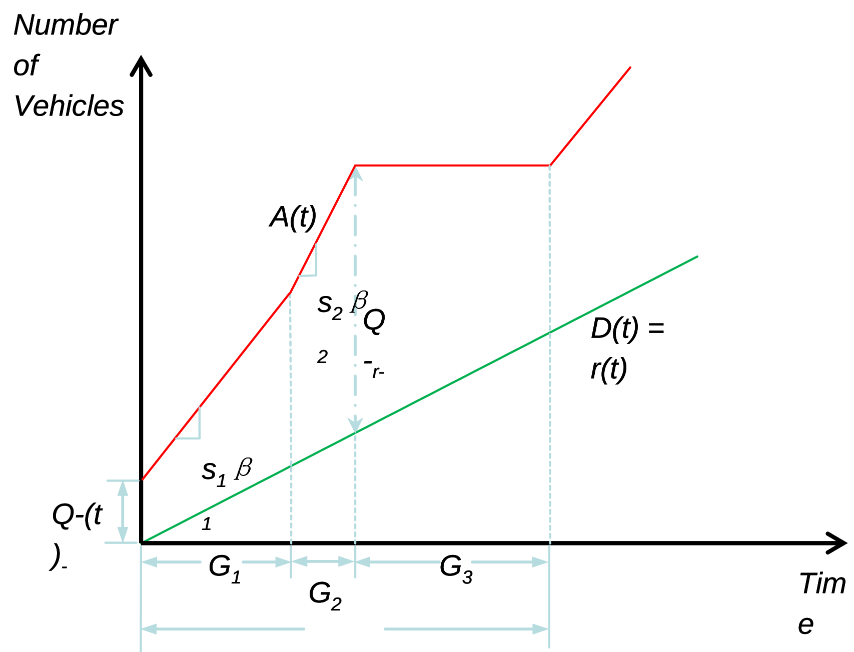
- $Q(t) + G_1 \cdot s_1 \cdot \beta_1 + G_2 \cdot s_2 \cdot \beta_2 - G_1 \cdot r(t) - G_2 \cdot r(t) \leq Q_r$

Residual on-ramp excess accumulation: $Q(t)$

Upstream arrival: $G_1 \cdot s_1 \cdot \beta_1 + G_2 \cdot s_2 \cdot \beta_2$

Downstream departure: $G_1 \cdot r(t) + G_2 \cdot r(t)$

Available queue storage: $Q_r$



# Proposed on-Ramp Access Control (4)

- On-ramp residual queue estimation:

$$Q(0) = 0$$

$$Q(1) = Q(0) + A(1) - D(1)$$

$$\vdots$$

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

- Green time distribution:

$$g_1 = \frac{y_1}{Y} \cdot (C - 3l)$$

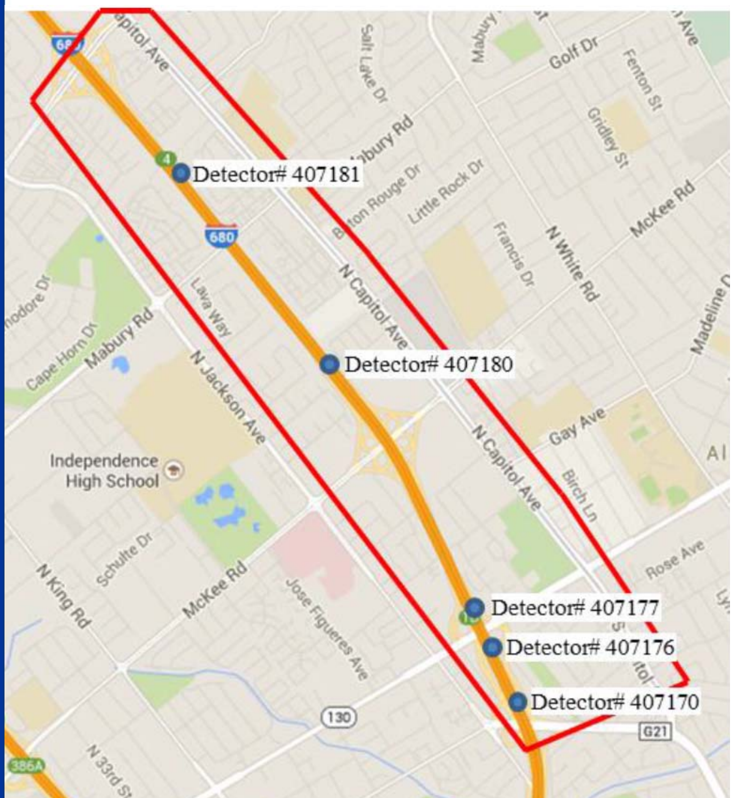
$$g_2 = \frac{y_2}{Y} \cdot (C - 3l)$$

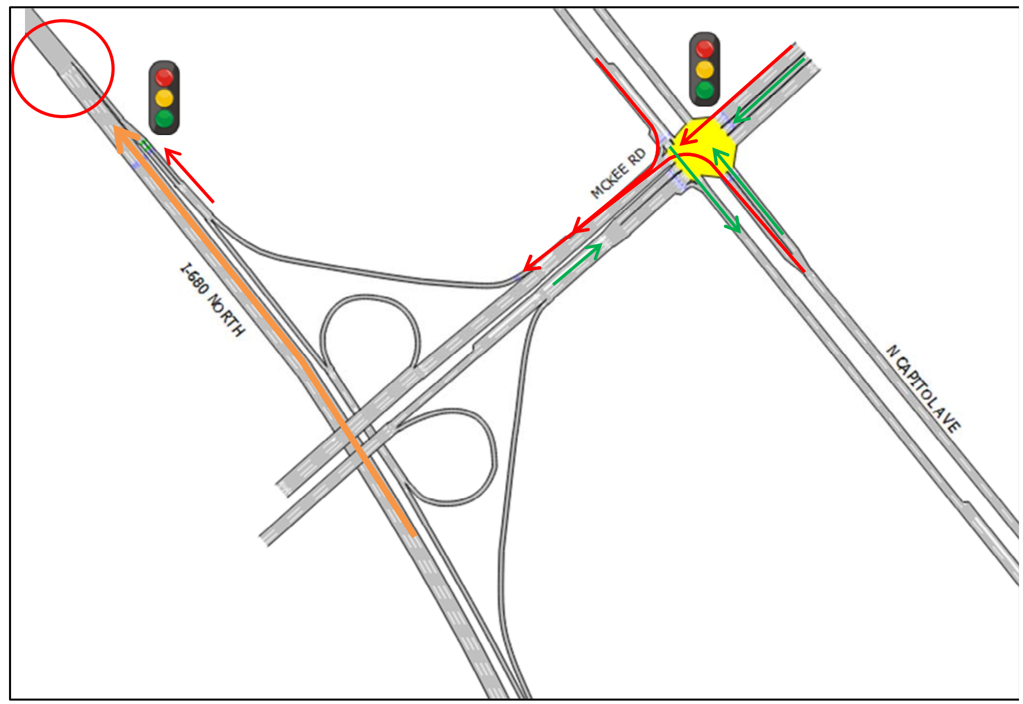
- Cycle length upper limit:

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

# Application: Simulation Test (1)

**Test Site:**
**NB I-680, San Jose CA**




- **AIMSUN Microscopic Simulator**

# Application: Simulation Test (2)

Simulation Test s

- Before: adjacent signals operate independent of ramp metering
- After: adjacent signals coordinate with ramp metering

Study Period:

- Date: Wednesday September 23, 2015
- Time of day: 7:00 AM to 9:30 AM

Input Data

- Freeway: detector data from PeMS and video recordings
- Arterial: manual counts and video recordings

Calibration:

- Loop Detector data: Bottleneck locations, volumes
- INRIX: Travel times

# Application: Simulation Test (3)

| | Before Coordination | | After Coordination | | % 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 | **799.06** | **37295.75** | **655.81** | **37788.13** | **-17.93%** | **1.30%** |
| 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%** | |
| Total System | | | | | | |
| | **Total Delay (veh-hr)** | | **Total Delay (veh-hr)** | | **Change in Total Delay** | |
| Freeway & Arterial | **2847.02** | | **2642.36** | | **-7.19%** | |

# Updated Simulation Results

# Updated Simulation Results

## AIMSUN Model Limitation

- AIMSUN cannot replicate capacity drop, underpredicts queue override avoidance benefits
- Modified AIMSUN version
  - Based on acceleration/deceleration asymmetry
  - Calibrated with NGSIM data
  - Used in CACC Modeling

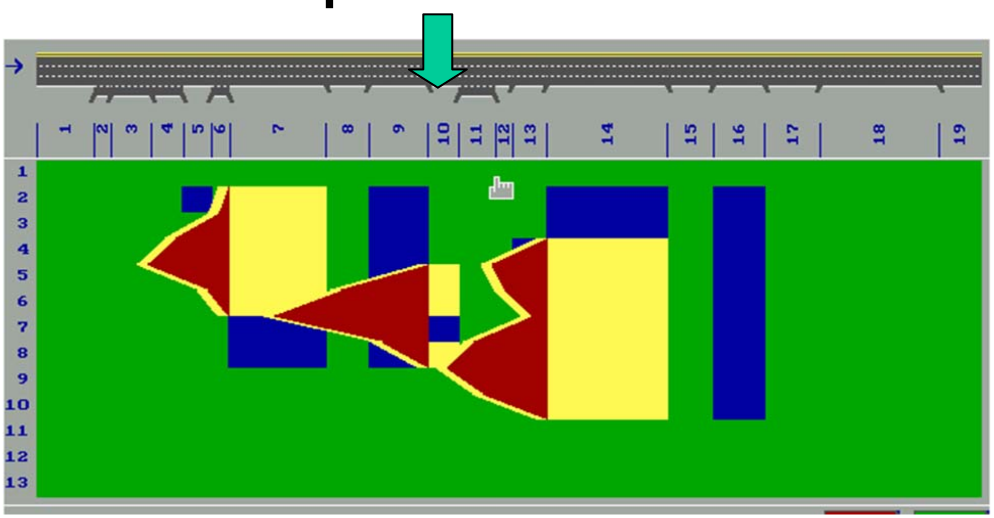
| | Before Coordination | | After Coordination | | % Difference | |
|---|---|---|---|---|---|---|
| **Freeway Mainline** | | | | | | |
| | Total Delay (veh-hr) | Total Distance Traveled (veh-mile) | Total Delay (veh-hr) | Total Distance Traveled (veh-mile) | Change in Total Delay | Change in Total Distance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

# Non-Recurrent Congestion: Diversion Strategies

- **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**

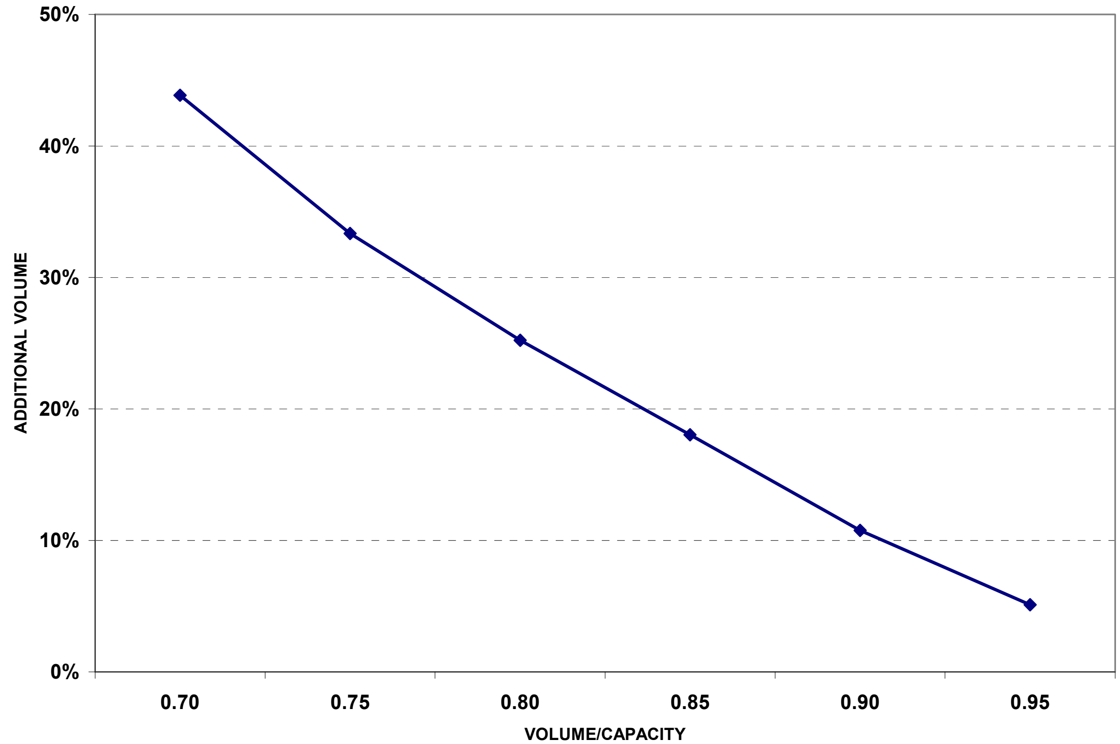

**Incident Upstream of Bottleneck**



# Diversion: A Planning for Operations Approach (1)

**Maximum Amount of Diverted Volume? = f(remaining capacity at critical intersection)**

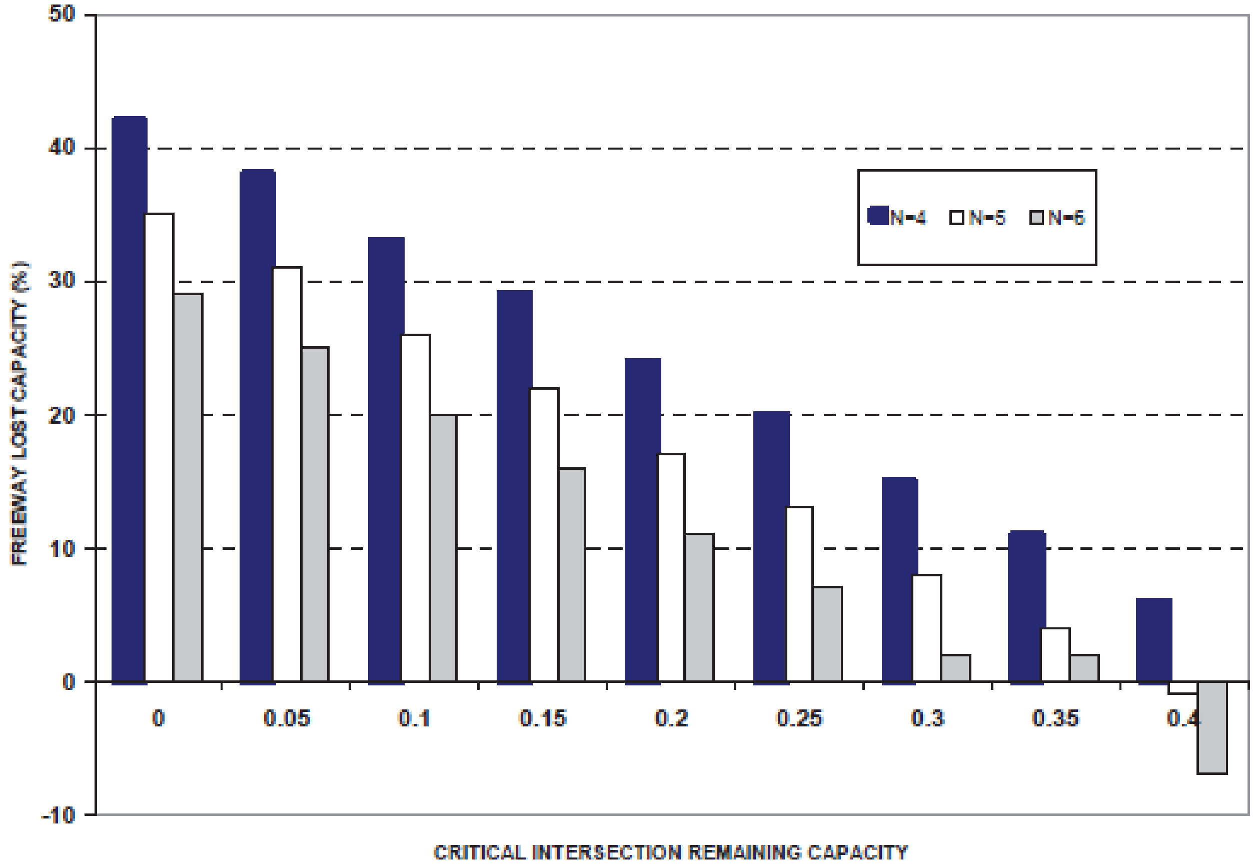
$$dV_i = \frac{RC_i}{X_i} \cdot 100$$




**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: A Planning for Operations Approach (2)




**Freeway Lost Capacity vs. Critical Intersection Remaining Capacity**

# Looking Ahead: CAVs