IPAM Workshop

Mathematical Approaches To Traffic Flow Management

II. Freeway Control

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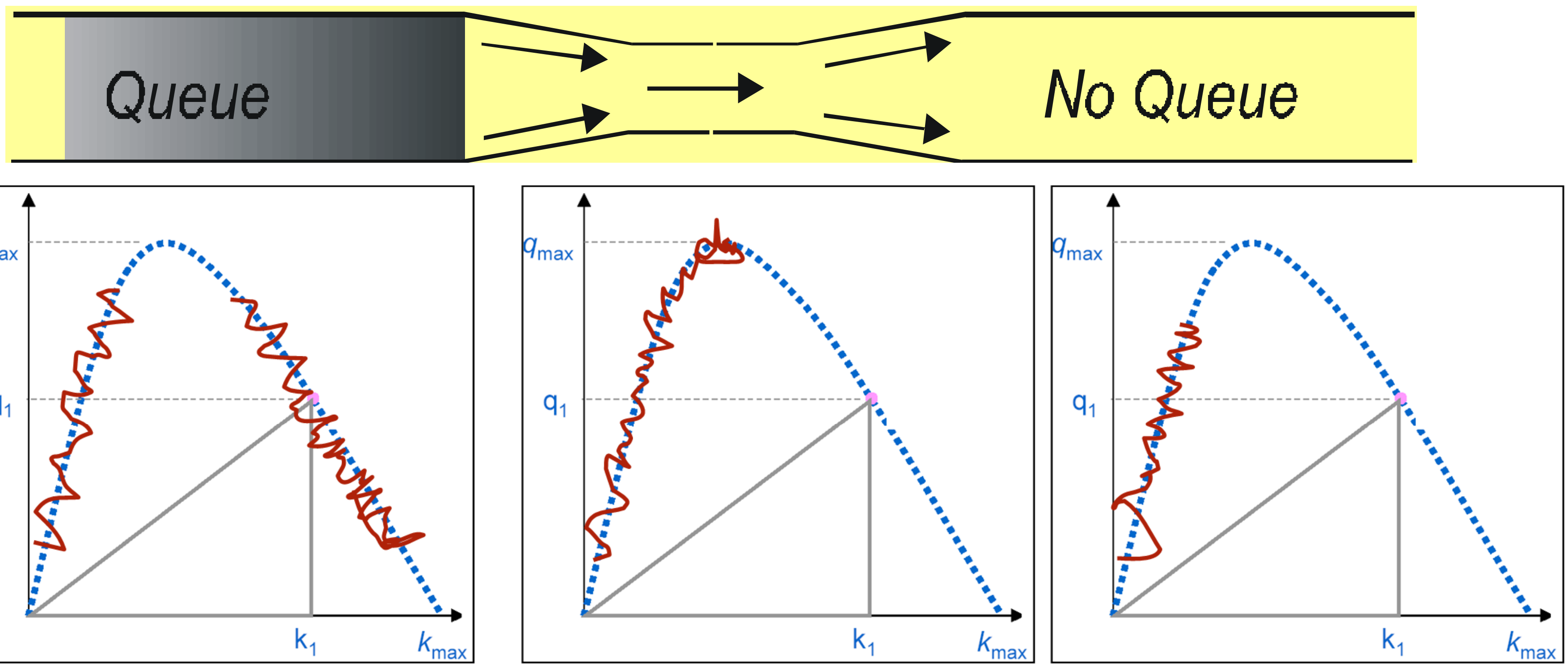
September 10, 2015

Bottlenecks

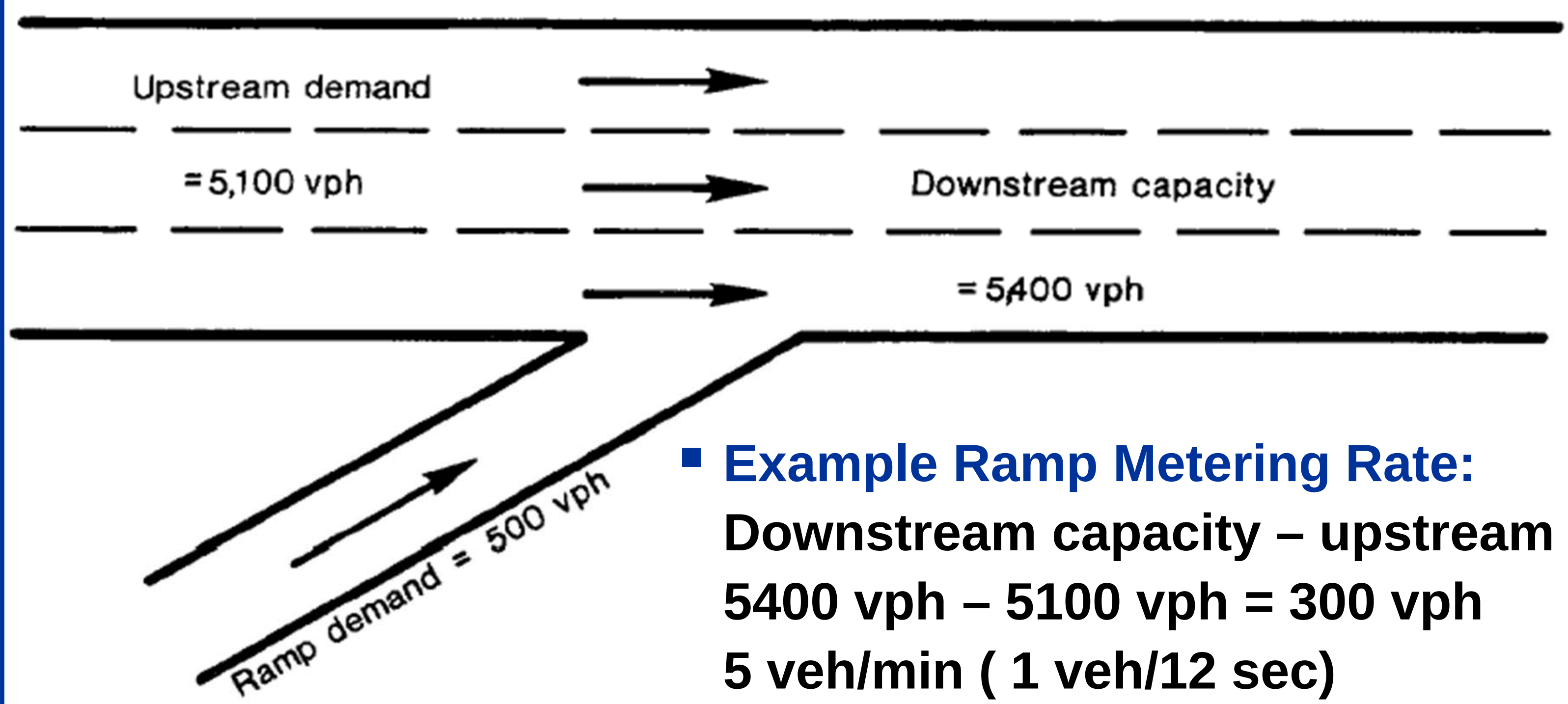
Characteristics

- Queue present upstream of the bottleneck
- Traffic discharges at "capacity" at bottleneck location
- "Free-flow" downstream
- Activation time and location reproducible over typical weekdays



Ramp Metering: Objectives

- Control the entry of on-ramp vehicles so downstream freeway capacity is not exceeded
- Improve safety—break up merging platoons



- **Example Ramp Metering Rate:**

  Downstream capacity – upstream demand

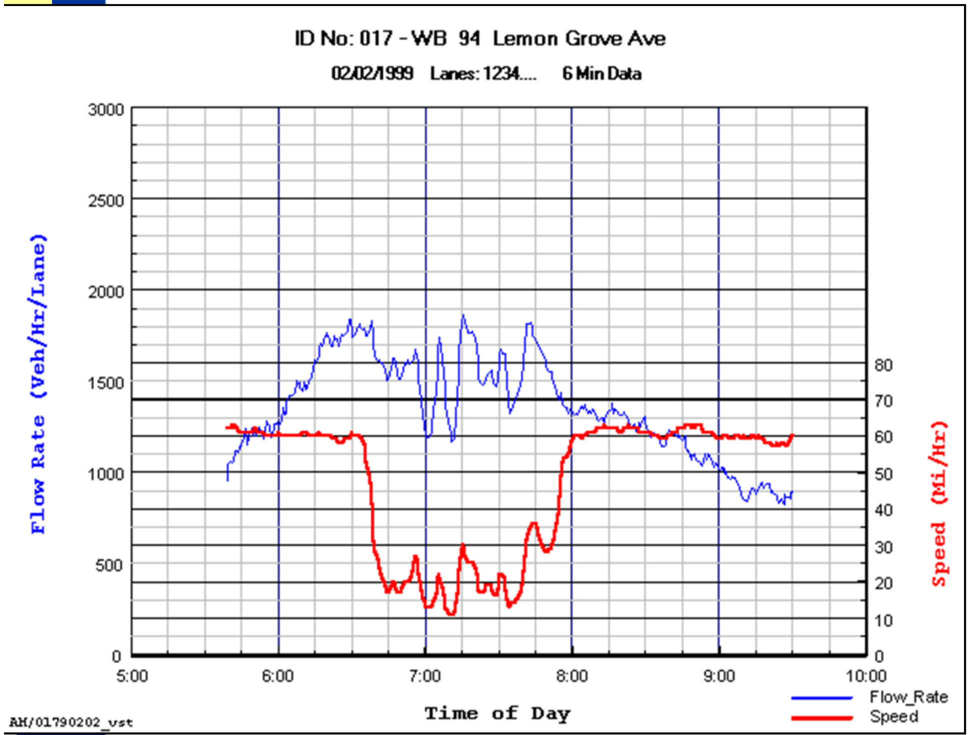
  5400 vph – 5100 vph = 300 vph

  5 veh/min (1 veh/12 sec)

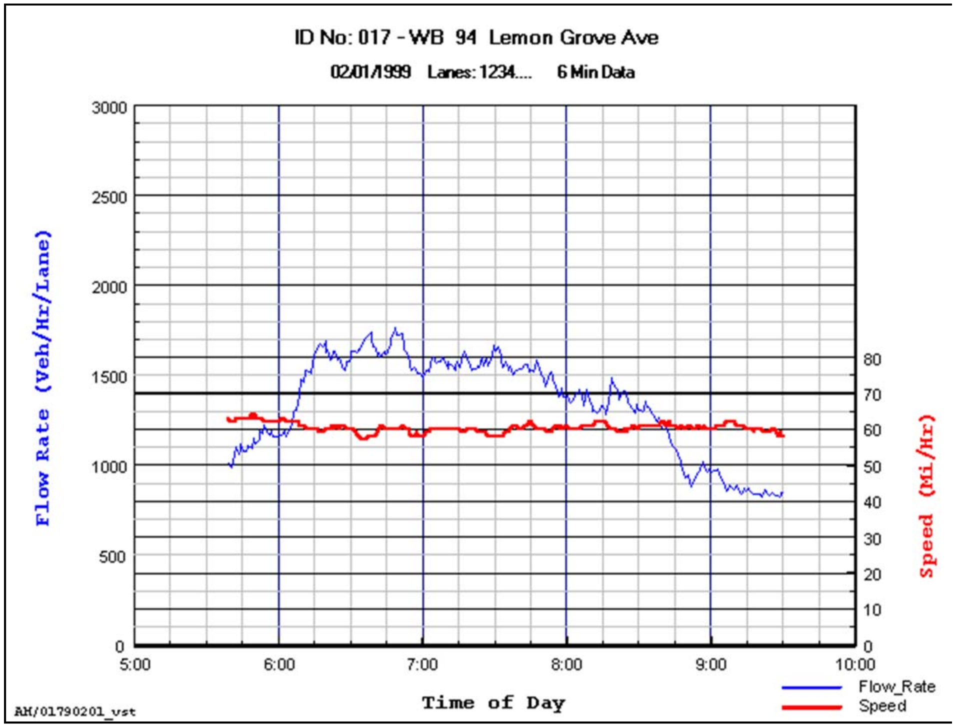
Why Ramp Metering: Example

- Control the entry of on-ramp vehicles so downstream capacity is not exceeded
- Maximize freeway throughput, minimize time spent
- Preserve freeway capacity

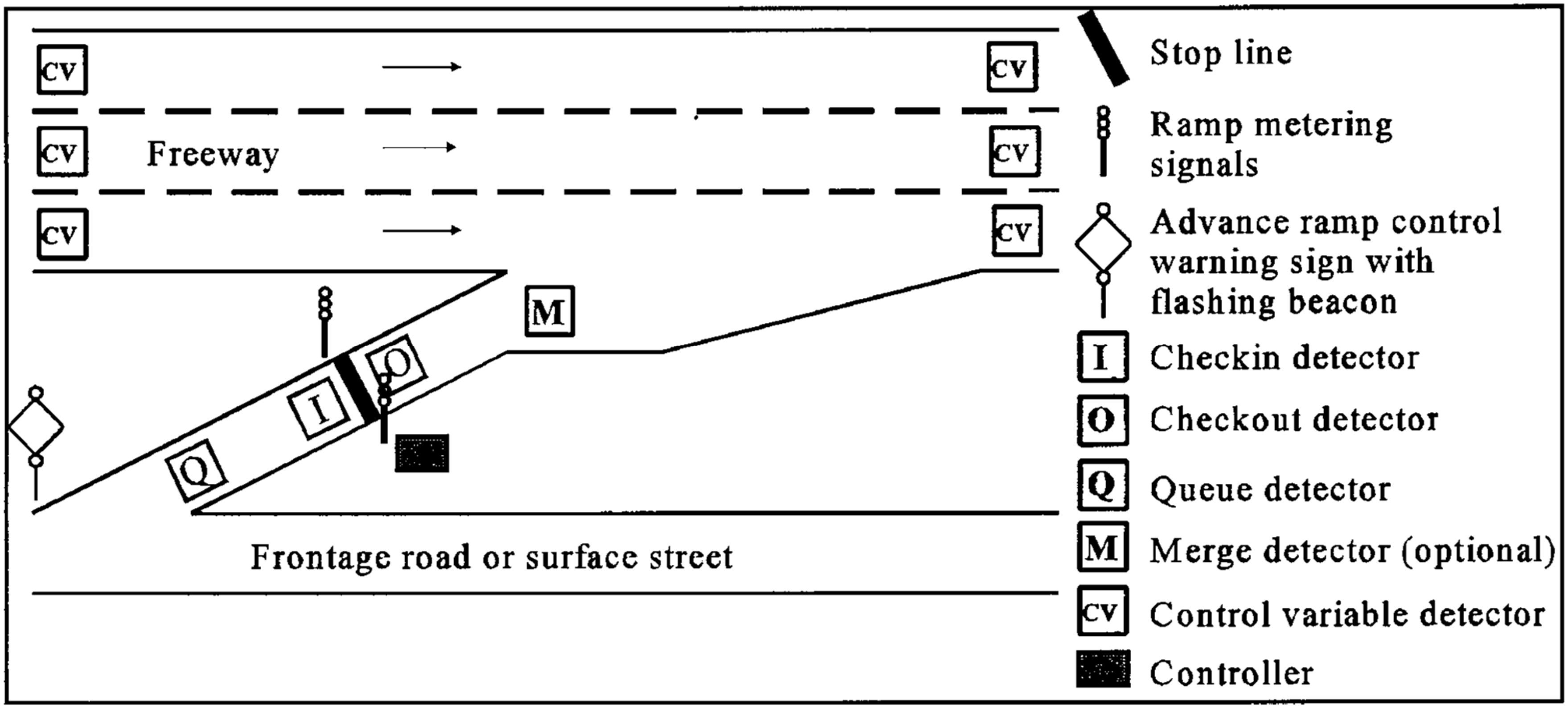
Fwy mainline: no metering



Fwy mainline: metering



Ramp Metering Implementation



CV: Sensors for traffic responsive control

Ramp Metering Rates

Types of Metering	Number of Metered Lanes	Approximate Range of Metering Rates (v/hr)	Comments
Single vehicle entry per green interval	1	240 – 900 (4)	• Full stop at the meter usually not achieved at 900 v/hr metering rate
Tandem Metering Single vehicle entry per green interval per lane	2	400 – 1700	• Applies when required metering rate exceeds 900 v/hr • Requires two lanes for vehicle storage • Vehicles may be released from each lane simultaneously or sequentially
Platoon Metering Single lane multiple vehicle entry per green interval geometrics	1	240 – 1100 (4)	• Platoon lengths permit passage of 1 to 3 vehicles per green interval • Principally used to increase metered volumes when geometrics do not permit use of more than one metered lane • Requires changeable sign indicating permitted number of vehicles in green interval • MUTCD requires yellow interval after green

Ramp Metering Strategies

- **Pretimed (Fixed-Time) Metering-- Historical data**

  Time-of-day (TOD) control

- **Traffic Responsive Metering-- Surveillance data**

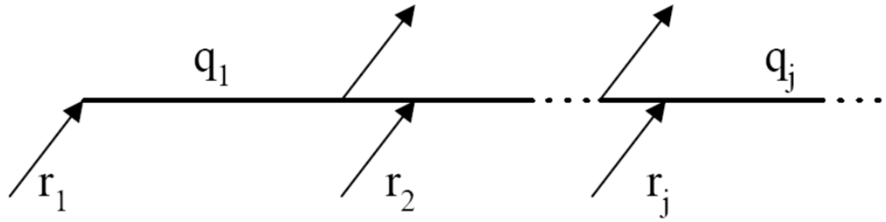
  Local traffic responsive

  - **Demand-Capacity (open loop, upstream detection)**
  - **ALINEA (closed loop, downstream detection)**

  System-wide traffic responsive

  - **ZONE**
  - **Bottleneck**
  - **SWARM**
  - **HEROS**

Ramp Metering: Fixed Time--TOD



$$q_j = \sum_{i=1}^{j} \alpha_{ij} \cdot r_i$$

- Allocate freeway resources so as to preserve freeway's limited capacity:

$$q_j \le q_{cap,j} \quad \forall j$$

- Constraints:

$$0 < r_{j,min} \le r_j \le \min\{r_{j,max}, d_j\}$$

  - Vehicles served $\rightarrow$Max

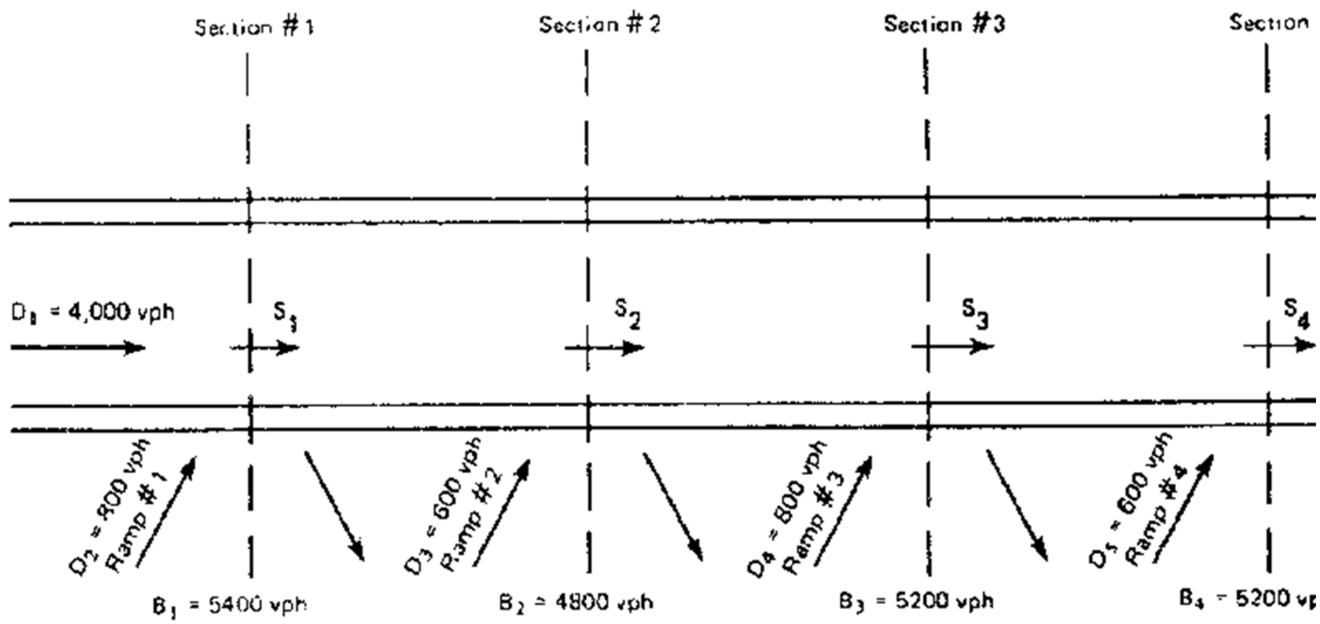
$$S = \sum r_j \rightarrow \text{Max}$$

  - Travel distance $\rightarrow$ Max

$$D = \sum q_j \Delta_j \rightarrow \text{Max}$$

System-wide Pretimed Metering *(1)*

- **Input**
  - Geometrics (Capacities)
  - Demands
  - O-D table



X_i = allowable volume at input i

D_i = demand at input i

B_j = capacity at section j

A_{ij} = decimal fraction of vehicles entering at input i which pass through section j

S_j = demand at section j

A_{ij} Values

i \ j	1	2	3	4
1	1.00	0.95	0.90	0.85
2	1.00	0.75	0.70	0.60
3	–	1.00	0.90	0.85
4	–	–	1.00	0.90
5	–	–	–	1.00

-ting at section #1

- Set $X_1 = D_1$ = 4000 vph

System-wide Pretimed Metering *(1)*

- **Solution**

<u>Compute X_j's starting at section #1</u>

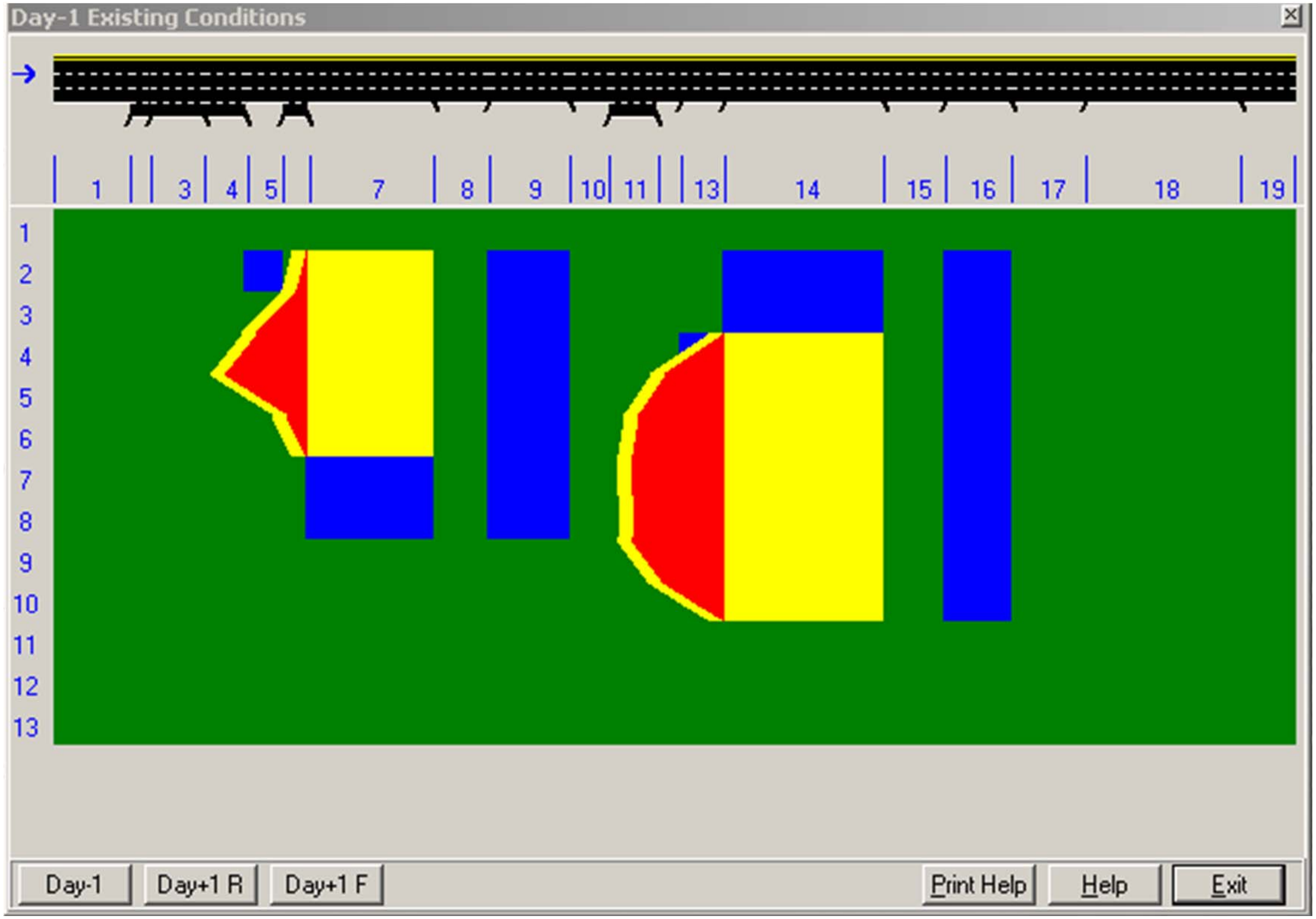
- Set $X_1 = D_1 = \underline{4000 \text{ vph}}$
- $S_1 = A_{11}X_1 + A_{21}D_2 = (1.00)(4000)+(1.00)(800) = 4800 \text{ vph} < B_1 = 5400 \text{ vph}; \therefore \underline{X_2 = 800 \text{ vph}}$
- $S_2 = A_{12}X_1 + A_{22}X_2 + A_{32}D_3 = (0.95)(4000)+(0.75)(800)+(1.00)(600) = 5000 \text{ vph} > B_2 = 4800 \text{ vph}; \therefore \underline{X_3 = 400 \text{ vph}}$
- $S_3 = A_{13}X_1 + A_{23}X_2 + A_{33}X_3 + A_{43}D_4 = (0.90)(4000)+(0.70)(800)+(0.90)(400)$
  $+ (1.00)(800) = 5320 \text{ vph} > B_3 = 5200 \text{ vph}; \therefore \underline{X_4 = 680 \text{ vph}}$
- $S_4 = A_{14}X_1 + A_{24}X_2 + A_{34}X_3 + A_{44}X_4 + A_{54}D_5 = (0.85)(4000) + (0.60)(800) + (0.85)(400) + (0.90)(680)$
  $+ (1.00)(600) = 5432 \text{ vph} > B_4 = 5200 \text{ vph}; \therefore \underline{X_5 = 368 \text{ vph}}$

<u>Conclusion:</u>

- Ramp # 1: No control needed.
- Ramp # 2 : Meter at a rate of 400 vph.
- Ramp # 3: Meter at a rate of 680 vph.
- Ramp # 4: Meter at a rate of 368 vph.

Example: Fixed-Time Metering (1)

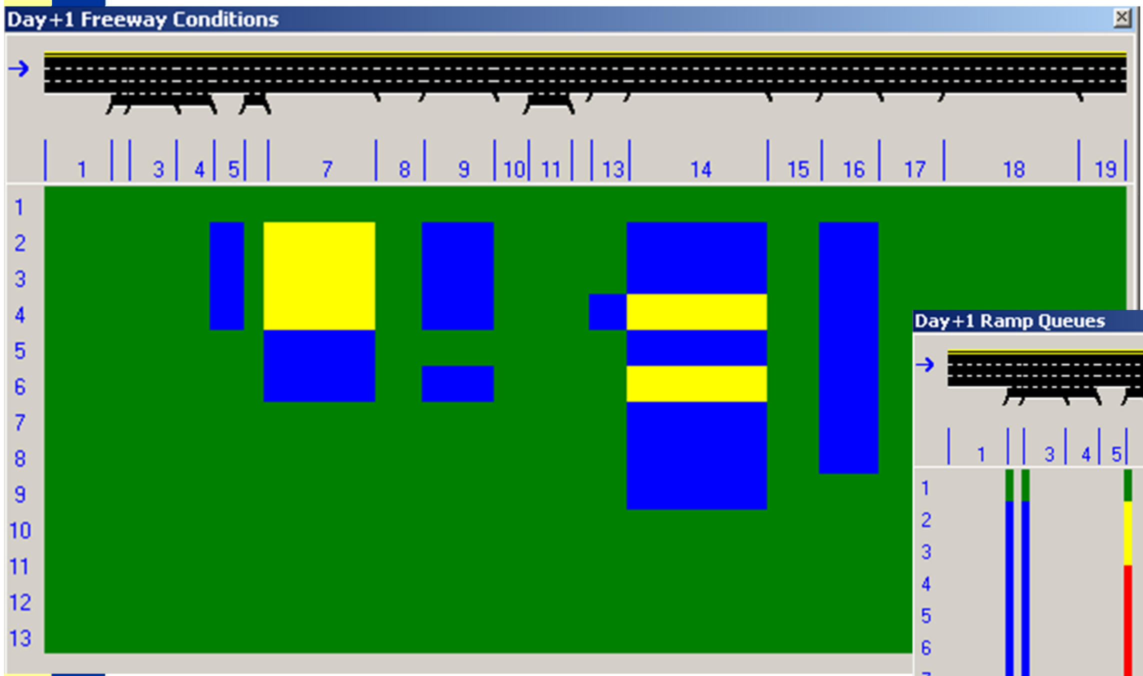
1. **Existing Conditions—Freeway**



Example: Fixed-Time Metering (2)

Fixed-Time Metering – No ramp constraints

Freeway Mainline



Ramp Queues

Example: Fixed-Time Metering (3)

Fixed-Time Metering – Ramp constraints

Freeway Mainline

Ramp Queues

Trade-off:

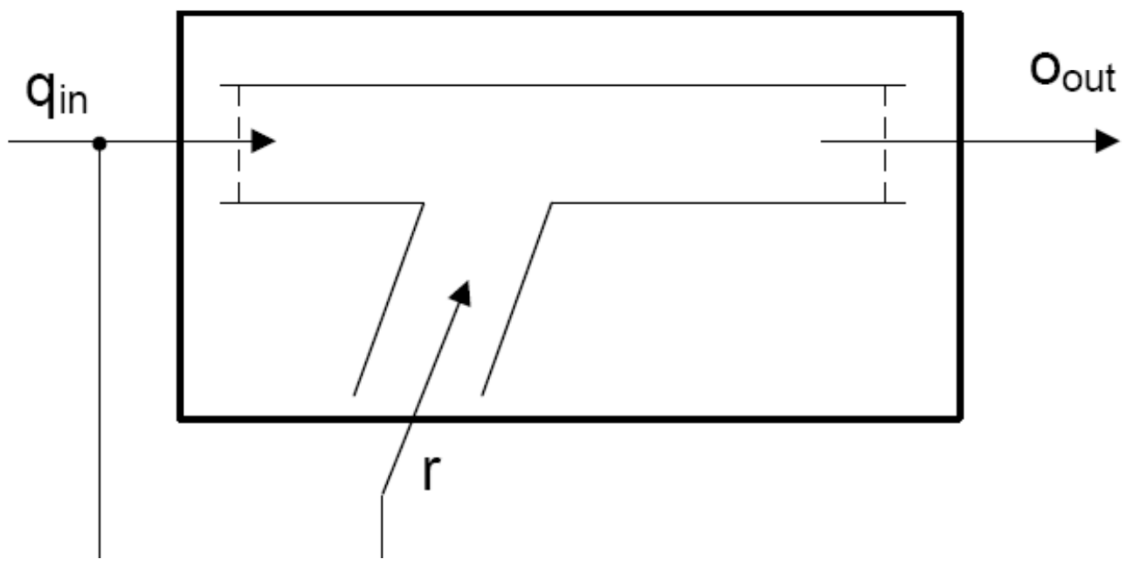
Mainline Congestion vs. Ramp Queue

Ramp Metering: Issues

- **Ramp Queues and Delays**
  - Ramp storage
  - Spillback to local street network
  - Excessive delays
  - HOV by-pass
- **Diversion**
  - Short trips
  - Alternate ramps
- **Equity**
  - Short trips vs. long commute

Ramp Metering: Local Traffic Responsive

Demand-Capacity Metering

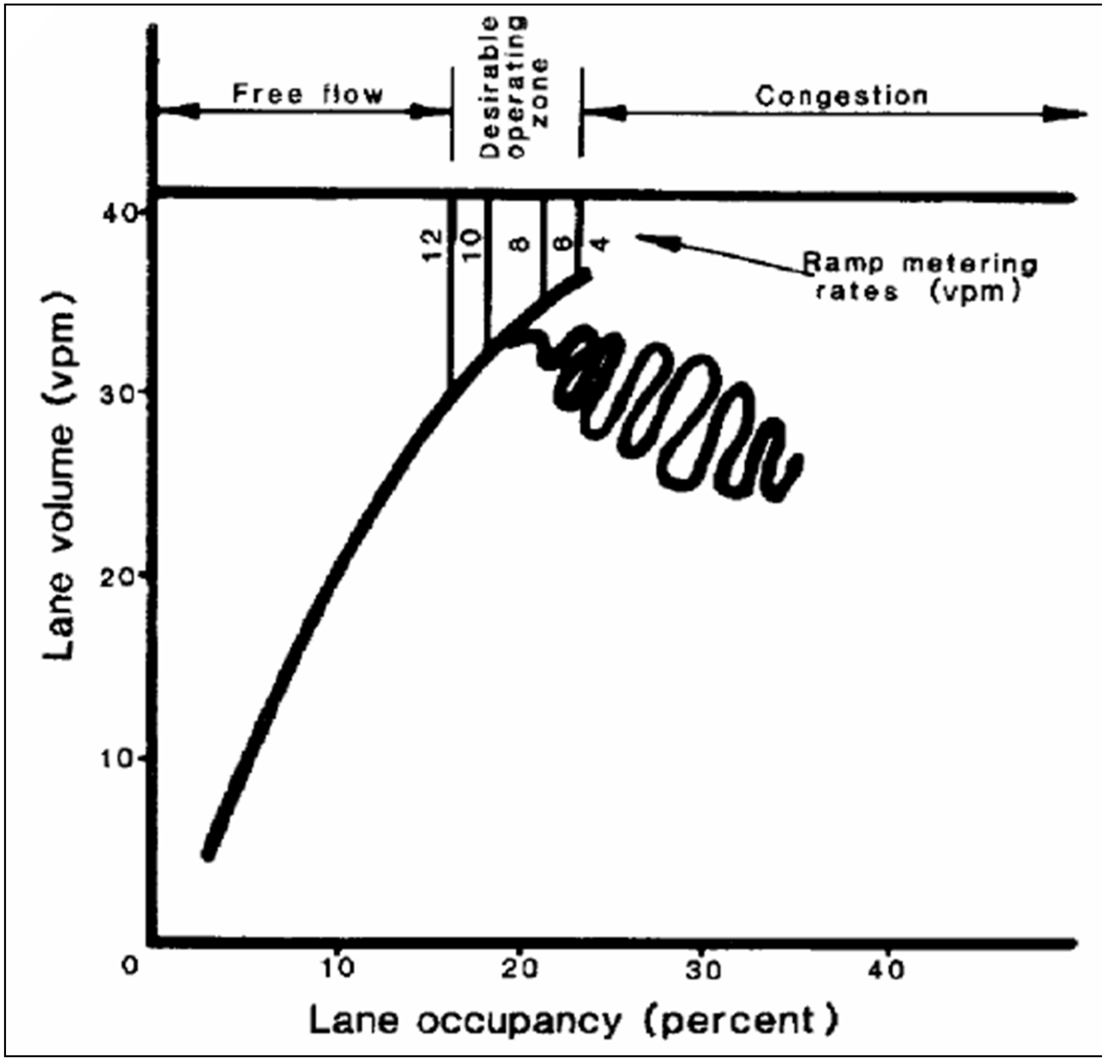


Demand-Capacity Metering

Implemenation

OCCUPANCY (%)	METERING RATE (veh/min)
< 10	12
11-16	10
17-22	8
23-28	6
29-34	4
>34	3

Fwy mainline upstream

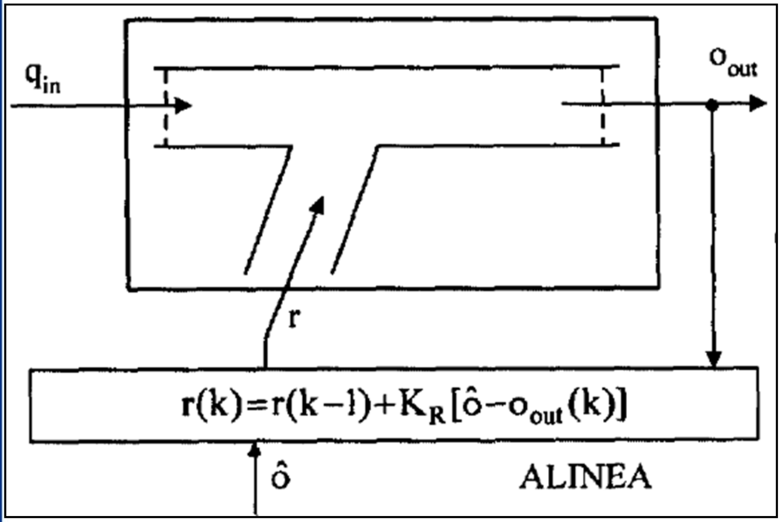


ALINEA Algorithm

- **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

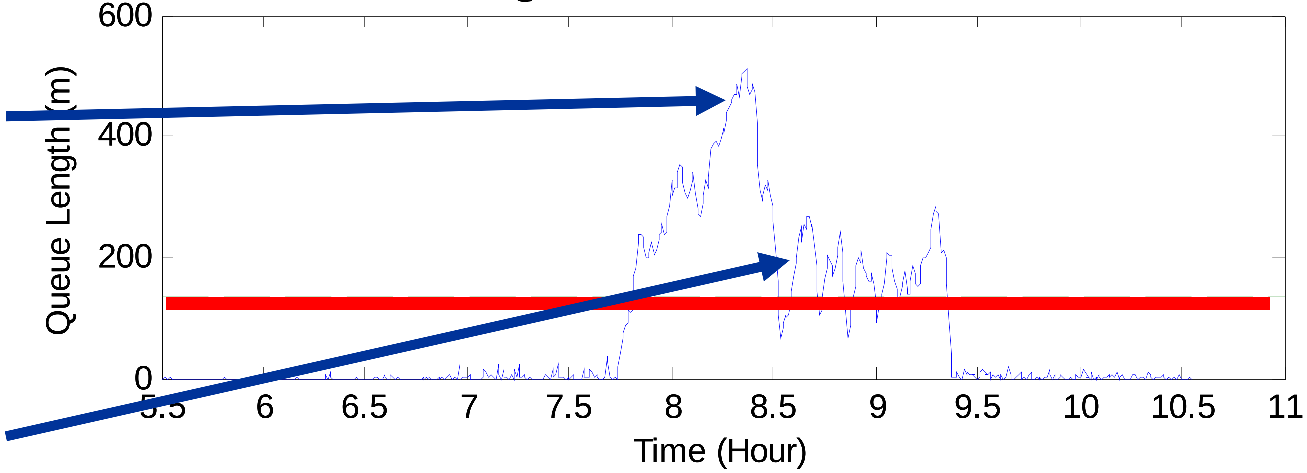


On-Ramp Queue Control Regulator (1)

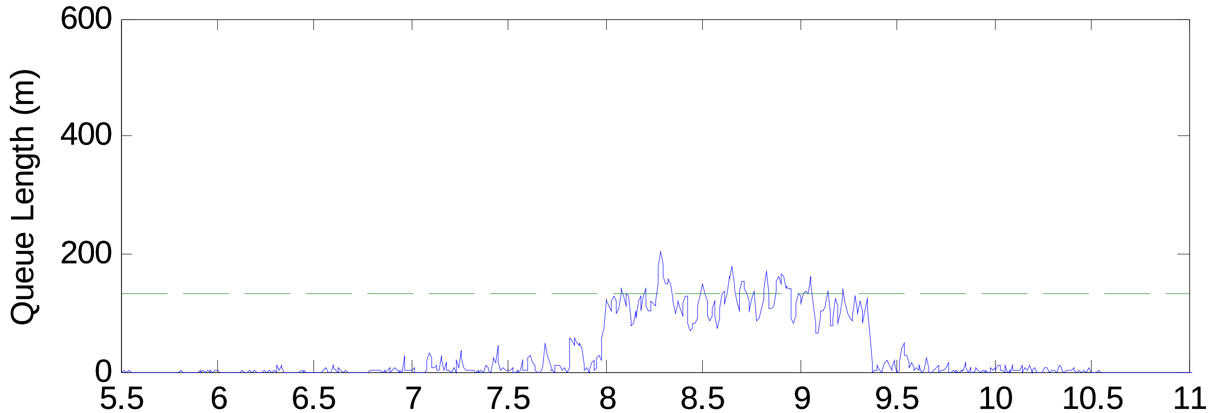
Queue Override

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

Queue Override



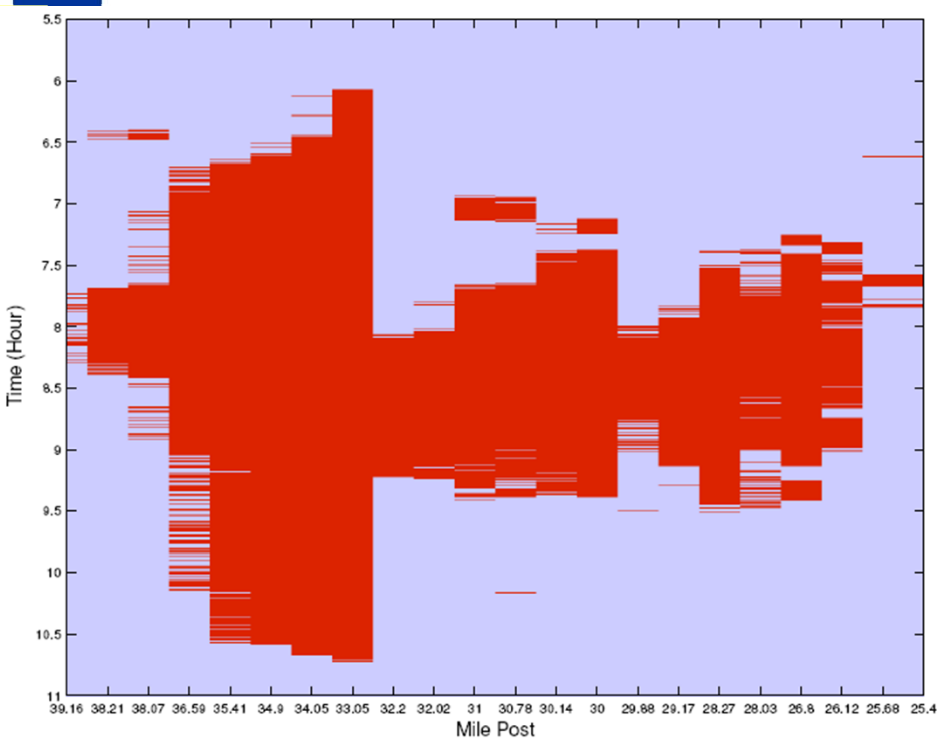
Queue Estimation & Control



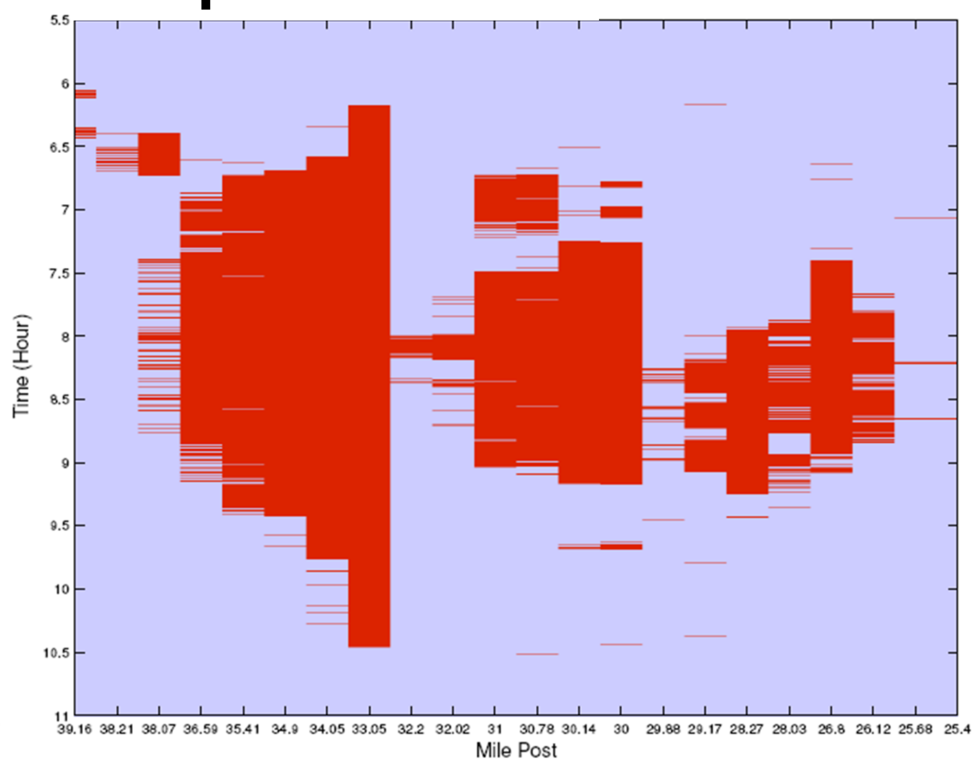
On-Ramp Queue Control Regulator (2)

Los Angeles I-210W Results

Existing



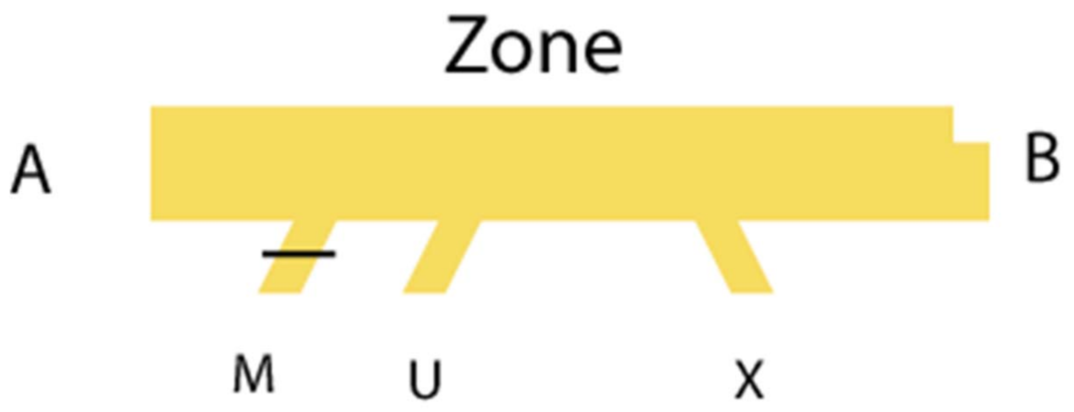
Proposed



- **6% Travel Time Reduction**
- **16% Delay Reduction**

Zone Algorithm (1)

- Minneapolis/St. Paul area along I-35 East in 1970
- Balance the volume entering & leaving the zone
- Each zone:
  - 3-6 miles long
  - upstream boundary : free-flow area
  - downstream boundary : bottleneck



$$A+U+M \leq X+B+S$$

Zone Algorithm (2)

where

S: the spare capacity available within the zone (estimated from the current and free-flow density)

U: Un-metered volume (example: fwy-to-fwy connector)

Maximum allowable volume:

$$M \leq (X + B) - (A + U)$$

Metering rate:

$$R_r = f_r M$$

f_r : Ramp factor

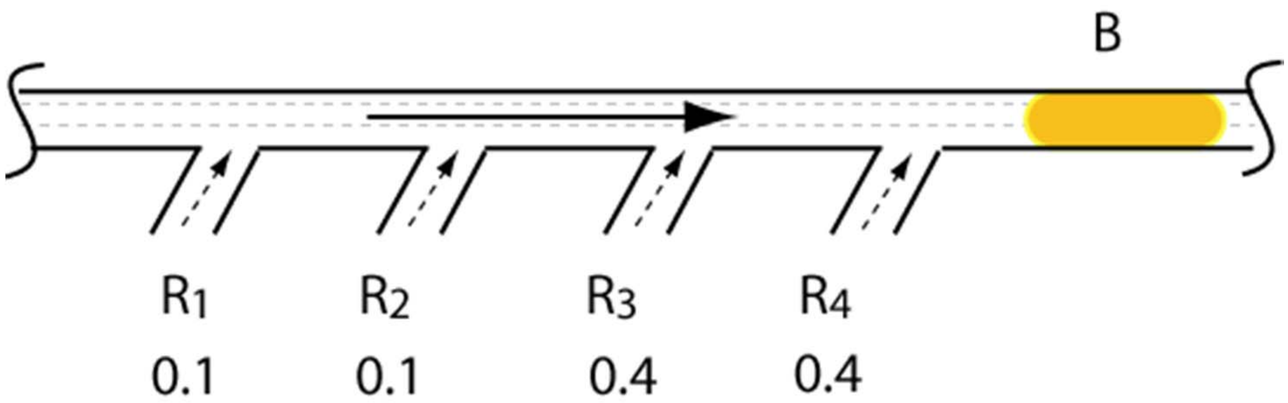
Bottleneck Algorithm

Implemented on I-5 in Seattle by WSDOT

- Two level formulation:
  - (1) Local traffic responsive
  - (2) Global volume adjustment

    Determine total volume reduction based on section bottleneck capacity

    Adjust metering rate = volume reduction × weighting factor



Implement the most restrictive metering rate

SWARM Algorithm (1)

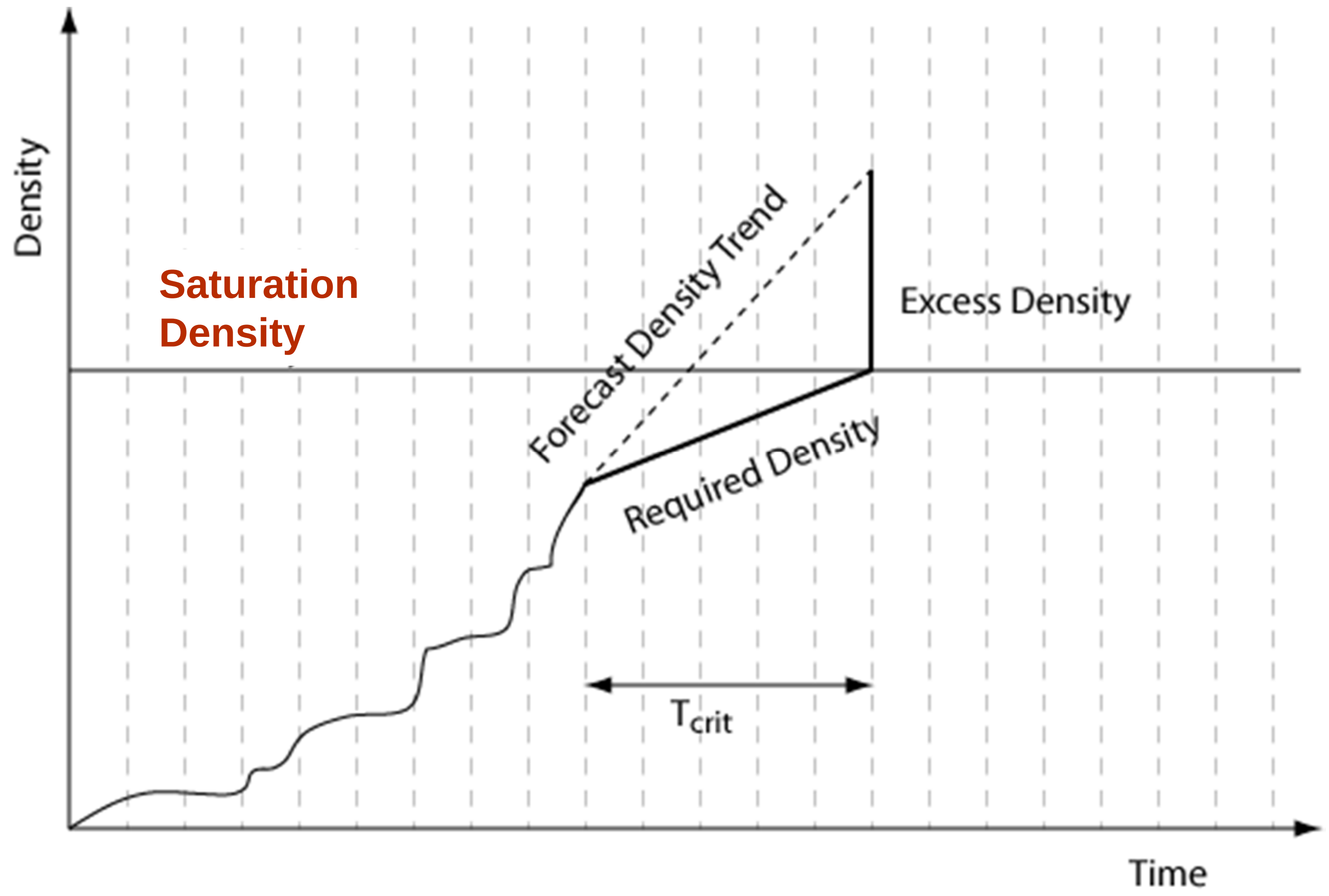
System-wide Adaptive Ramp Metering

Developed by Delcan (NET) for Caltrans

Implementations: California (Orange County, Los Angeles), Oregon (Portland) & Georgia (Atlanta)

- **SWARM consists of swarm1 and swarm2**
- **Swarm2 is a local traffic responsive algorithm-- currently replaced by ALINEA**
- **Swarm1 is a forecasting global apportioning algorithm**
- **Implement the more restrictive metering rate**

SWARM Algorithm (2)



T_{crit} = 7-10 min (prediction horizon)

SWARM Algorithm (3)

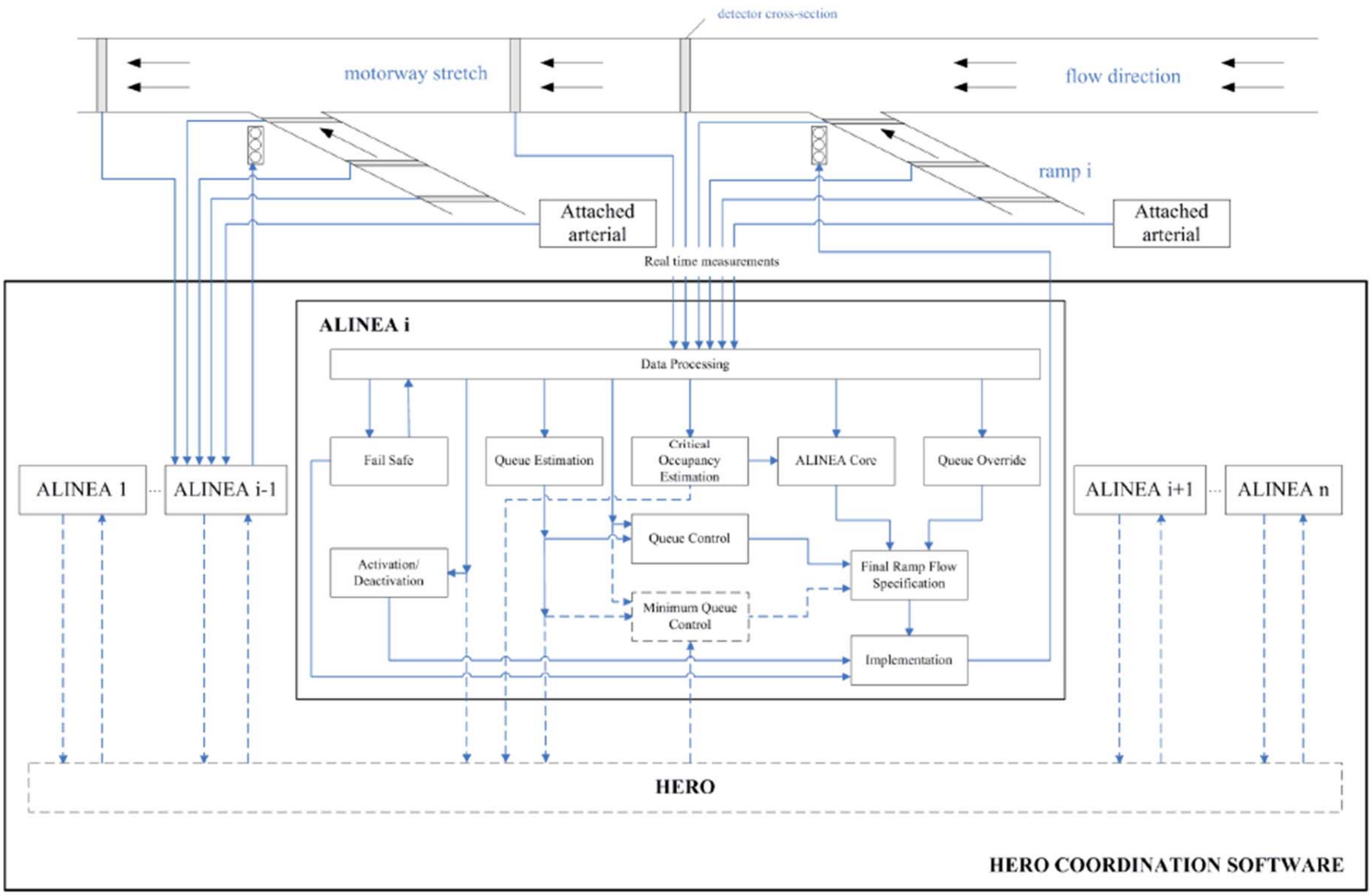
Predicted density = current density + trend * T_{crit}

Target density =
(current density) – ($1/T_{crit}$) * (excess density)

Volume reduction =
(local density – target density) * (# lanes)* (distance to next station)

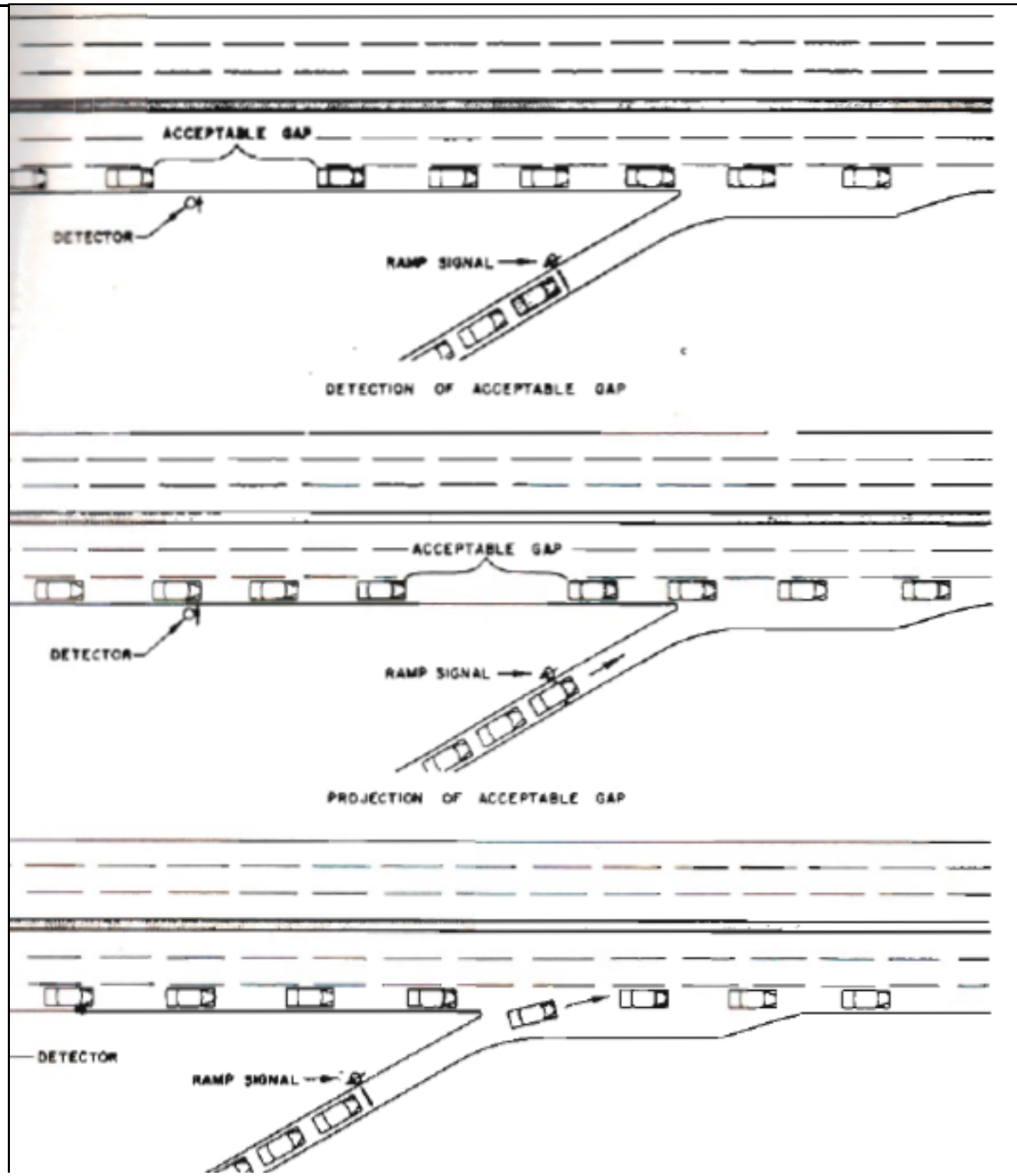
Ramp reduction = volume reduction * weighting factor

HERO
(HEuristic Ramp metering cOordination)



Gap Acceptance Ramp Control

HISTORY



Moving Merge System