UFTI Seminar

Control of Freeway Corridors: Objectives, Performance Measures, Strategies

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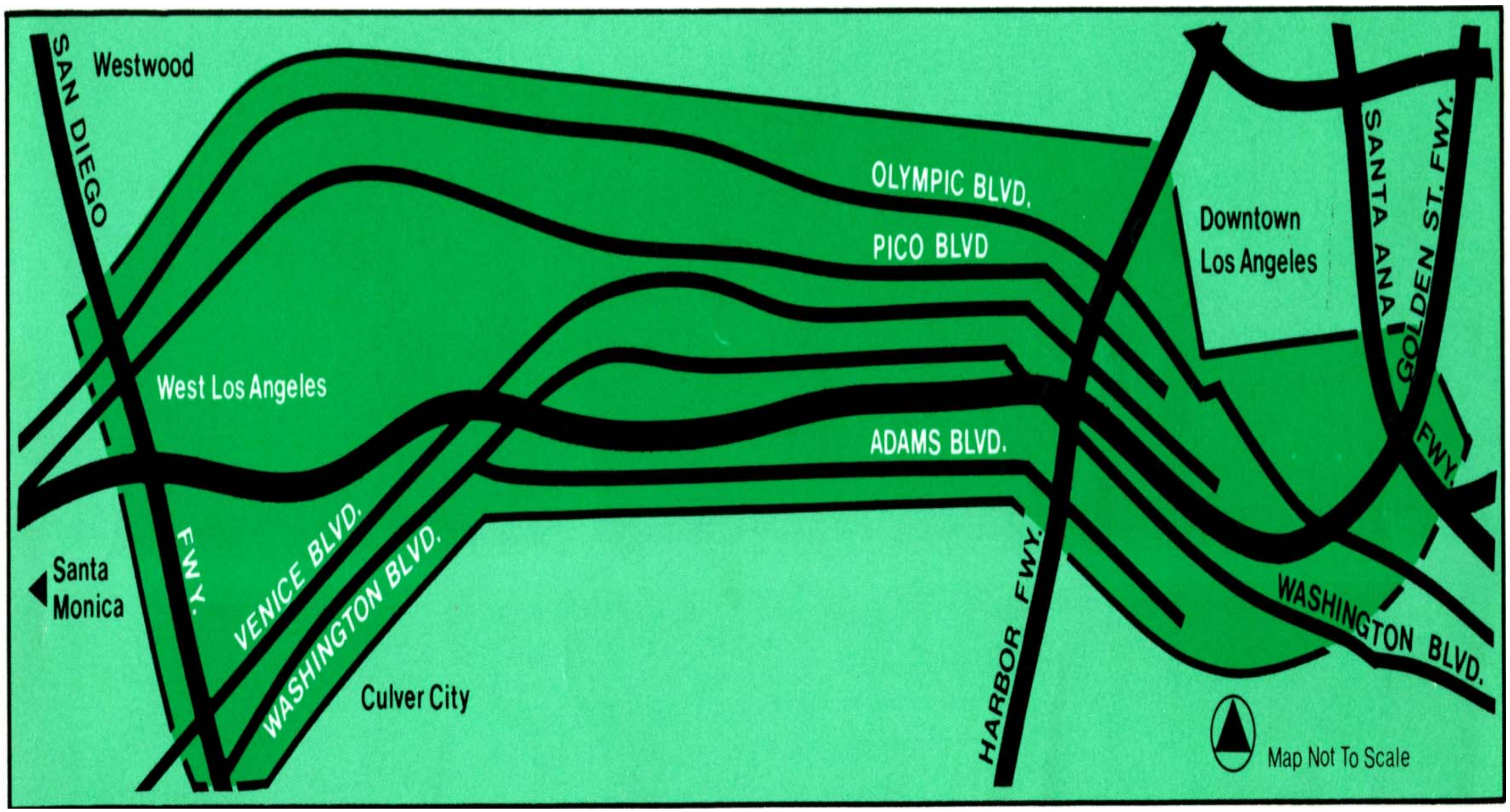
Outline

- Freeway Corridor management
  - Background/Problem Statement
  - National Programs: ICM
- Signalized Intersections: Performance Measurement
- Freeway-Arterial Coordination
- Looking Ahead

Background: Corridor Management

Cooperative management of freeways and adjacent arterial networks

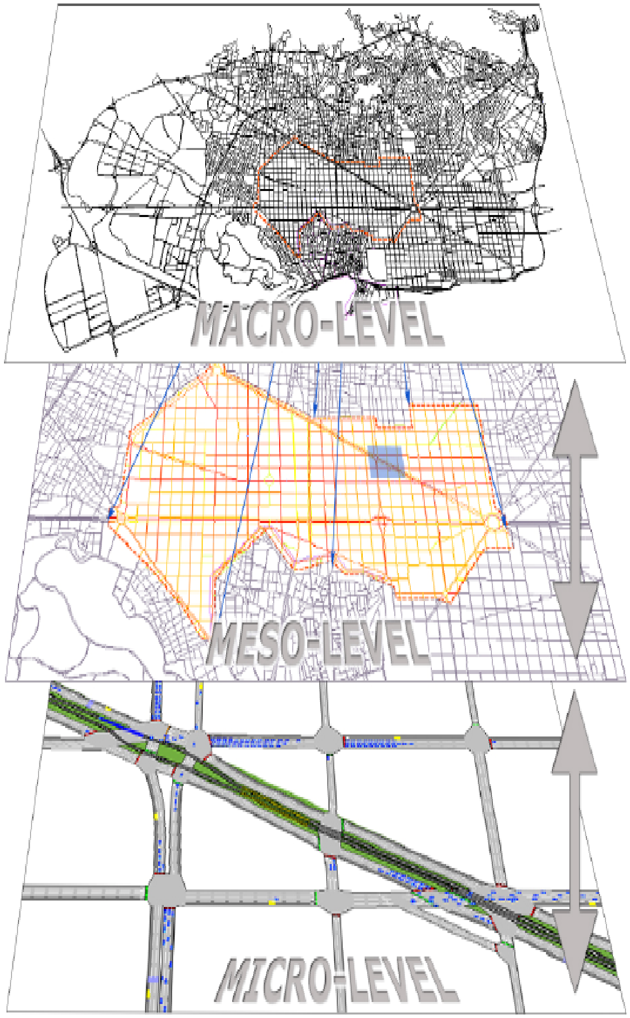
Los Angeles, Smart Corridor 1988



Background: Corridor Management

Corridor Traffic Management & Information Vision

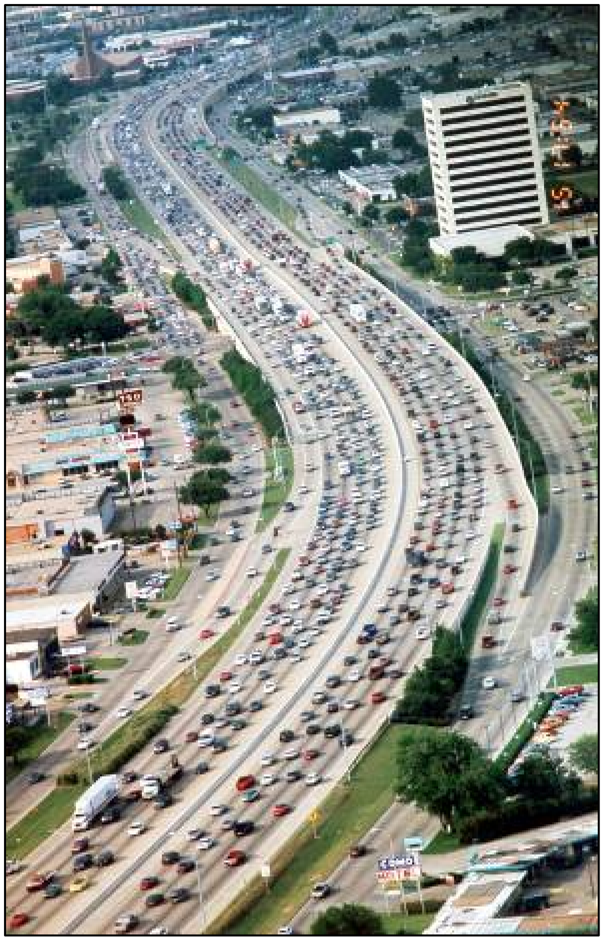
USDOT ICM Program (1)

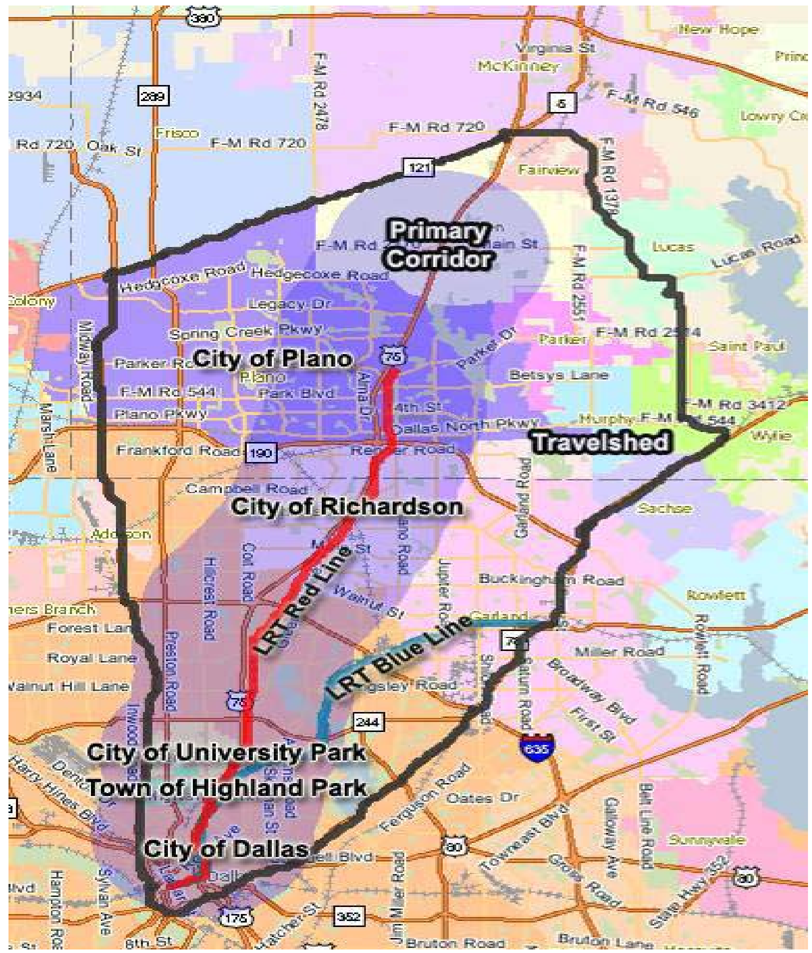


- Multimodal operations
- Complex modeling approaches
- Operational procedures/plans
- Institutional constraints
- Decision support systems
- Limited field evaluation
- Limited research

USDOT ICM Program (2)

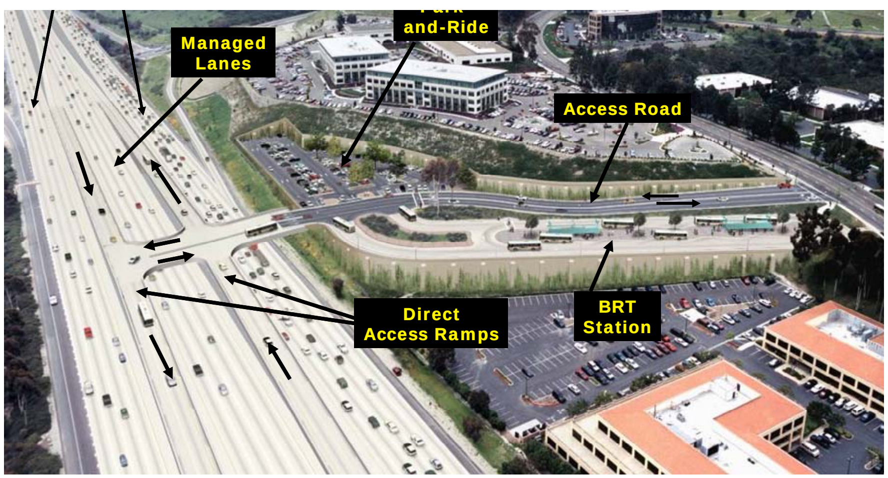
US-75 ICM Corridor, Dallas, TX

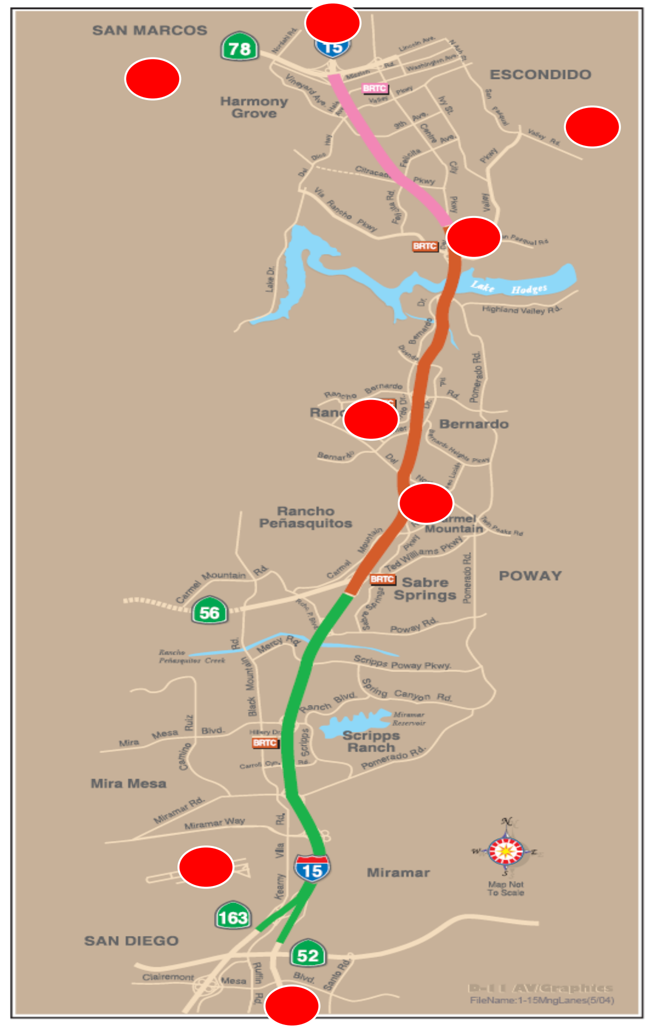




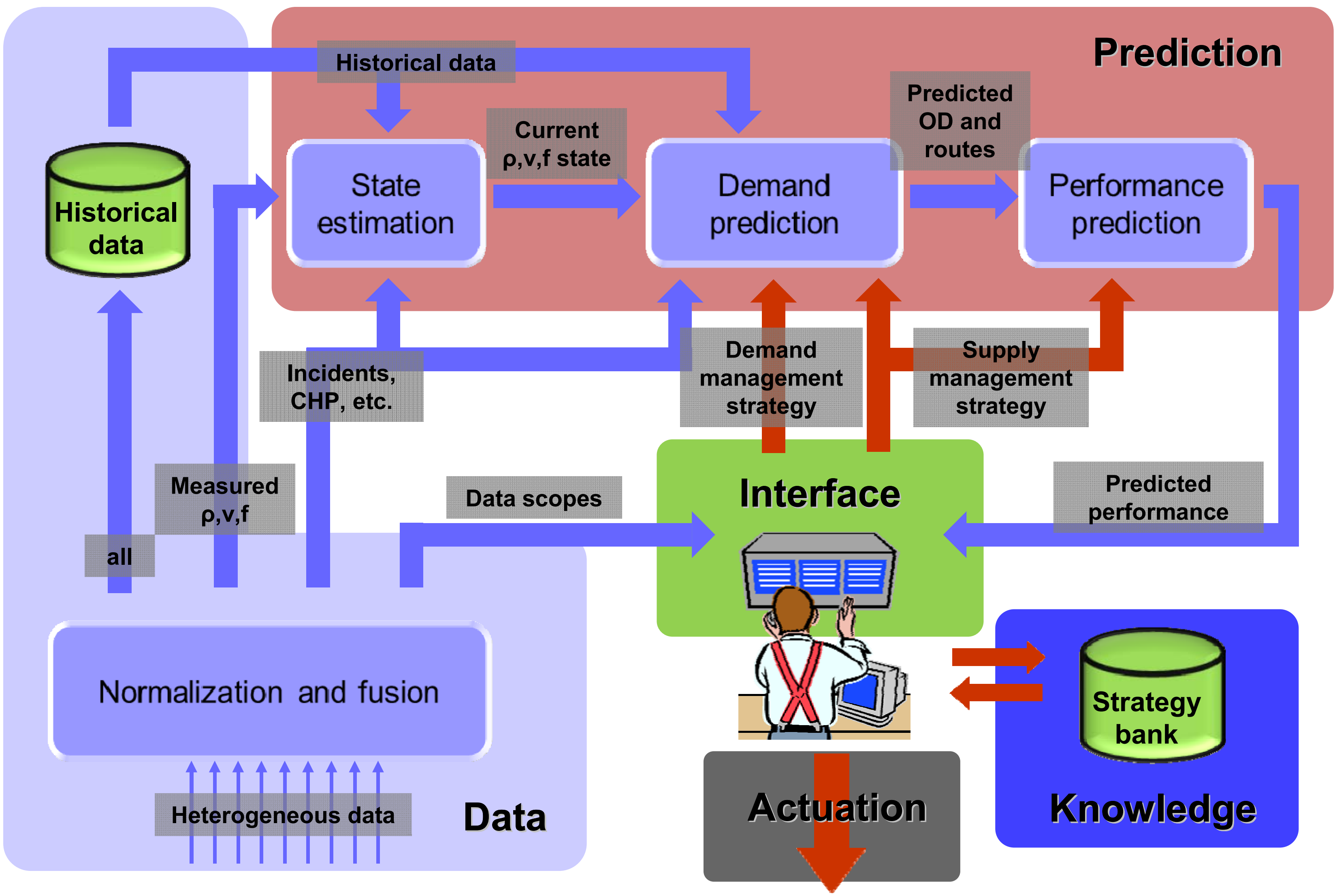
USDOT ICM Program (3)

I-15 ICM Corridor, San Diego, CA





CA CC I-210: Decision Support



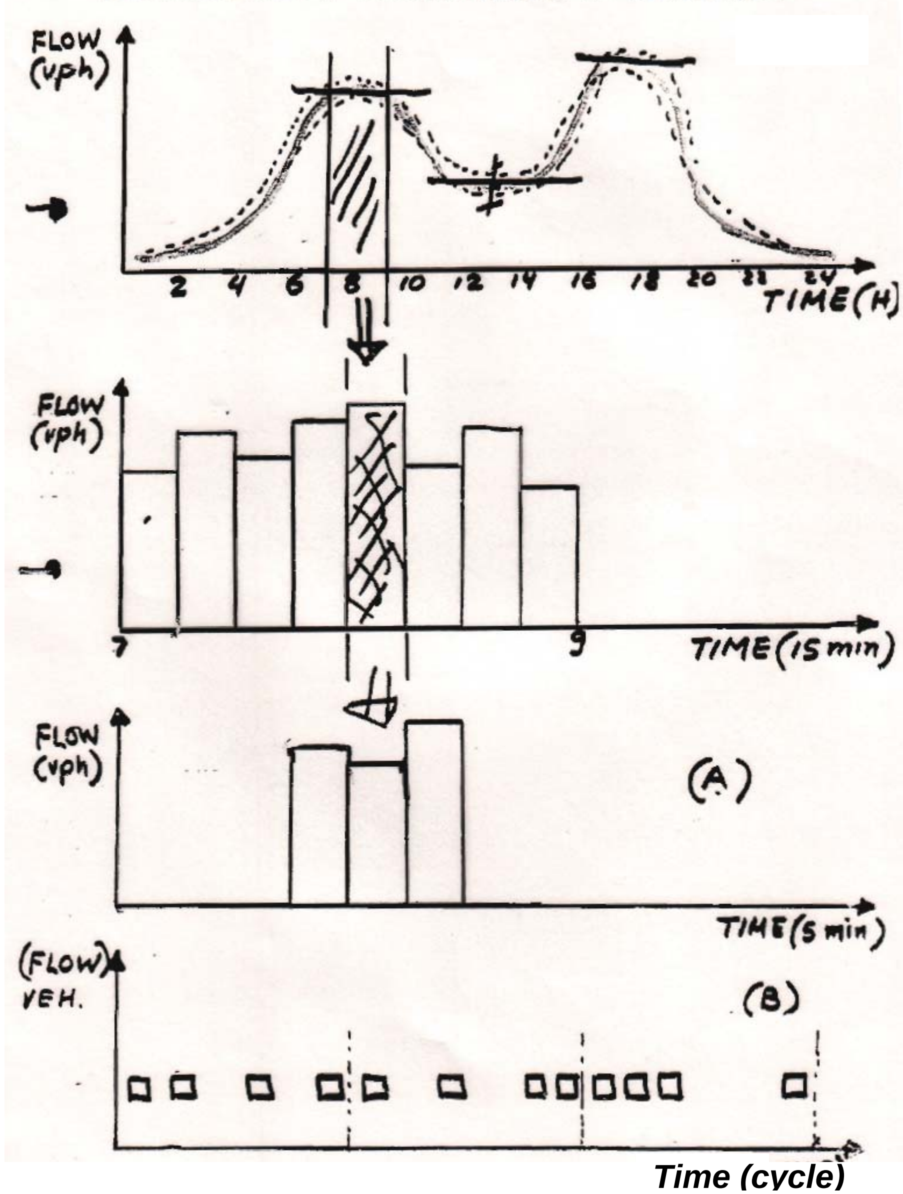
Urban Arterials/Networks: Traffic Flow Variability vs. Control

A
- Fixed-Time Plans
- Time of Day (TOD)
- No Detection
- May be actuated

B
- Fixed time plans
- Traffic responsive plan selection
- System detection

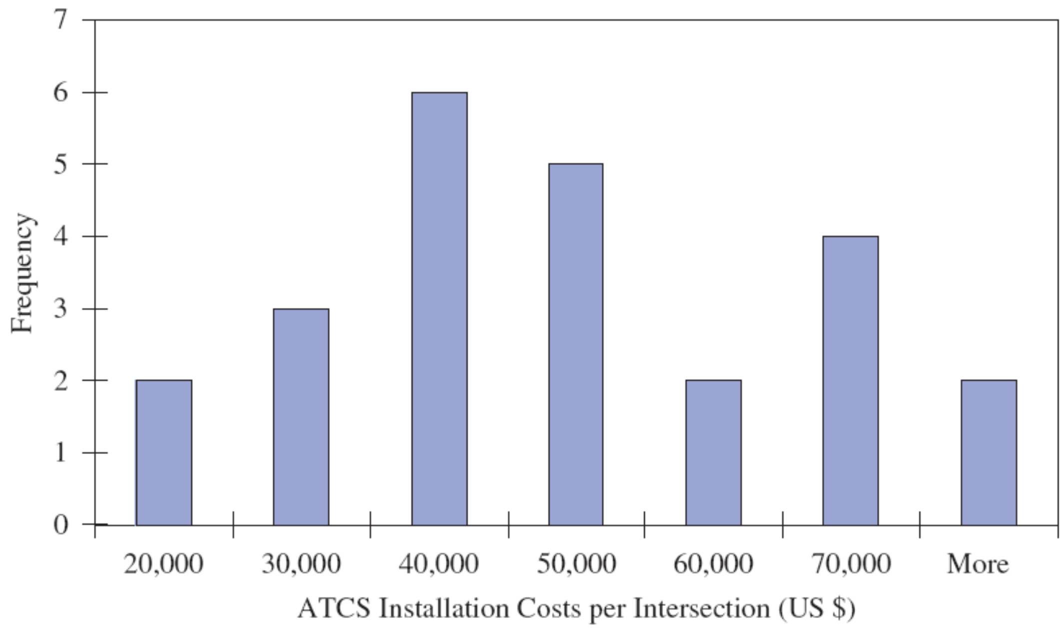
C
- Traffic responsive control
- On-line timing development
- Approach & system detection

D
- Adaptive control
- Measure & predict arrivals per cycle
- Extensive detection



Arterial Networks: Traffic Control

- **Most signal systems fixed-time control**
  - **Limited data**
  - **Out-dated timing plans**
- **Adaptive systems**
  - **High cost**
  - **Complex to understand and operate**



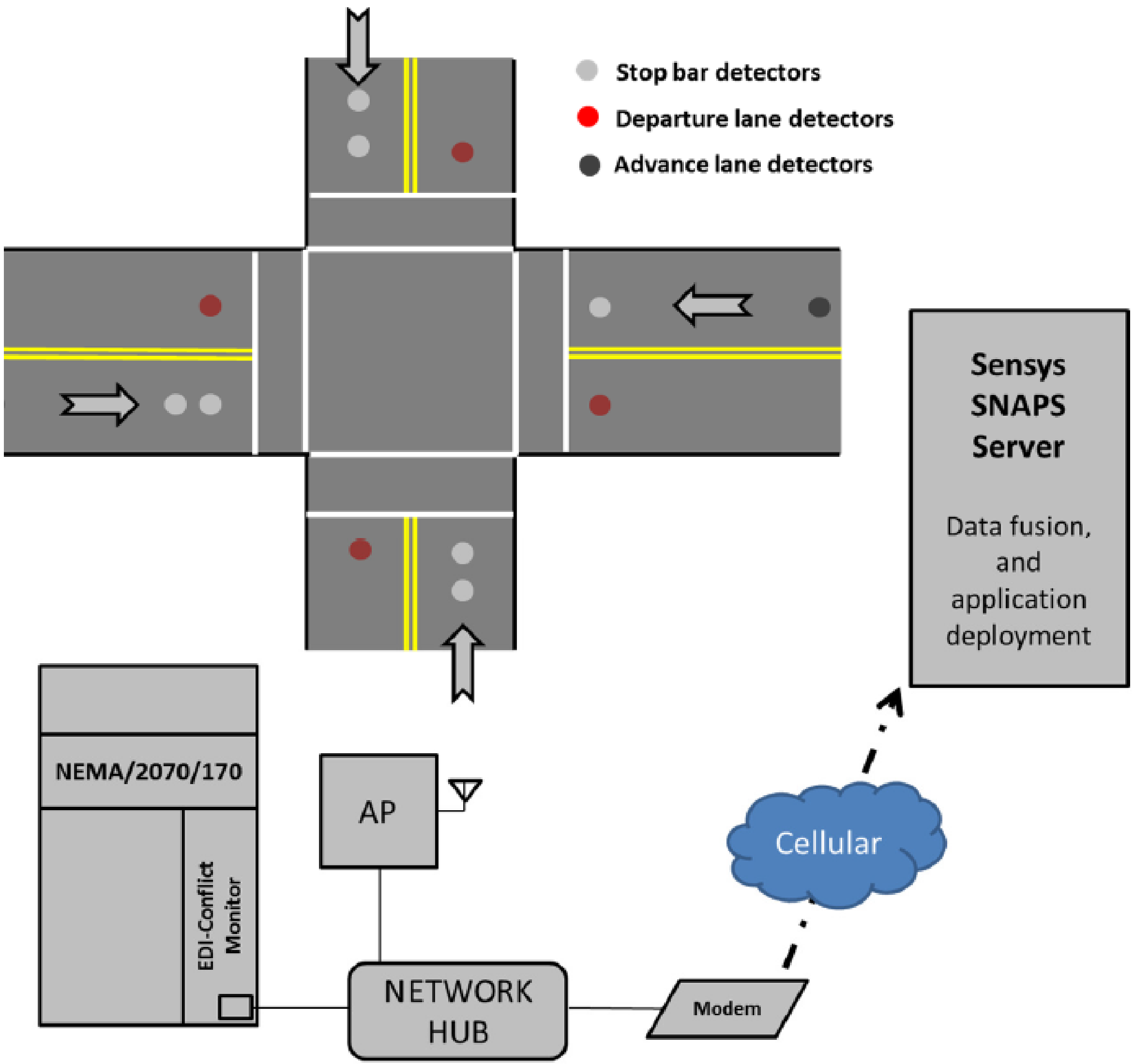
Source: Alek Stevanovic, NCHRP Synthesis 403

Approach: Use of HR data*

- **Performance measures for operators and travelers**
  - Use of existing infrastructure
  - No interference with controller operation
- **Improving Signal Timing Plans**
  - Performance derived signal settings
  - Robust timing plans
- **On-Going/Future Work**
  - Traffic volume prediction
  - Safety (red light running)
  - Multimodal (pedestrians, bicycles)

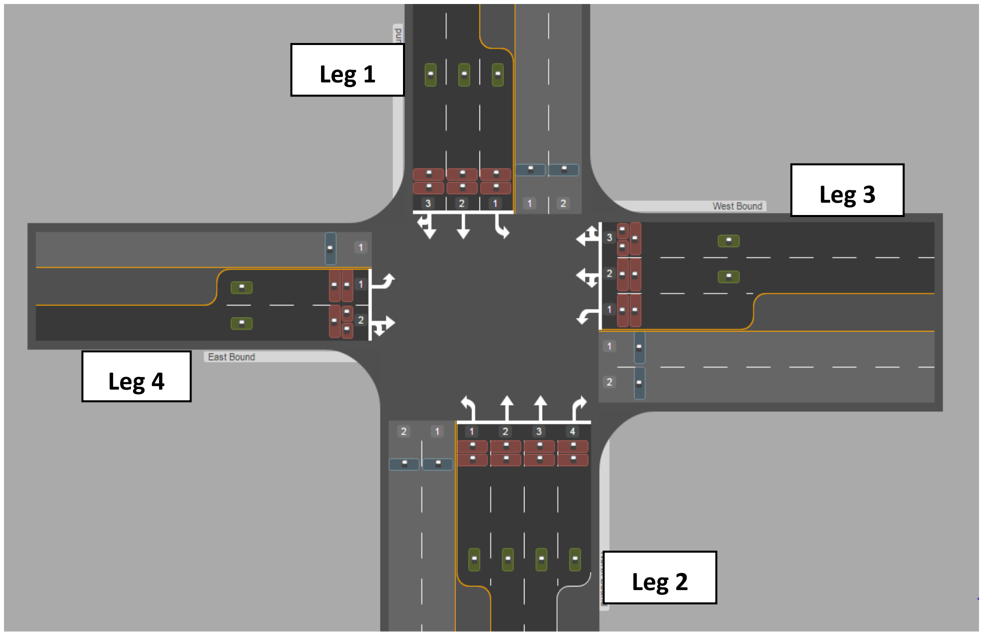
***Work with P. Varaiya & Sensys Networks**
"Management of Urban Traffic with H-R Data" IEEE ITSC 2014

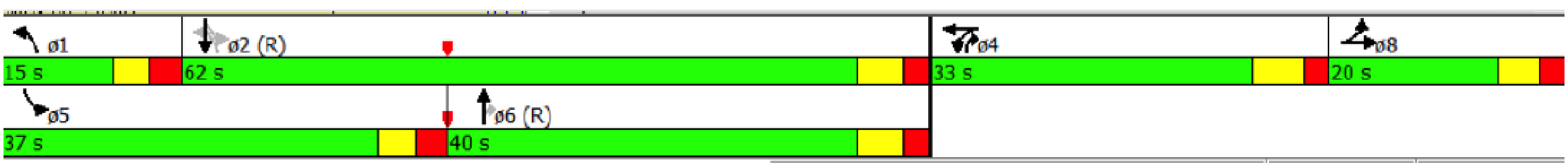
Data Collection System



SENSYS networks

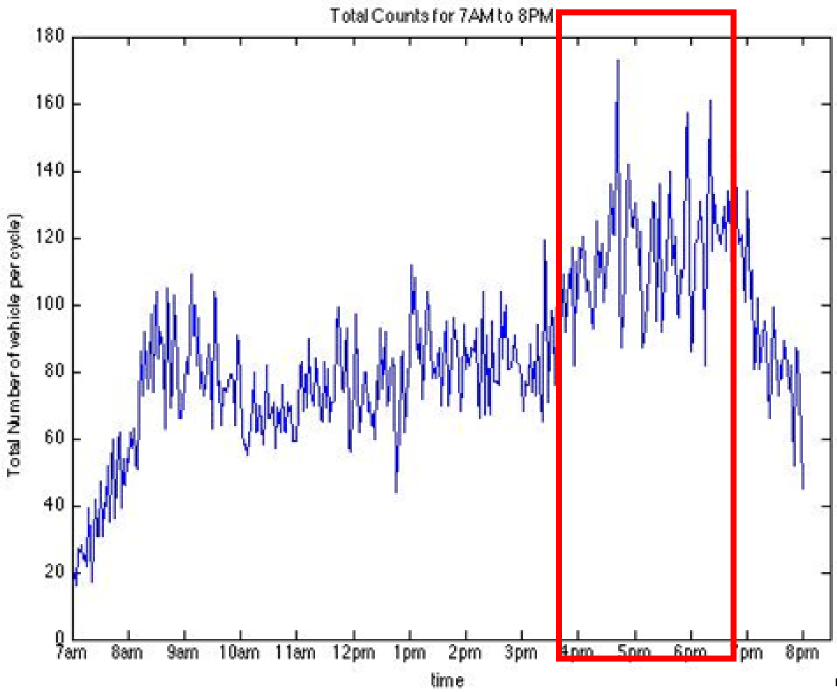
Selected Test Site: Beaufort, SC





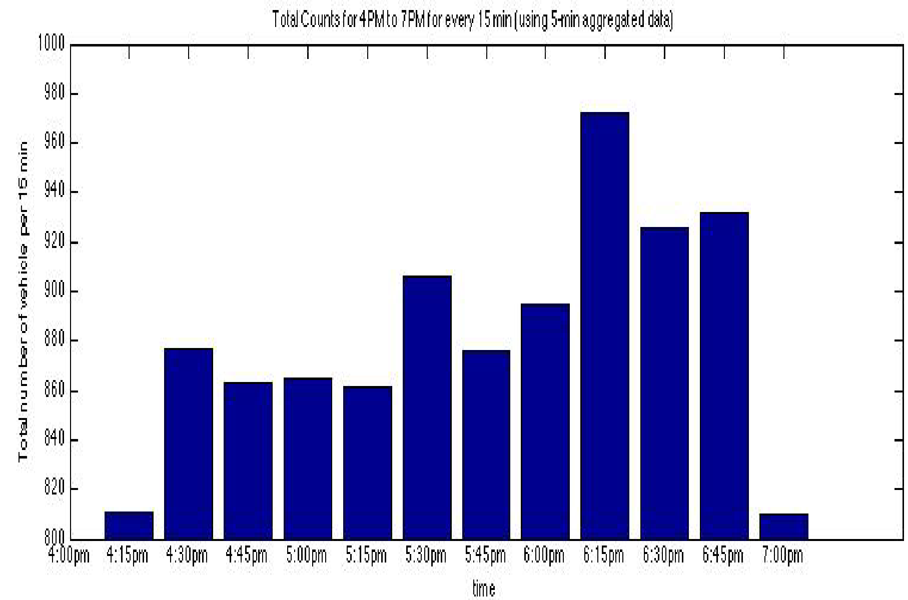
Intersection Volume; daily Variation

2/28/2015, 7AM to 8PM



Total volume (veh/cycle)

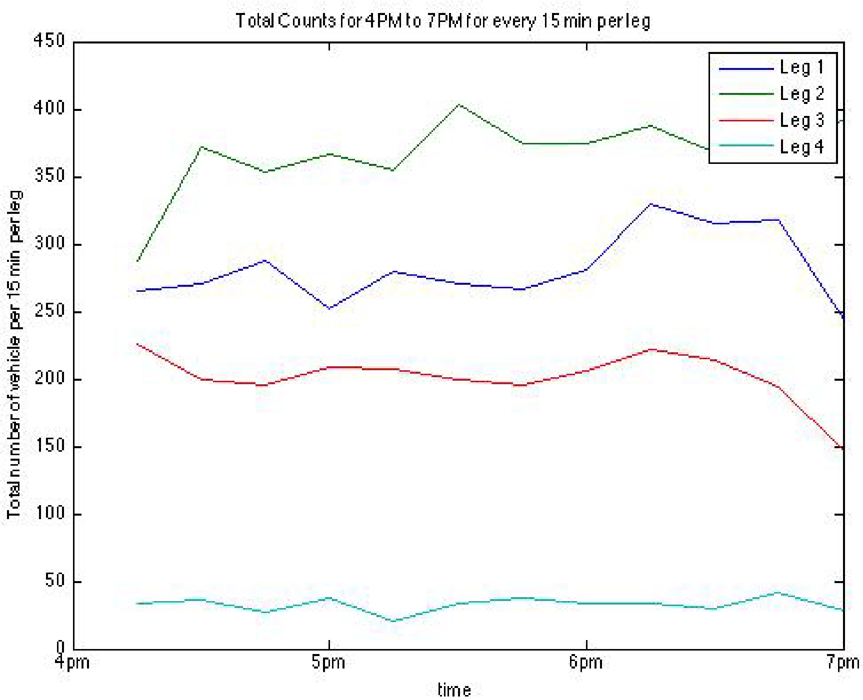
Peak Period, 4-7 PM



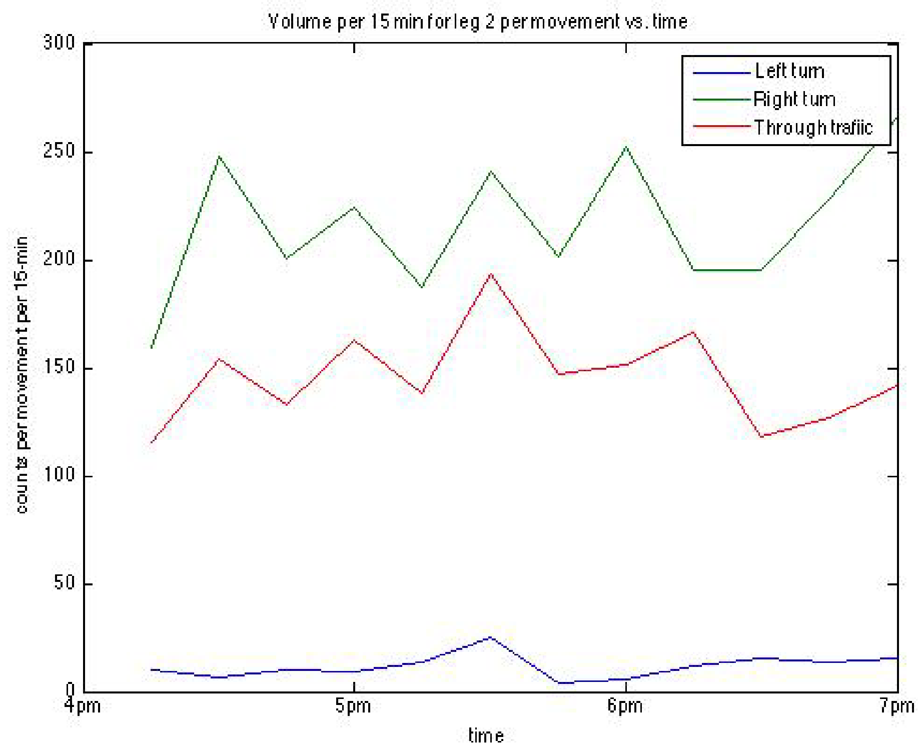
Total volume (veh/15 minutes)

Approach Volumes & Turning Movements

Peak Period, 4-7 PM

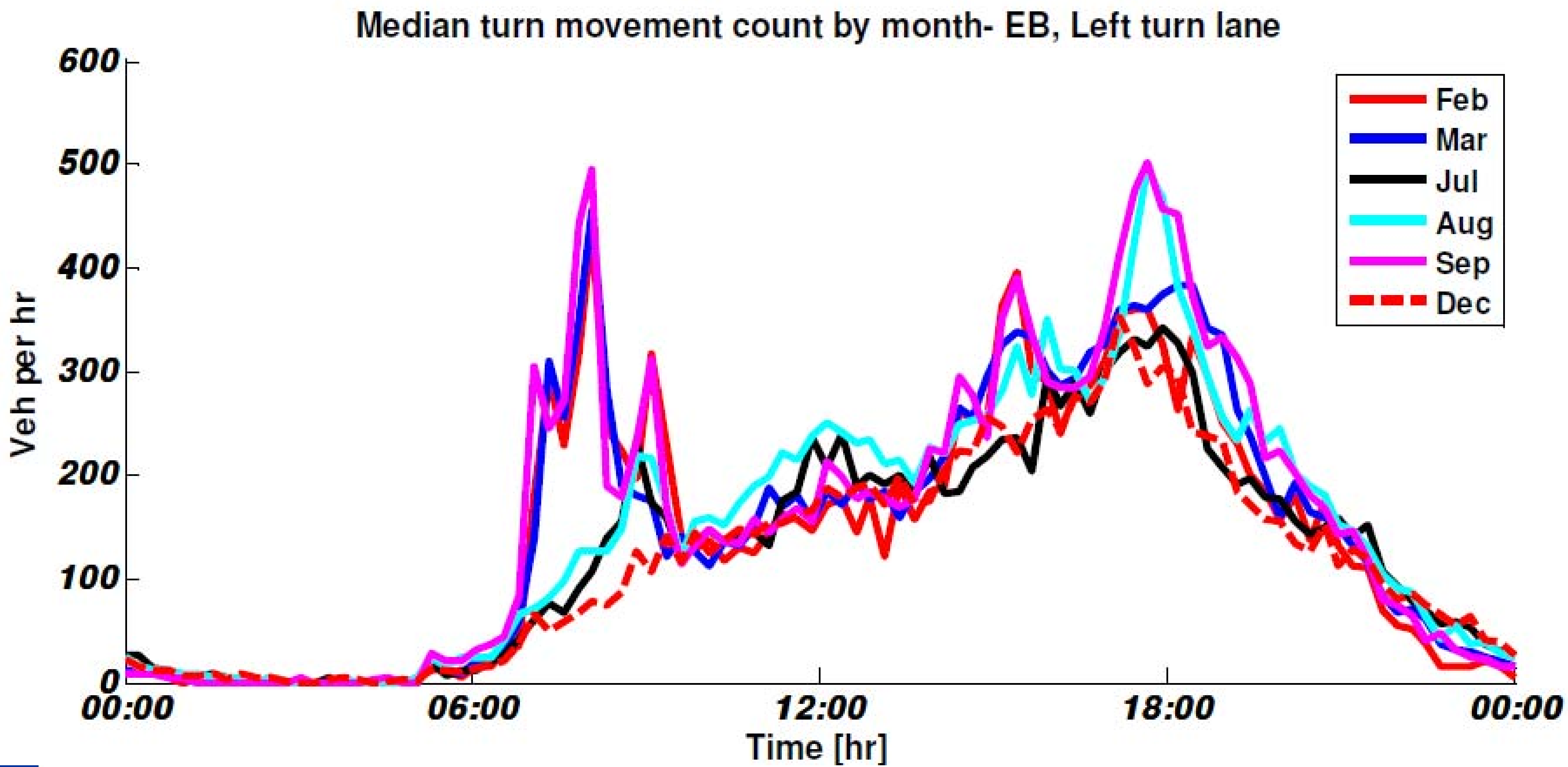


Approach Volume (veh/15 min)



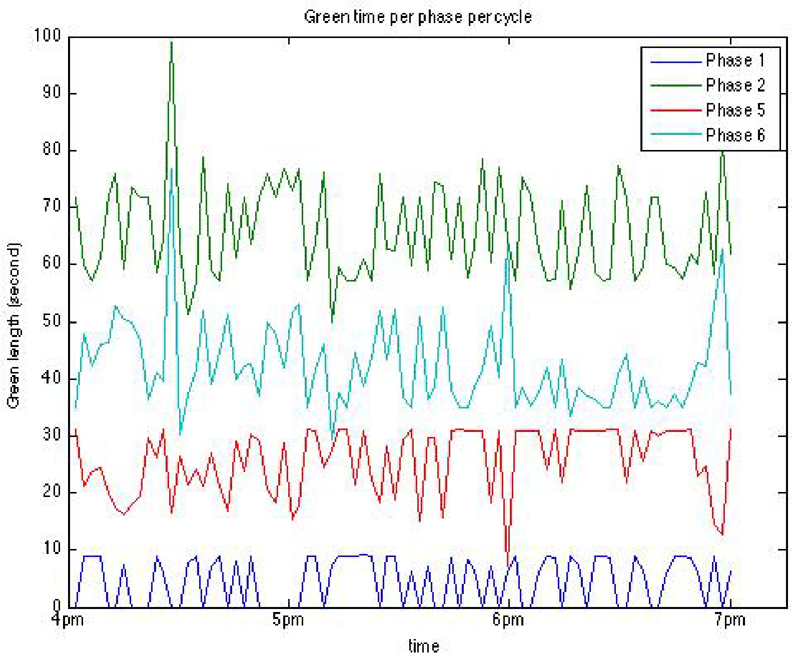
Turning Mov -Leg 2 (veh/ 15 min)

Seasonal Volume Variation

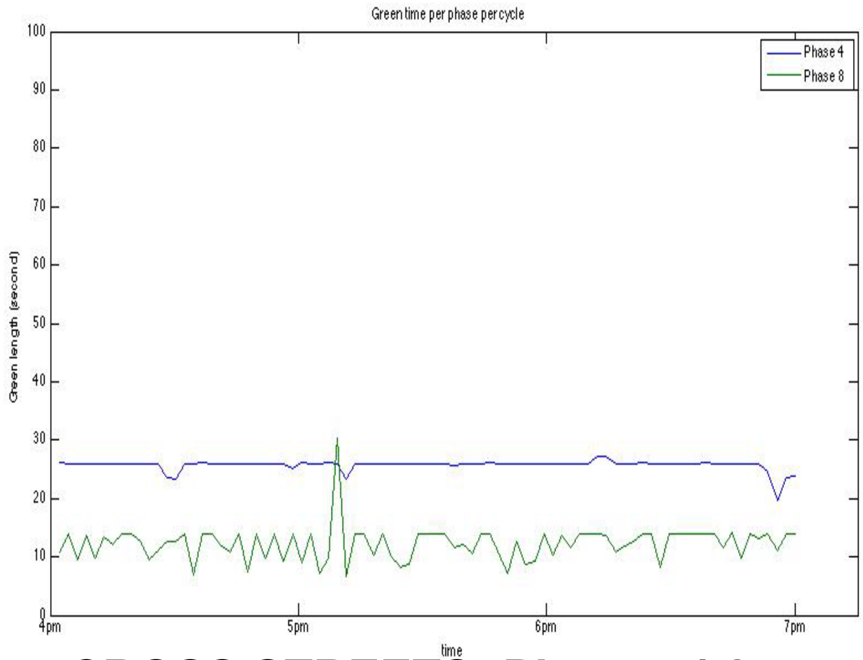


Signal Control Data

Green Times per Phase

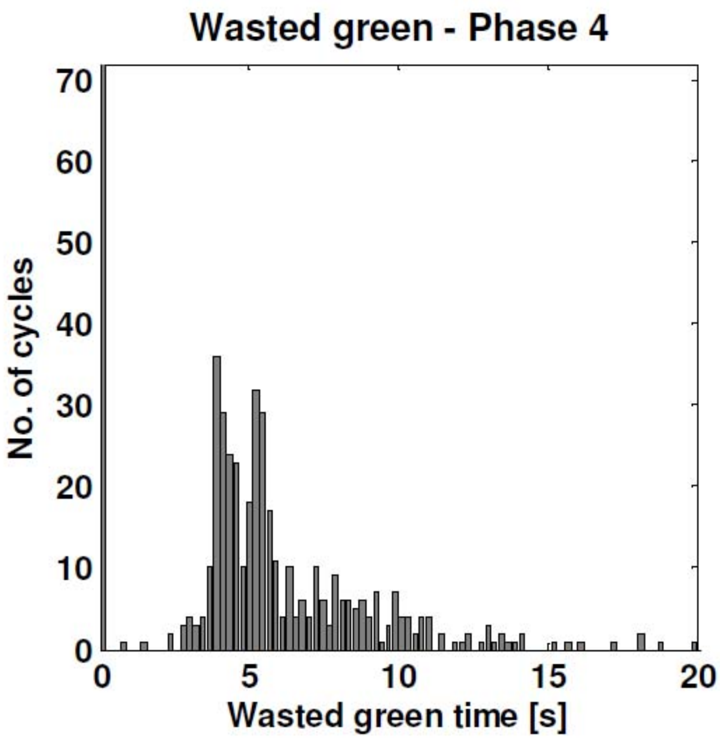


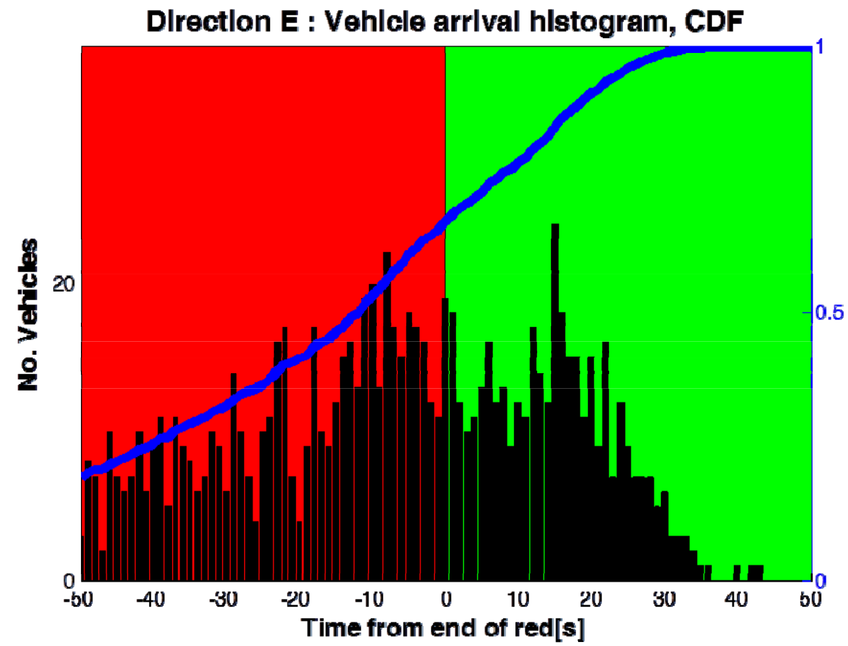
MAIN STREET: Phases 1,2,5,6



CROSS STREETS: Phases 4,8

Signal Phase Operations

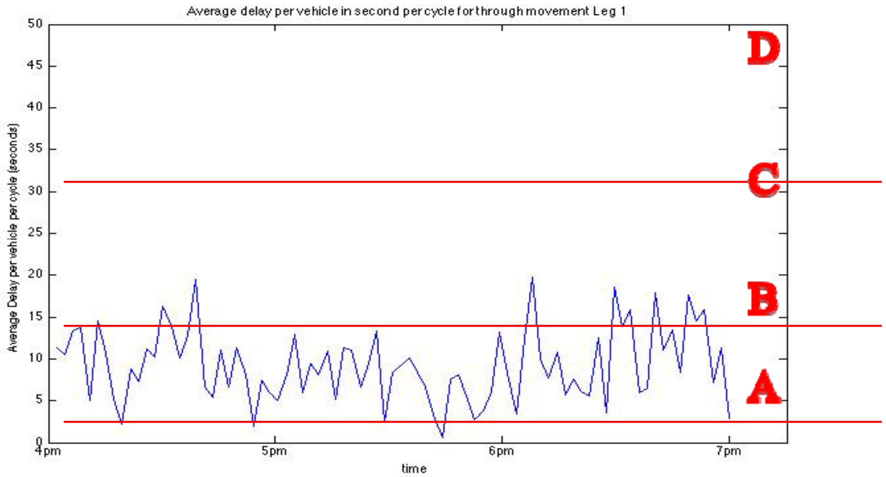




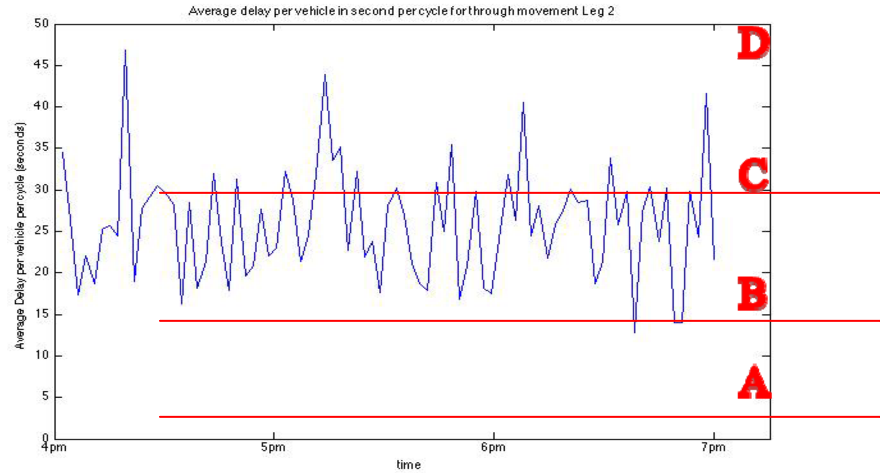
Wasted green time: time phase is active with no vehicle present and conflicting phase call

Vehicle arrivals: % arrivals on green

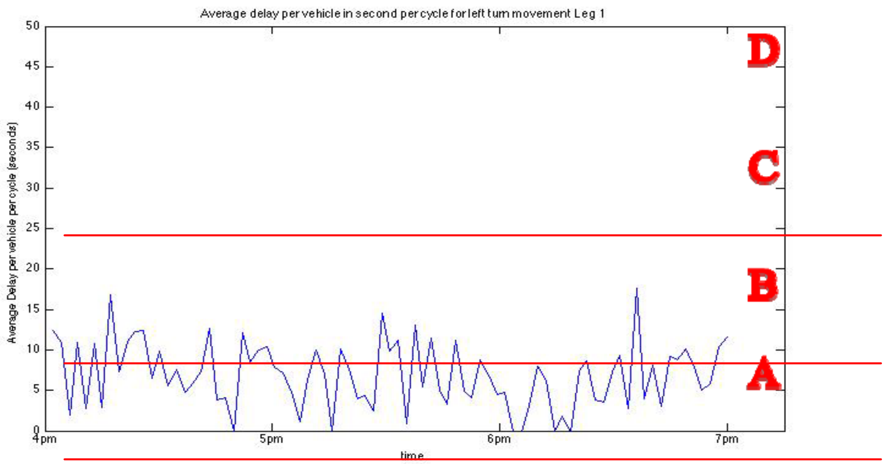
Performance: Average Delay (sec/veh) HCM Level of Service (LOS)



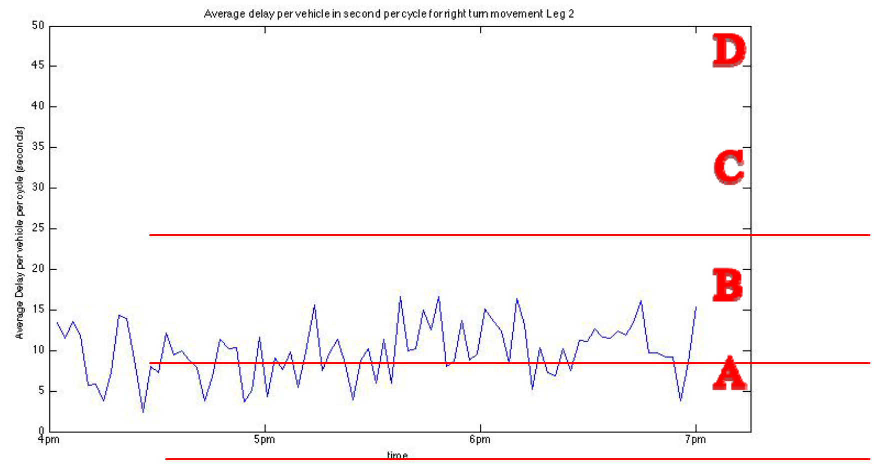
Through movement, Leg 1



Through movement, Leg 2

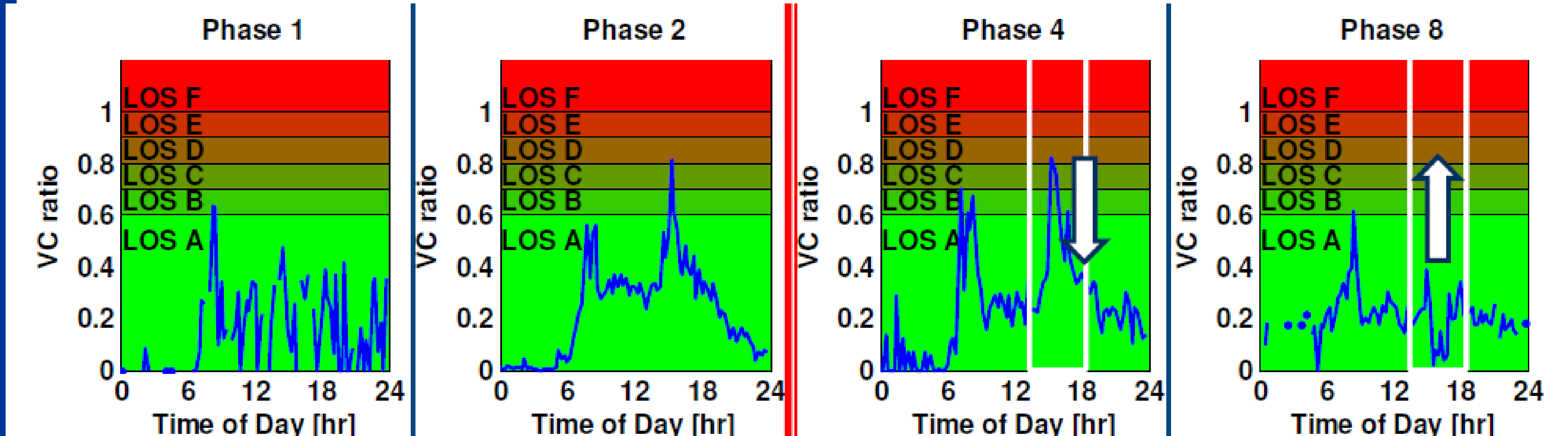


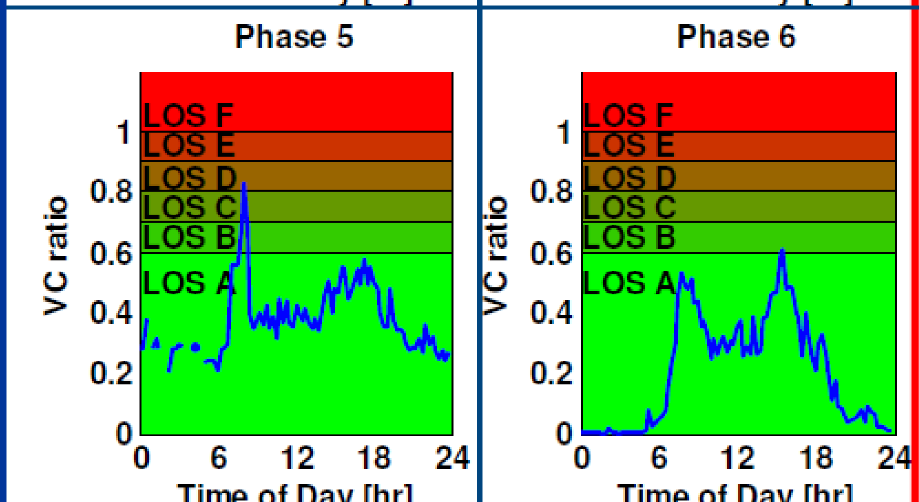
Left turn movement, Leg 1



Right turn movement, Leg 2

Performance: V/c and LOS





(V/C): (v*C/g*s)

S: sat flow (max discharge rate)

LOS: Level of Service per HCM

HR Data and Timing Plan Development

Traditional Approach

Local adjustments based on spot observations (complaints)

↓

Field data collection of turning movement counts (one day)

↓

Apply signal optimization software to develop timing plan(s)

↓

Field implementation-fine tuning. Before and after studies (limited)

Availability of HR Data

Assess existing intersection operations

- *Progression (% arrival on green)*
- *Capacity (V/c ratio)*
- *Delay*

↓

Develop and Implement Improved Settings

↓

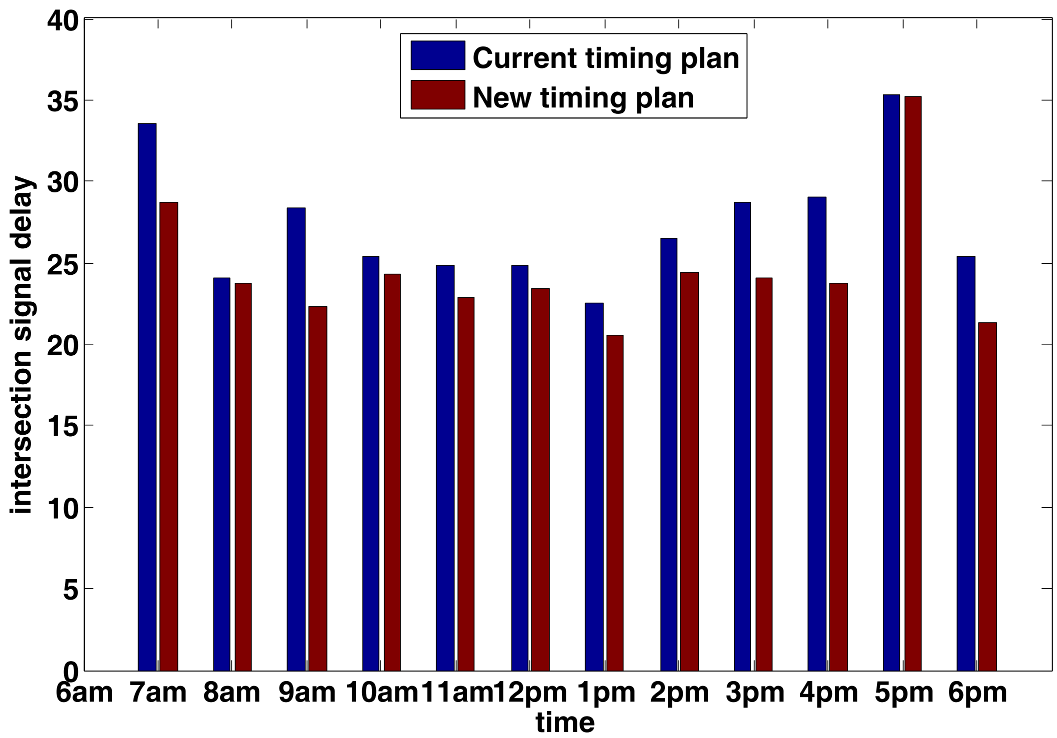
Evaluate performance

A*proach/intersection/system*

Over time

Improving Signal Timing Plans

- **Volume clustering – best set of volumes for the three timing plans available**
- **New timing plans reduce intersection signal delay by 10% on average***



Summary: Use of HR data

- **Performance measures for operators and travelers**
  - Use of existing infrastructure
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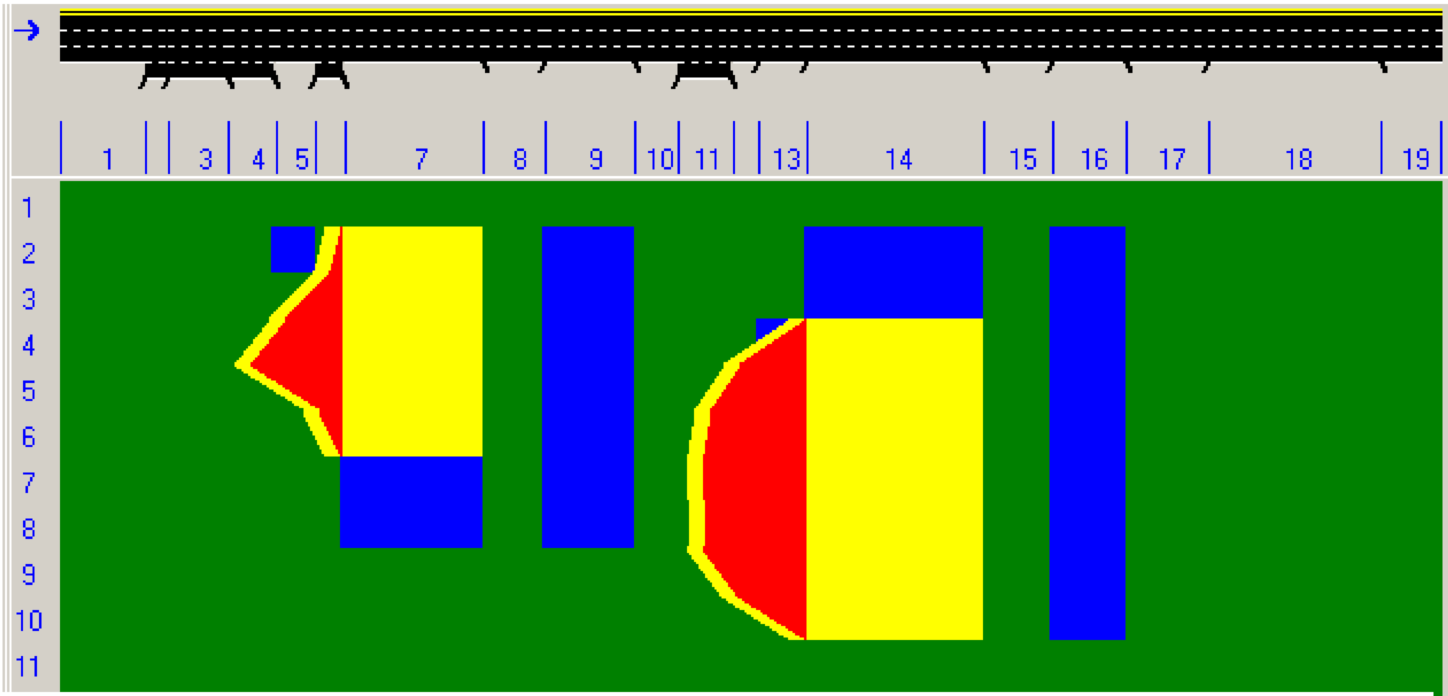
- **Improving Signal Timing Plans**
  - Performance derived signal settings
  - Robust timing plans
- **On-Going/Future Work**
  - Traffic volume prediction
  - Safety (red light running)
  - Multimodal (pedestrians, bicycles)

II. Freeway – Arterial Coordination

- **Important element of corridor management**
- **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**

Background: Freeway Ramp Metering

Control on-ramp flows to preserve freeway capacity



$$MAX \sum_{i=1}^{N} X_i$$

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

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

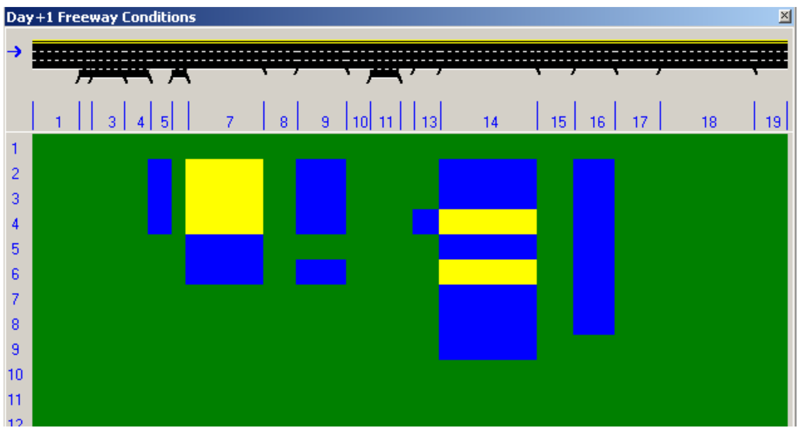
a_{ij} : proportion of traffic entering on-ramp i going through section j

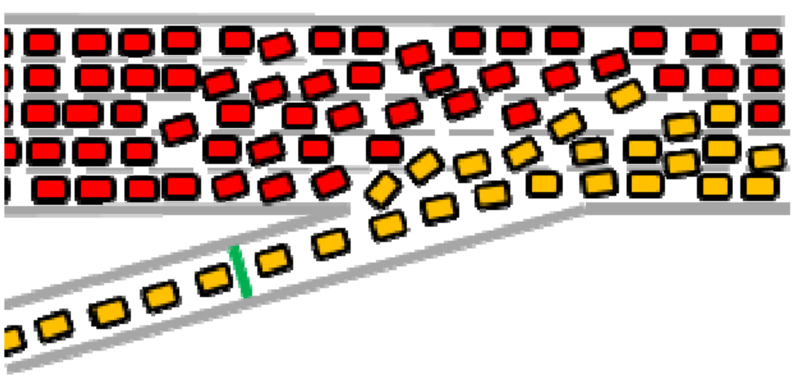
C_j : capacity of freeway segment j

Freeway Ramp Metering: Impacts

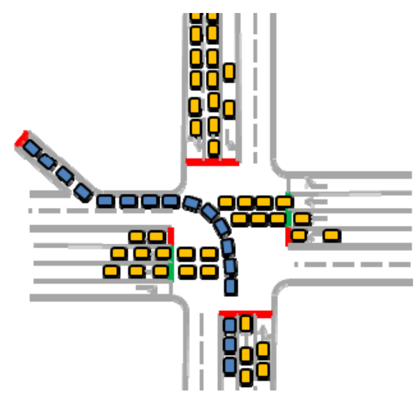
- Excessive delays to on-ramp vehicles
- Spillback to local streets
- Queue override –diminishes ramp metering benefits

Freeway Mainline





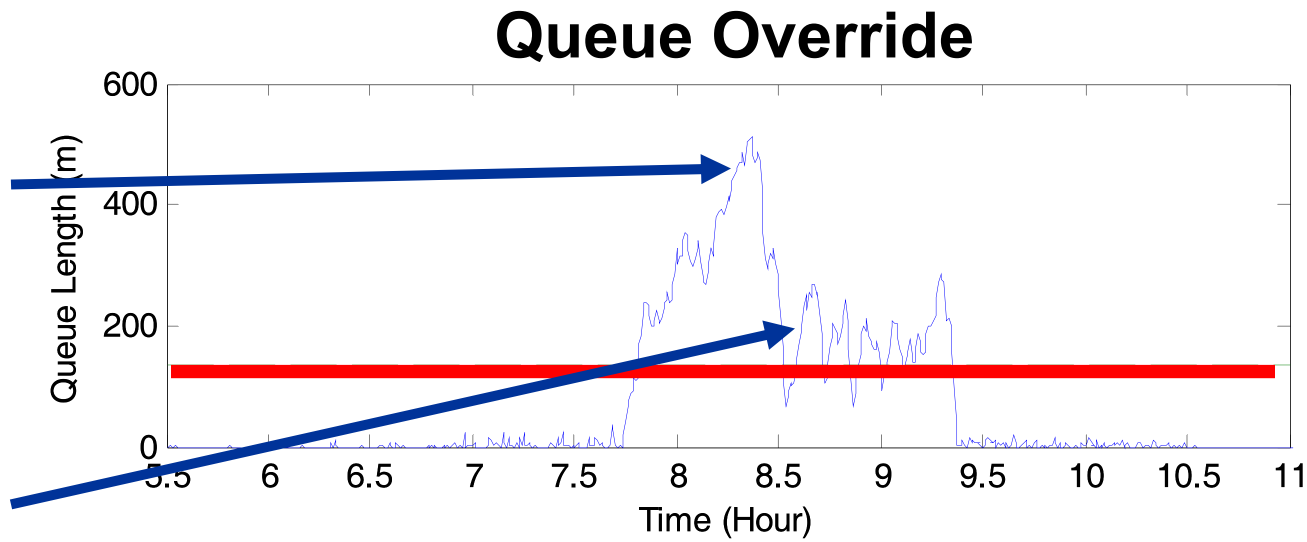
On Ramp Queues

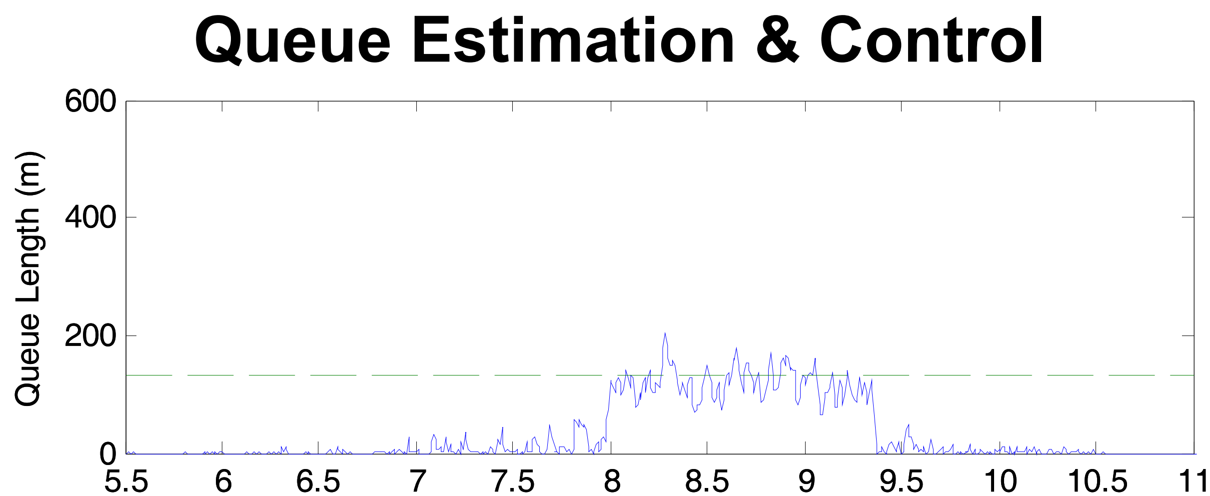


On-Ramp Queue Control Regulator

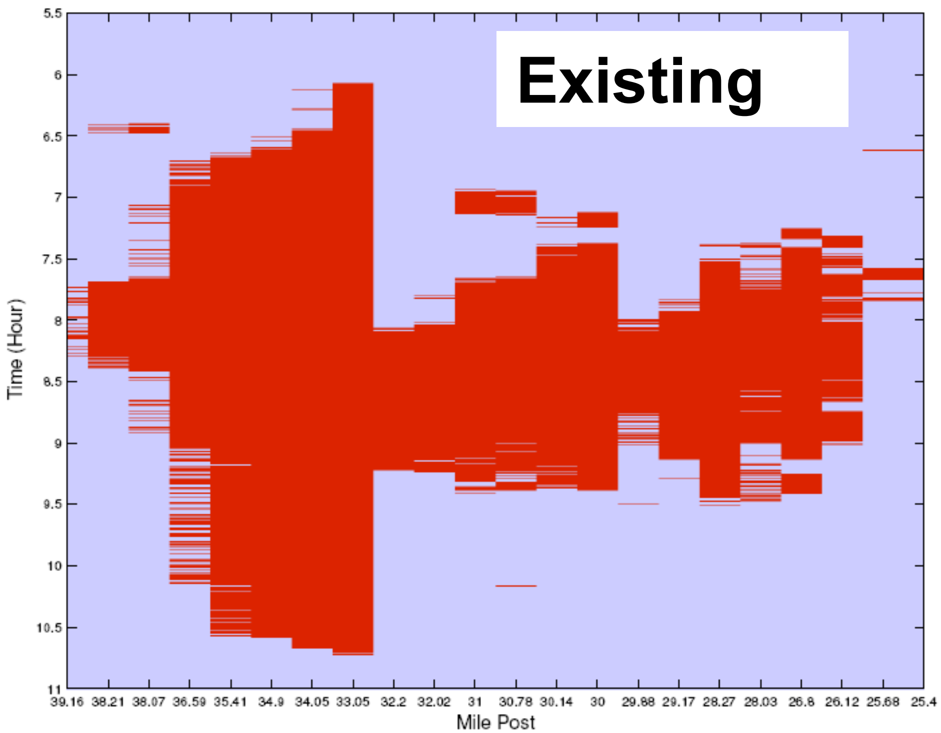
Queue Override

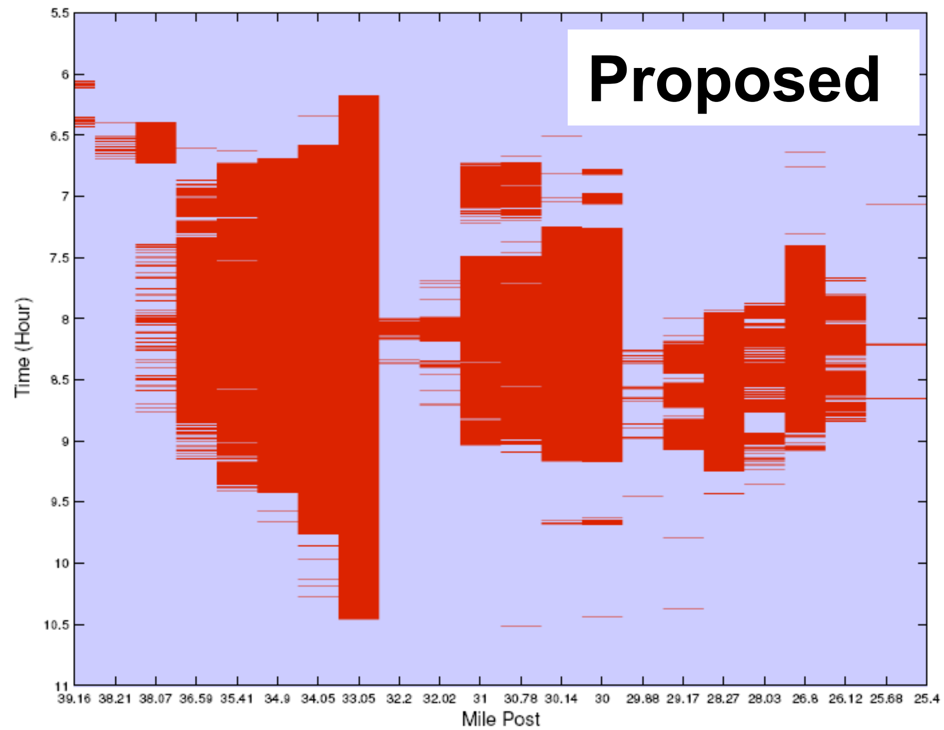
- **failed to limit the queue within the limits**
- **large variation in queue length**





Application: Los Angeles I-210W





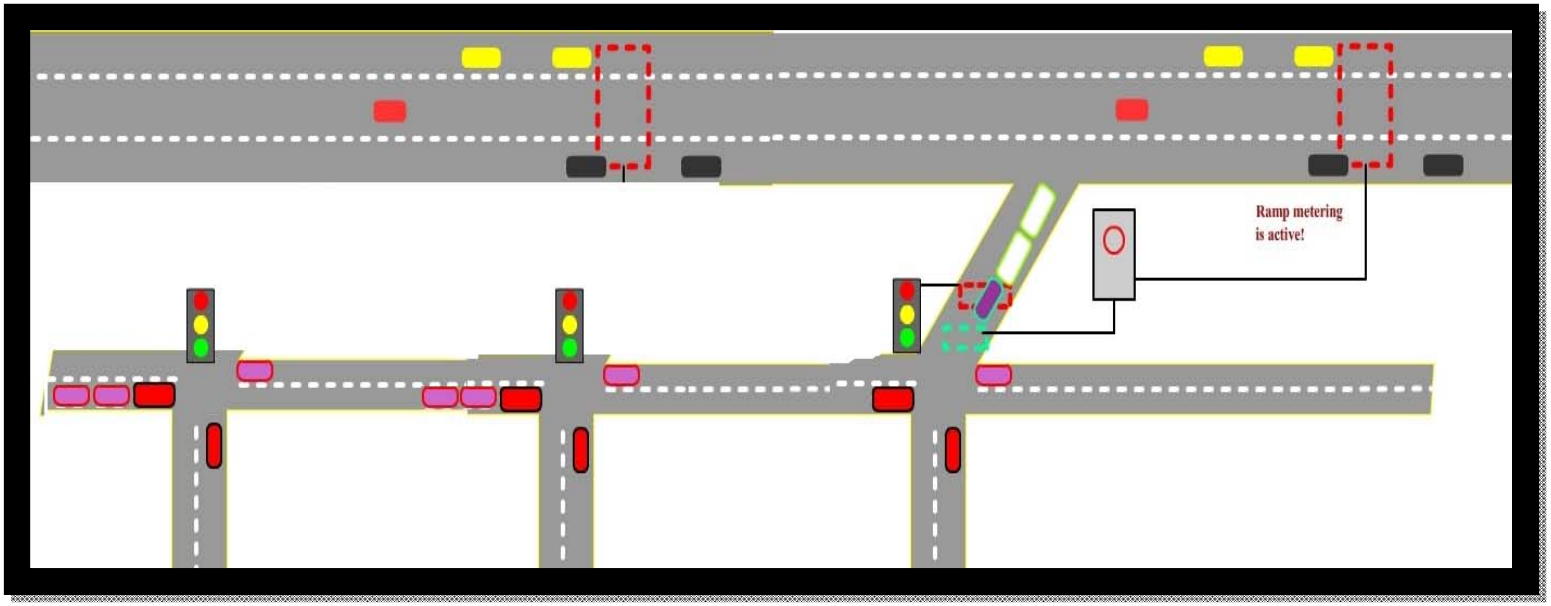
Improvements: **6% Travel Time/ 16% Delay Reduction**

"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

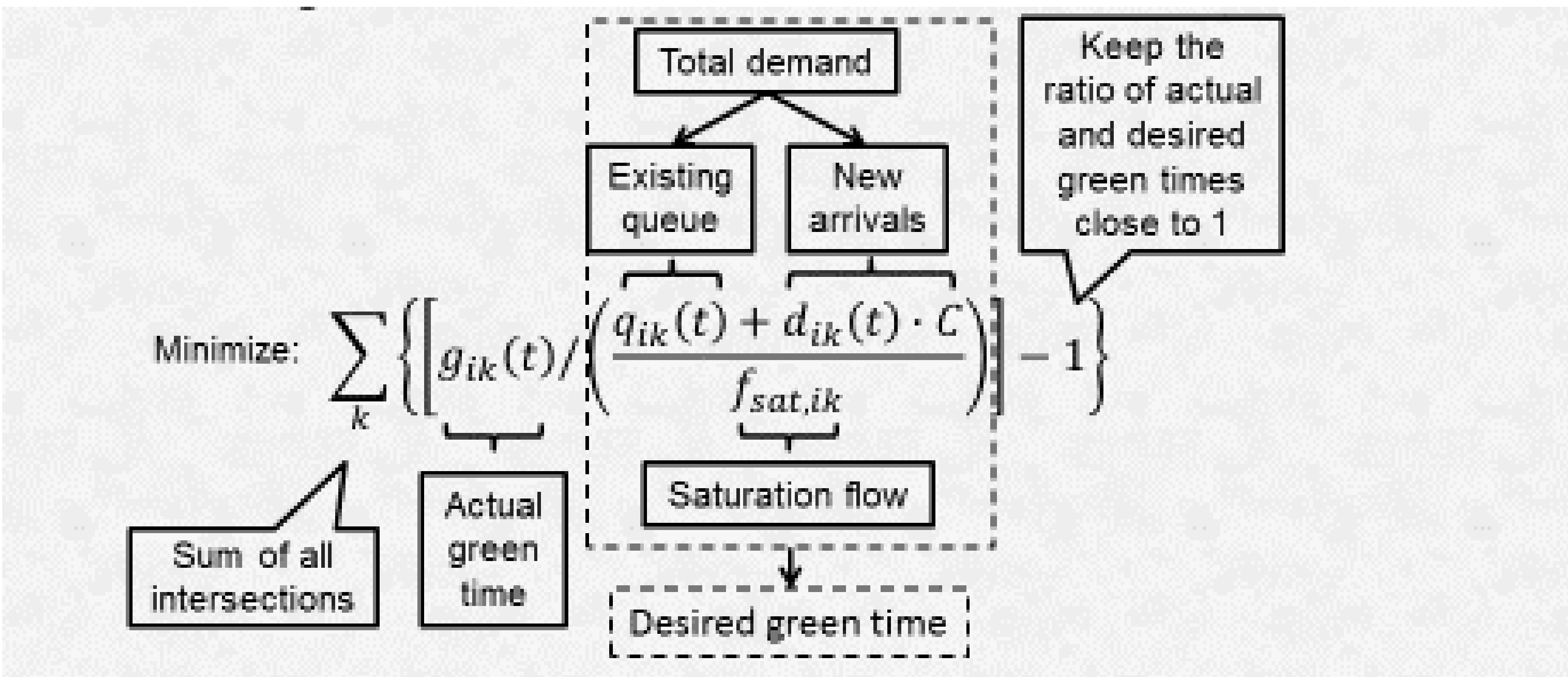
Arterial link storage (arterial spillback)

Minimum phase green times

Proposed on-Ramp Access Control (2)

Minimize the ratio of actual and desired green times per signal phase

Desired green time: minimum green time to serve the traffic demand



Proposed on-Ramp Access Control (3)

Constraints

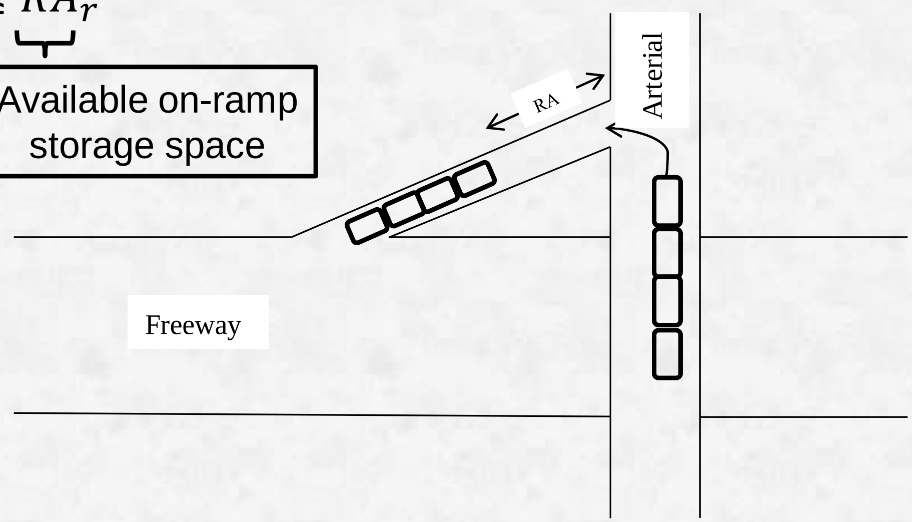
- Minimum green time constraint: $g_{ik}(t) \geq G_{ik,min}$
- Cycle length constraint: $\sum_i g_{ik}(t) = C$
- On-ramp storage constraint:

$$\sum_{i \in R} f_{sat,ik} \cdot g_{ik}(t) \leq RA_r$$

Phases for on-ramp access

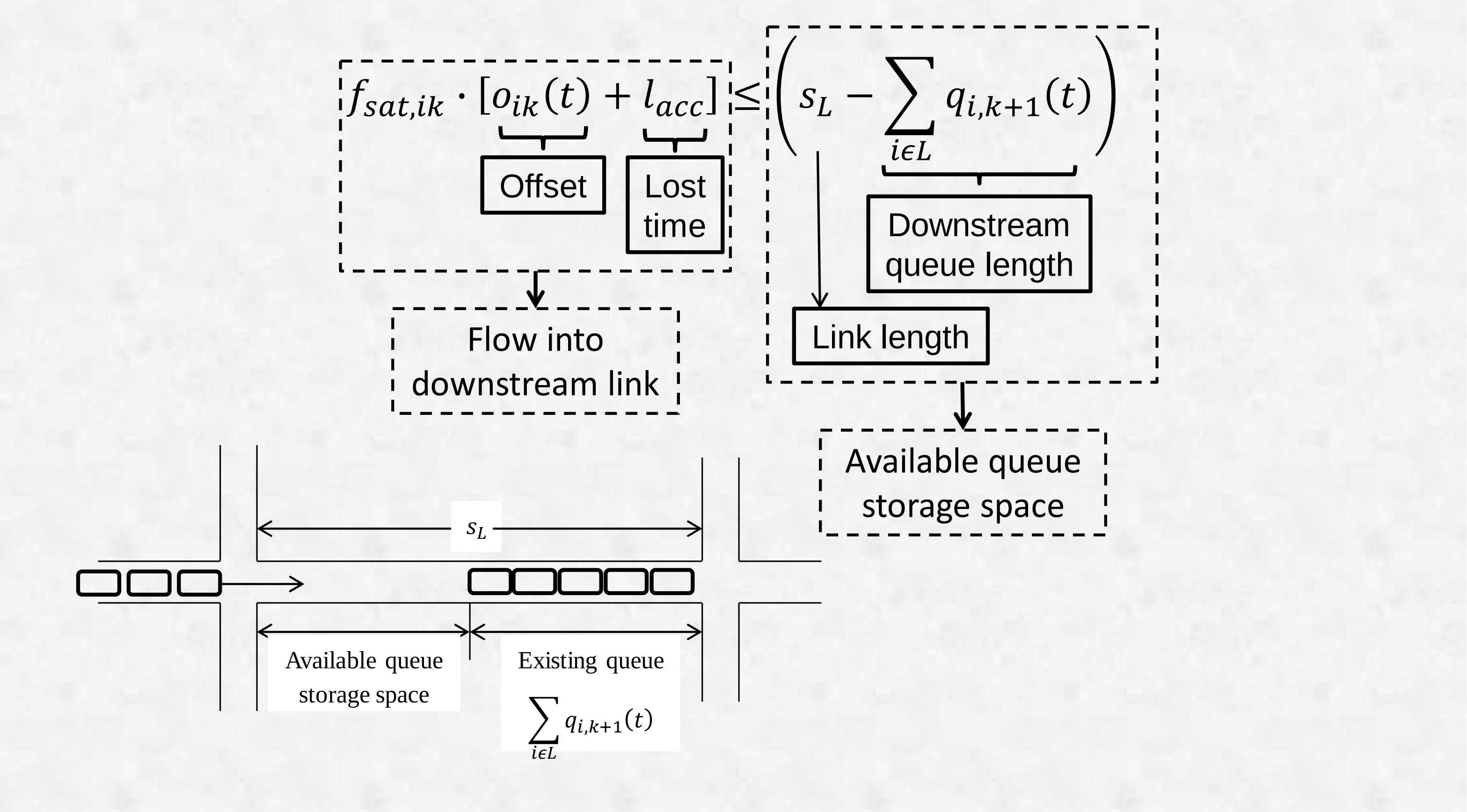
Available on-ramp storage space

Total flow onto freeway on-ramp



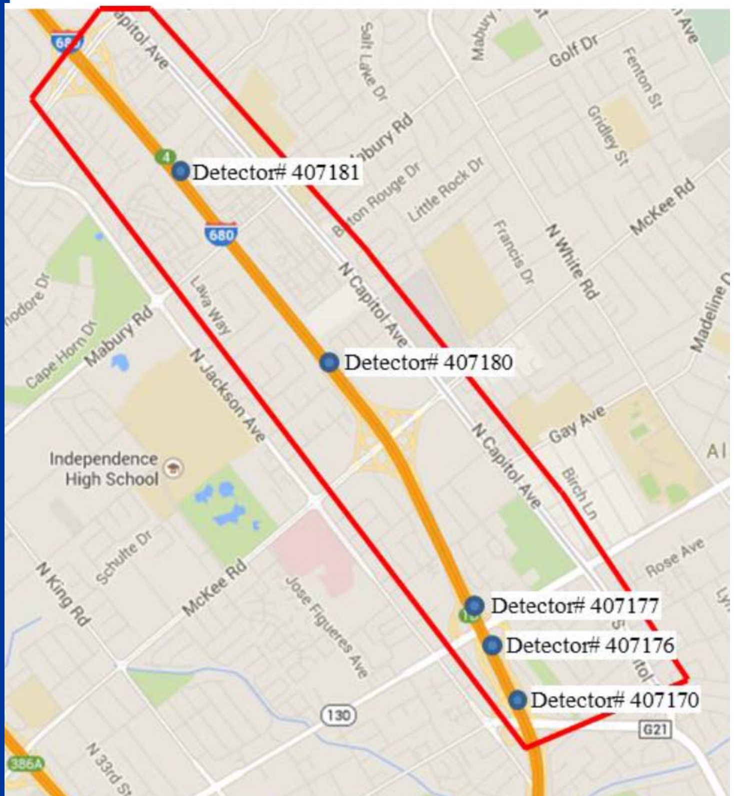
Proposed on-Ramp Access Control (4)

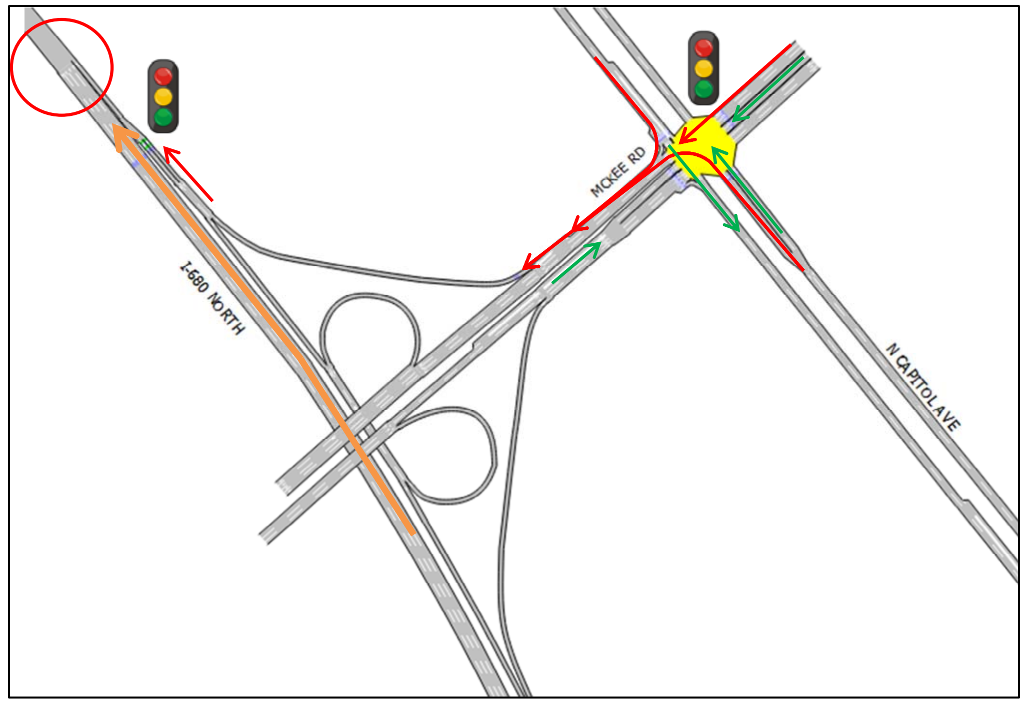
Constraint: Arterial link storage



Application: Test Site

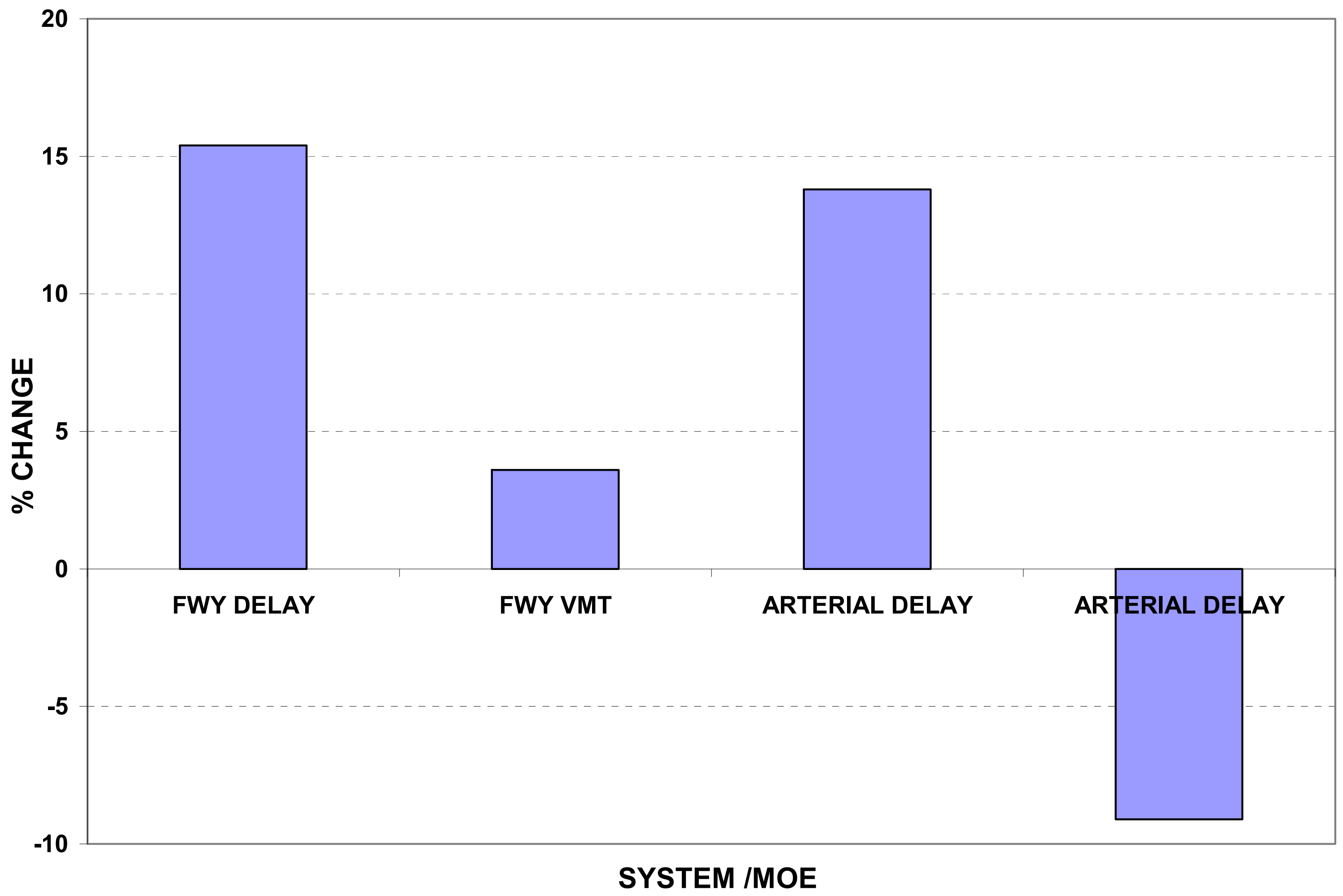
Test Site: I-680, San Jose CA





• **AIMSUN Microscopic Simulator**

Application: Fidings



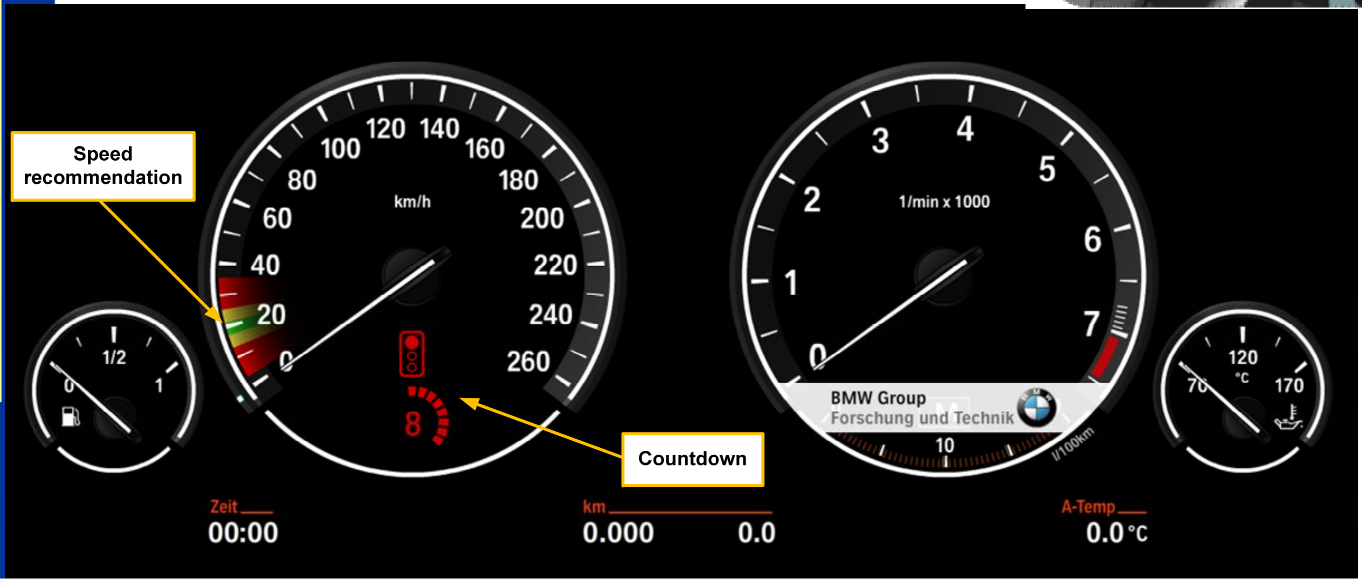
Looking Ahead: Connected Vehicles

"Here I am"

V2V and V2I

V2I Example: SPaT message

Application: Dynamic Speed Advisory (source: UC & BMW)



Field Test Results*

Uninformed Driver (Baseline Scenario): no speed recommendation

Informed Driver: follow speed recommendation

Individual Vehicle Priority & Uninformed Driver: no speed recommendation. Intersection adapts timing with individual vehicle priority

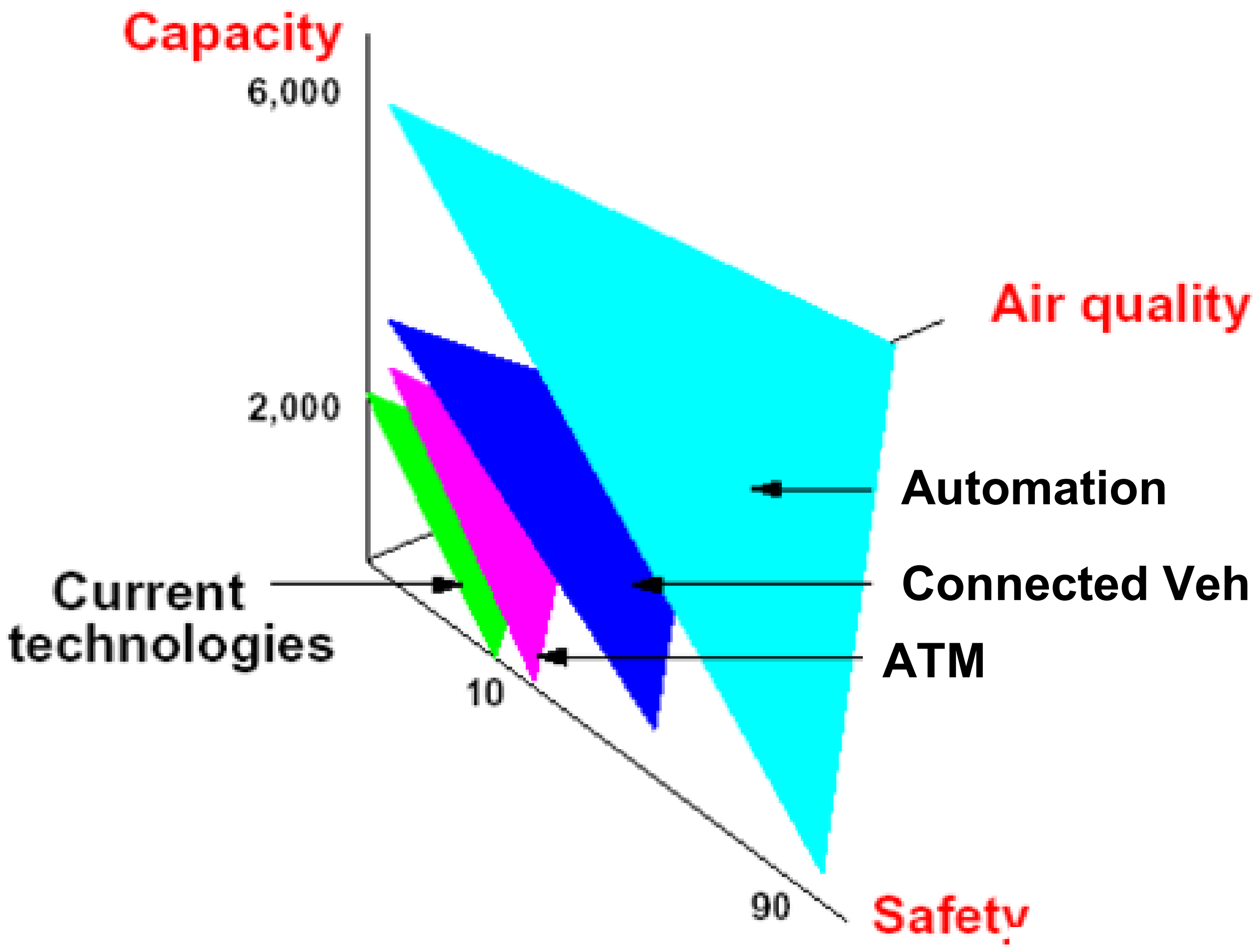
Individual Vehicle Priority & Informed Driver: follow speed recommendation. Intersection adapts timing with individual vehicle priority

	Uninformed Driver	Informed Driver	Uninformed Driver &APIV	Informed Driver &APIV
Fuel (L/100KM)	10.23	8.84	8.28	7.33
Improvement	Base Scenario	-13.60%	-19.10%	-28.40%

**https://www.fhwa.dot.gov/multimedia/research/advancedresearch/index.cfm*

“ Advanced Signal Control Strategies,” PATH Research Report UCB-2013-3

Looking Ahead: Beyond Connected Veh

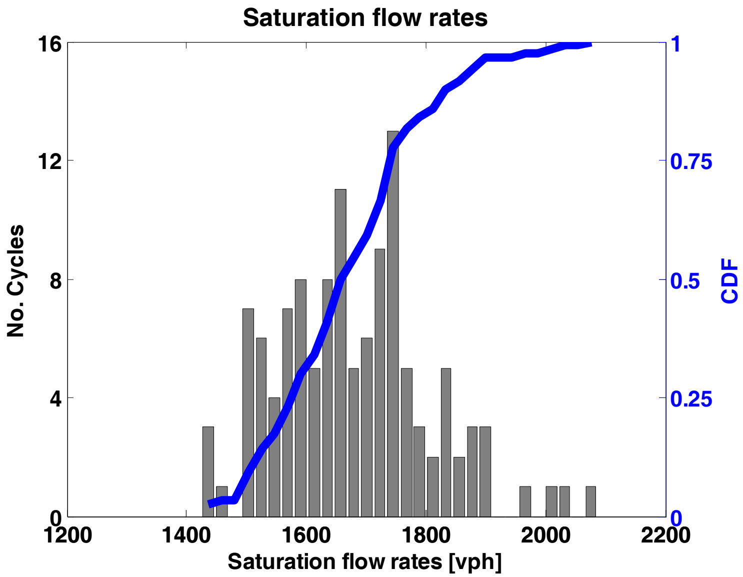


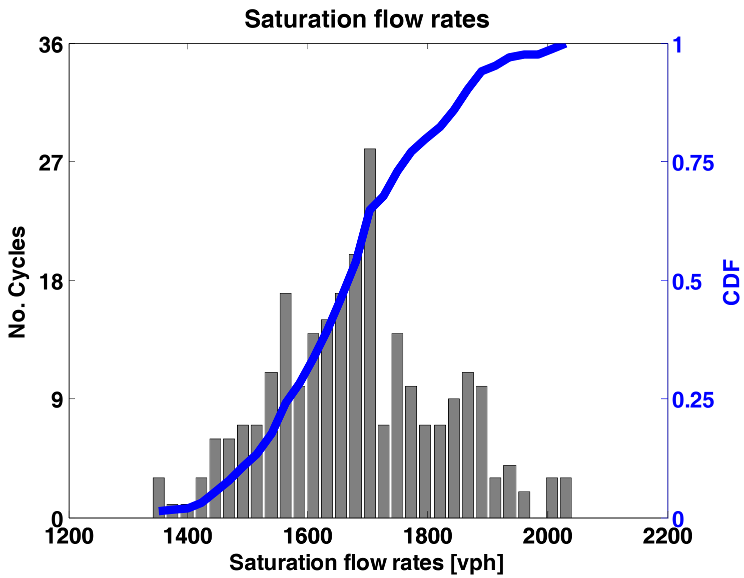
Back Up Slides

Measuring Saturation flow

Through/ Left turn shared

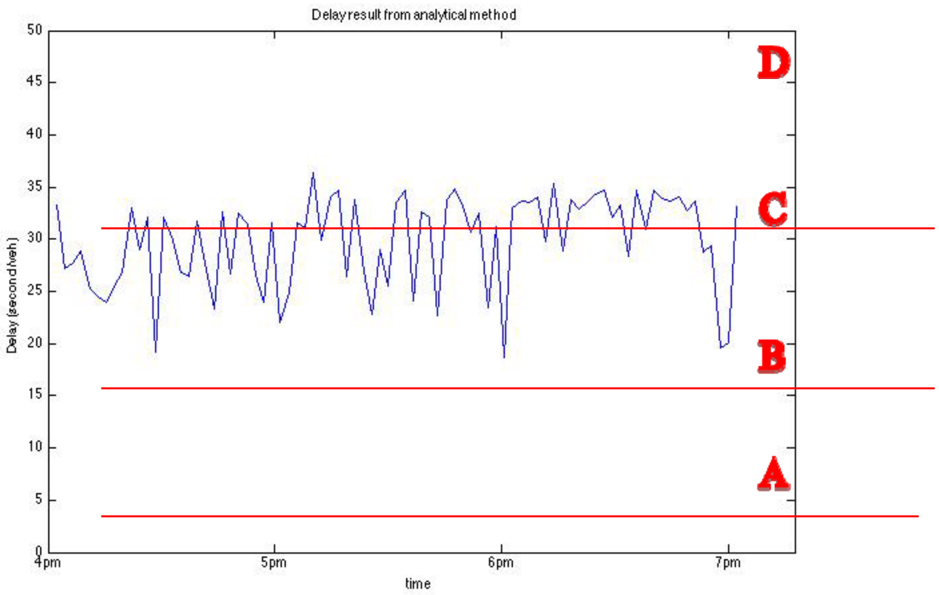
Left turn lane





Statistics of saturation flow rates.

Performance: Delay (Analytical solution)



Leg 2 through movement

$$d = \frac{C(1-\frac{g}{C})^2}{2(1-\frac{g}{C}\times\frac{V}{c})}$$

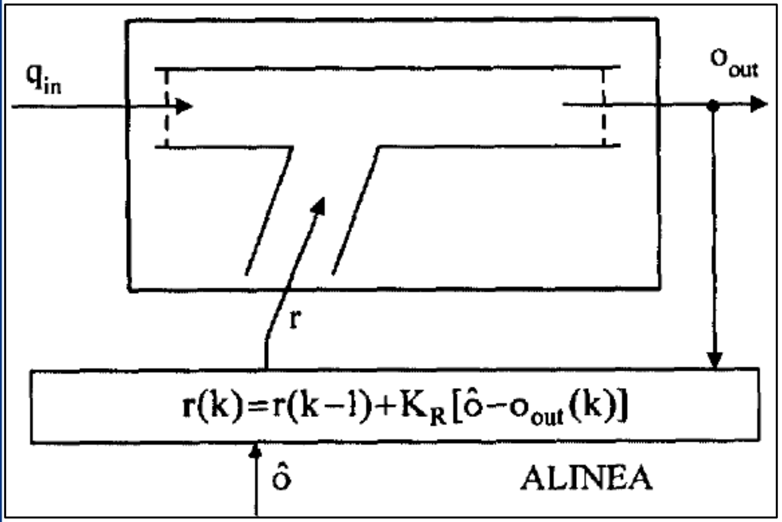
- d : Delay (sec/veh)
- C : Cycle length
- g : green time
- V/c : Volume to capacity ratio

ALINEA Algorithm

- **Local traffic-responsive strategy –closed loop**

$$r(k) = r(k-1) + K_R[O_c - O_{out}(k)]$$

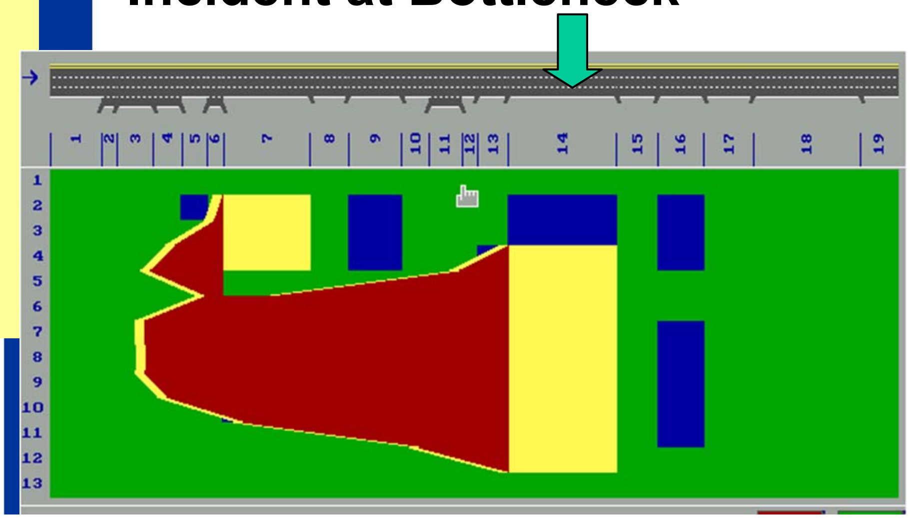
r(k) is the metering rate in time step k;
r(k-1) is the metering rate in time step k-1
K_R is the regulator parameter (constant);
$O_{out}(k)$ is the current occupancy measurement



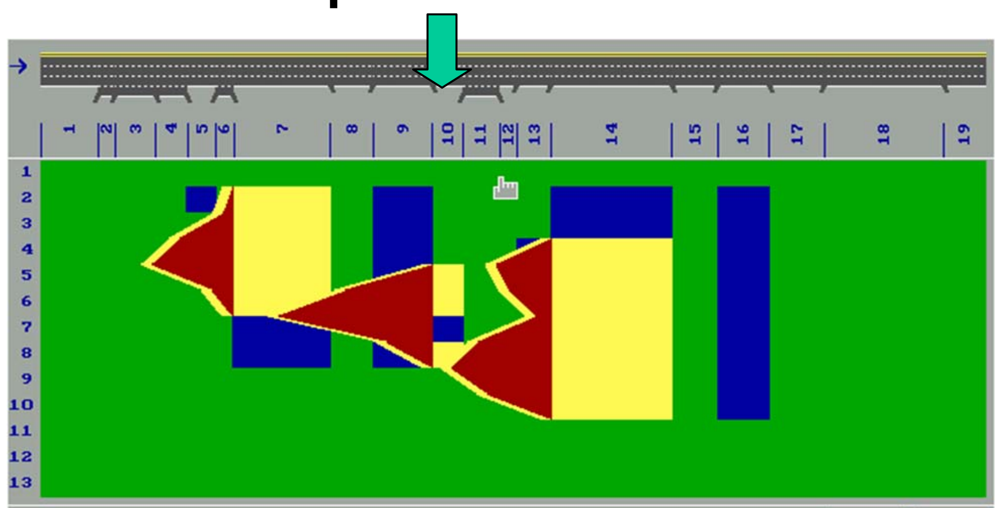
Non-Recurrent Congestion: Diversion Strategies

- **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

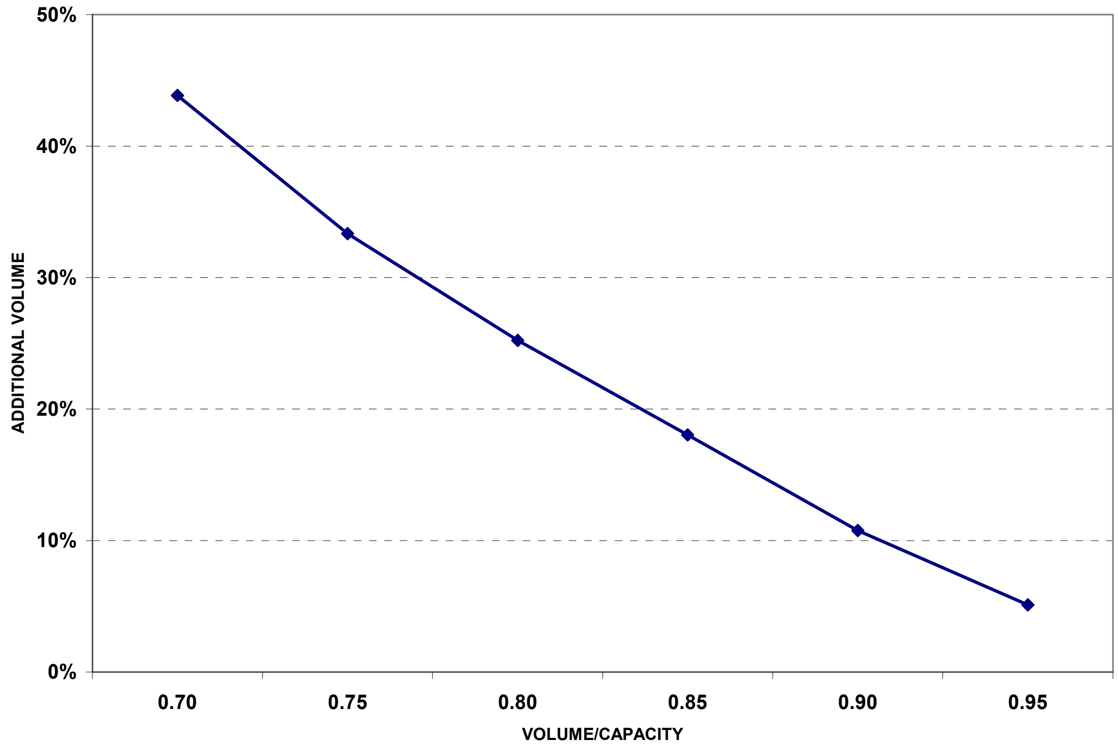


Incident Upstream of Bottleneck



Amount of Diverted Volume?

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



where:

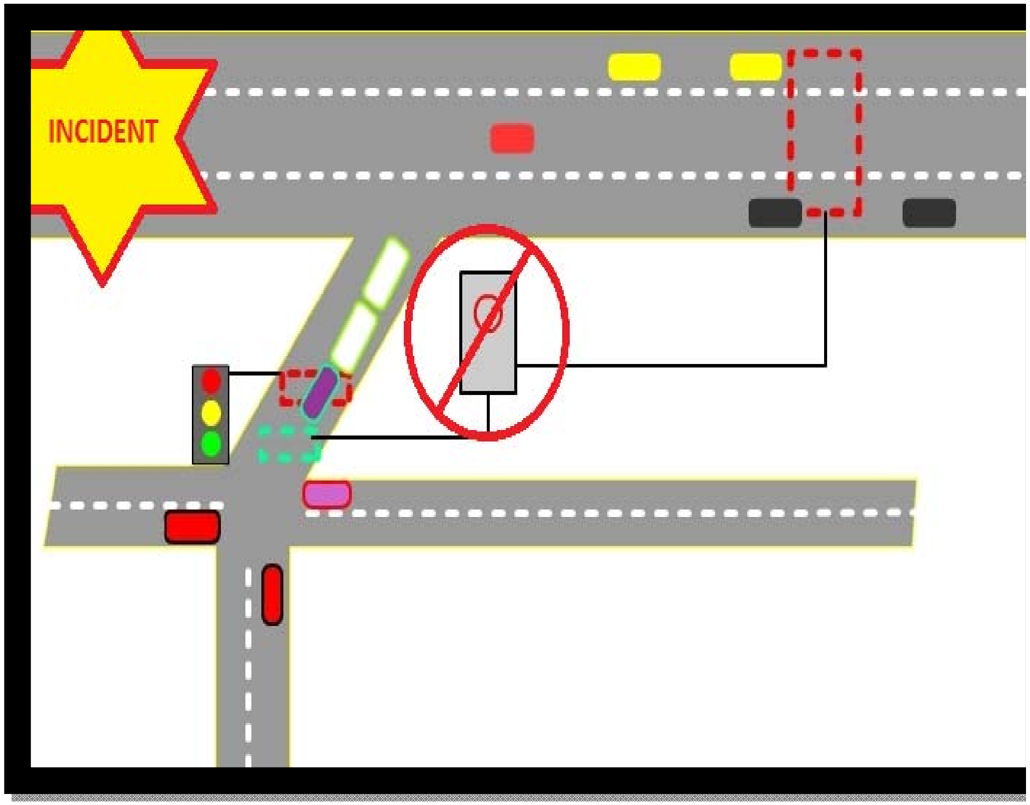
- **DV_i** : additional traffic volume on approach *i* *(%)*
- **X_i** : volume/capacity (degree of saturation) on approach *i* *(%)*
- **RC_i** : reserve capacity on approach *i* = *1*- X_i

Control Strategies: Non-Recurrent Congestion

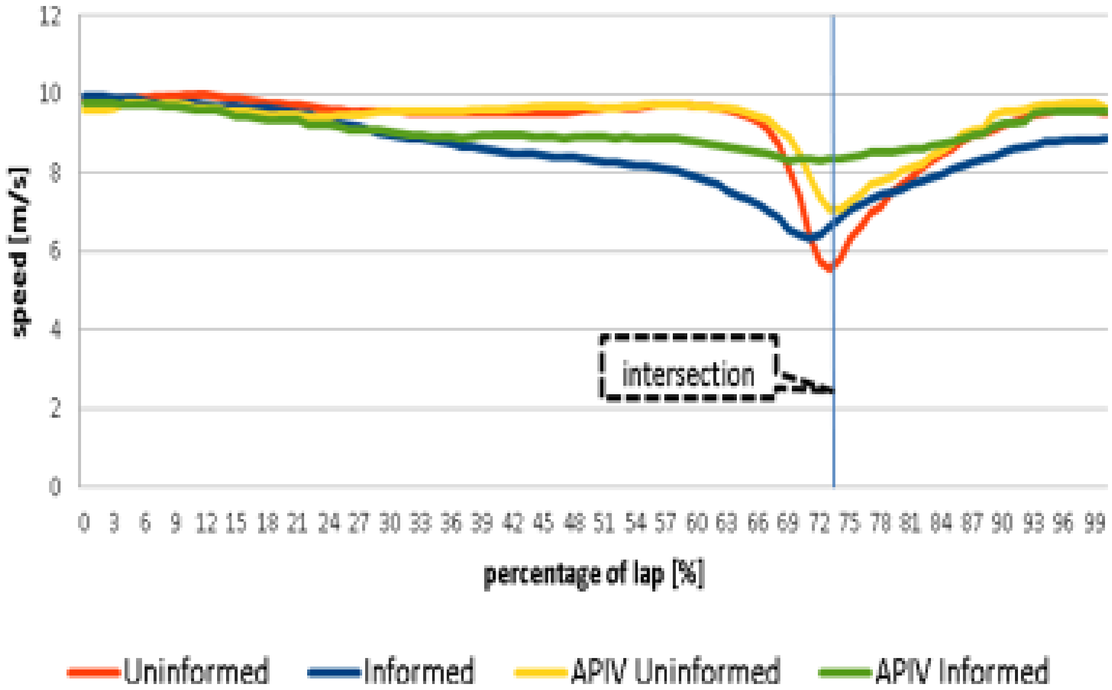
- **Inhibit Metering**

  maximize flow from arterial into freeway

  In case of incidents upstream of the on-ramp



Results (2)


12
10
8
6
4
2
0
speed [m/s]
intersection
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75 78 81 84 87 90 93 96 99
percentage of lap [%]
Uninformed
Informed
APIV Uninformed
APIV Informed