Risk-Aware Active Traffic Management

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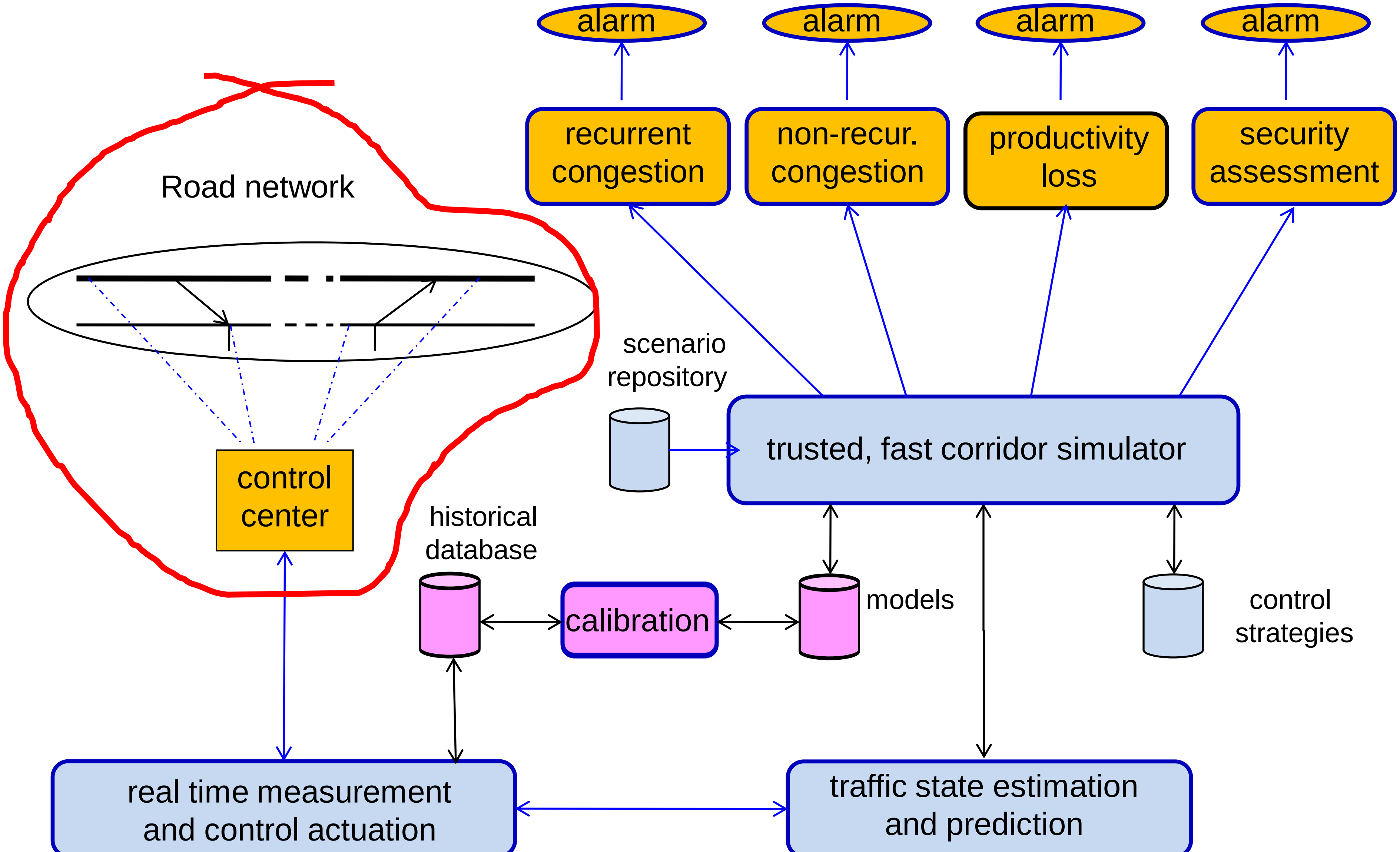
Aurora software and data available at
http://path.berkeley.edu/topl/
http://pems.eecs.berkeley.edu

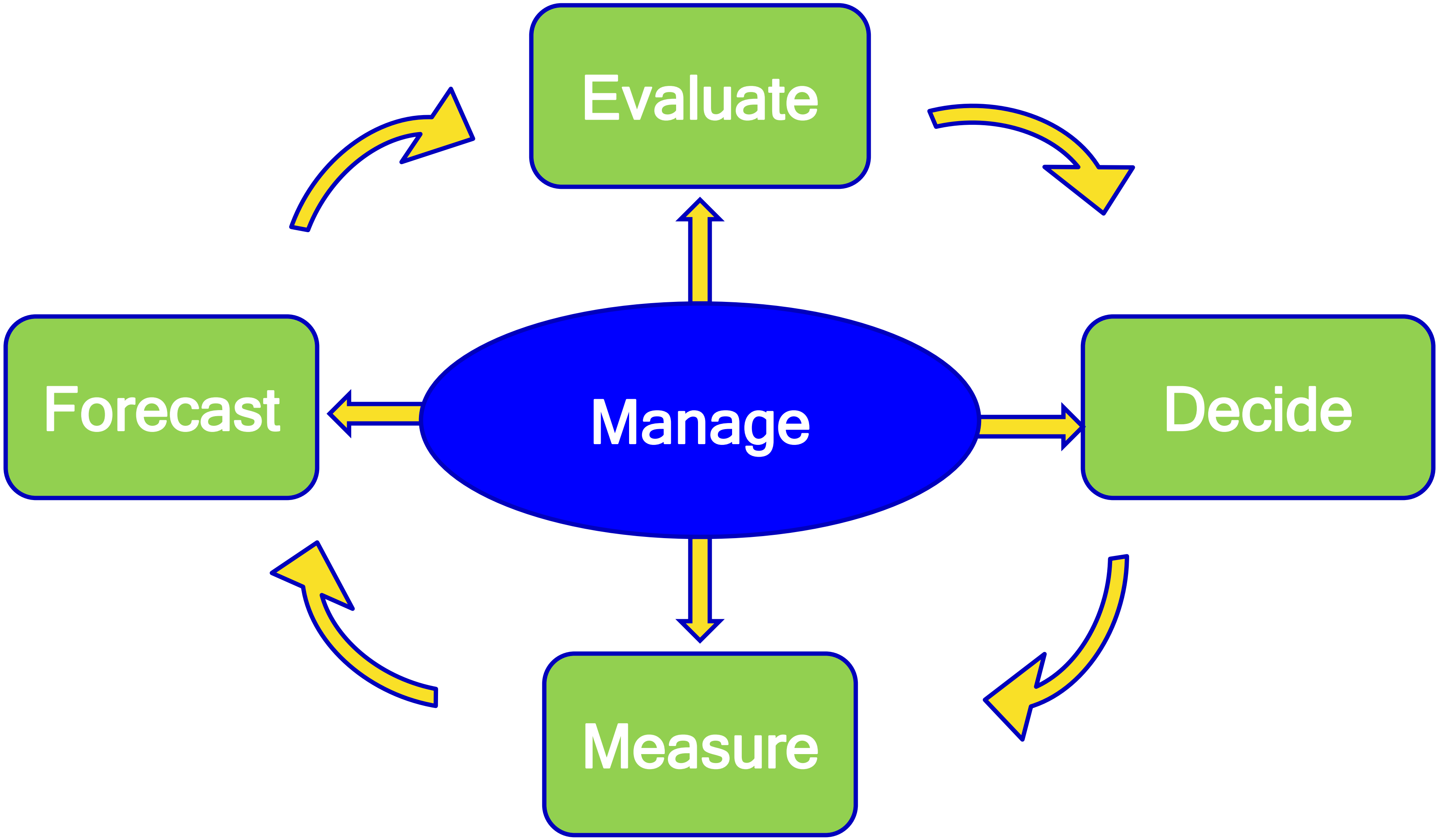
Outline

- What is ATM?
- Database support for ATM
- Detection infrastructure
- Theory: the Cell Transmission Model (CTM)

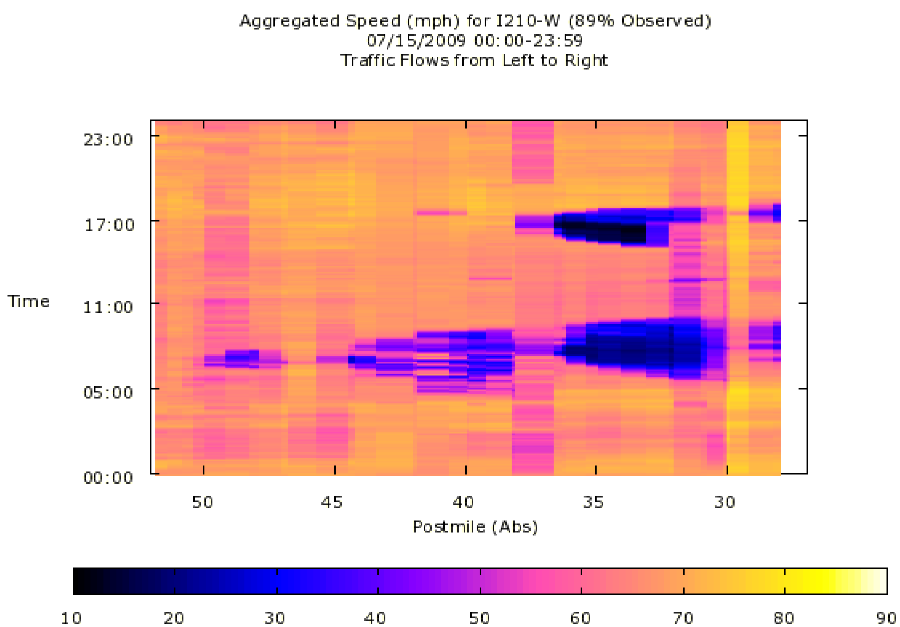
ATM workflow

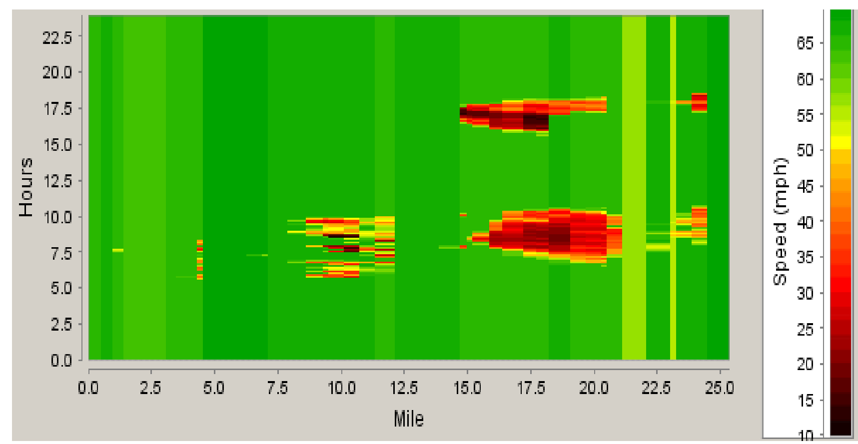


Active management

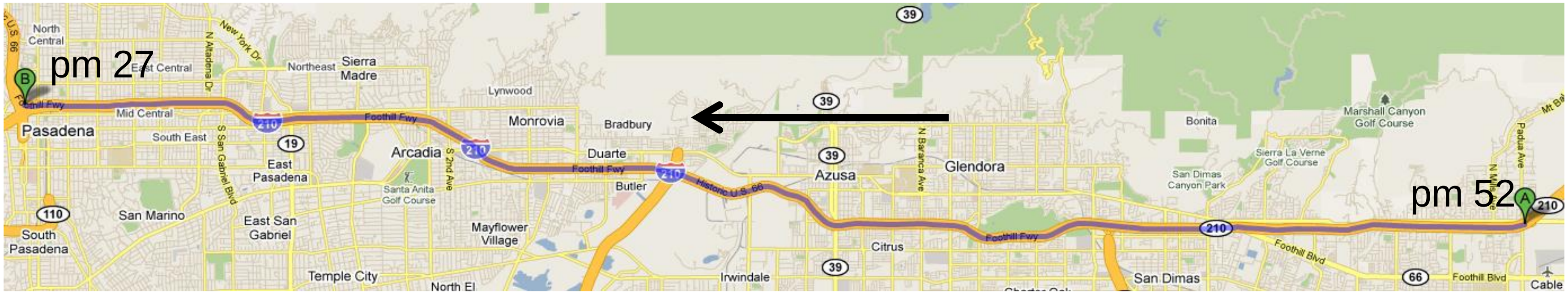


I-210 West on July 15, 2009: speed contours



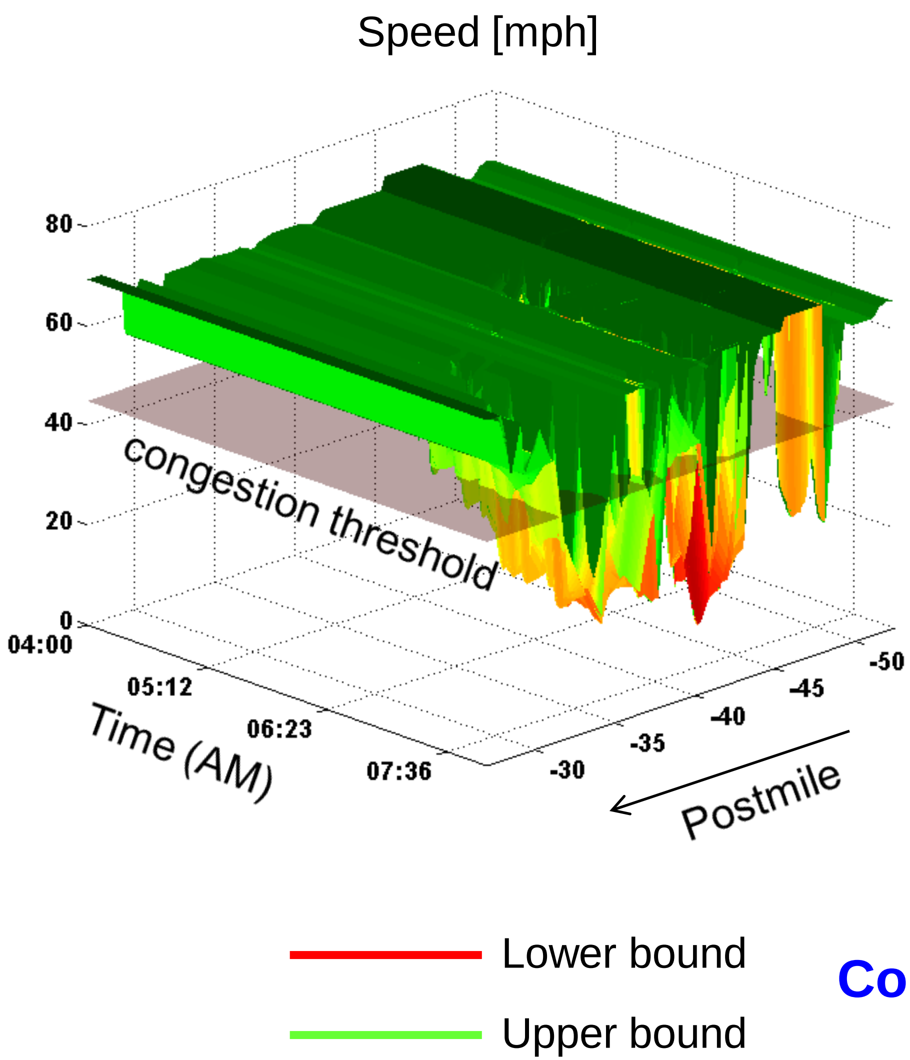


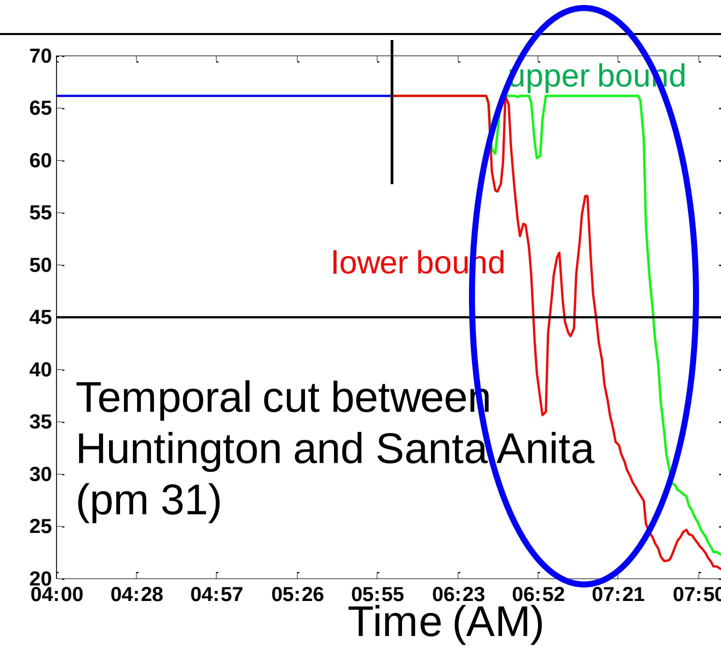
I-210 West on July 15, 2009: assumptions

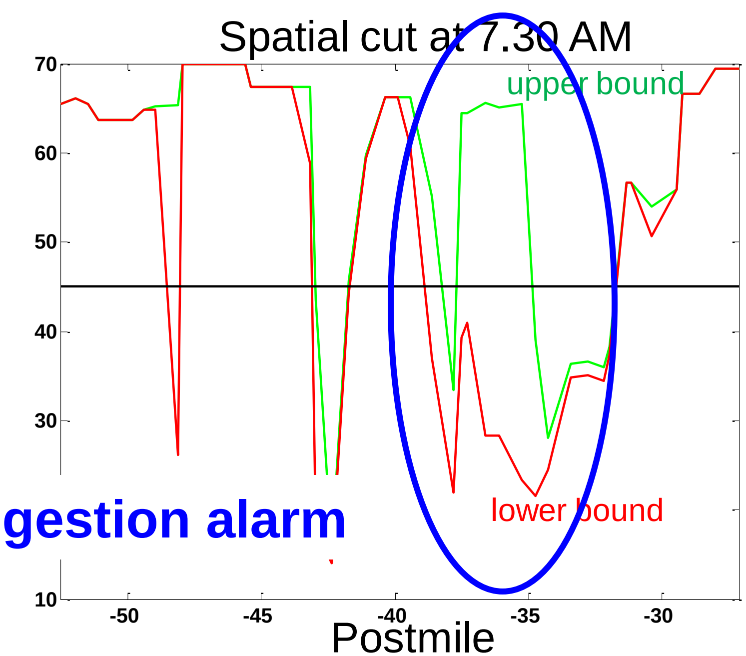


- Measure during 4AM-6AM
- Forecast 6AM-8AM, with +/- 2% demand uncertainty

Forecast of speed

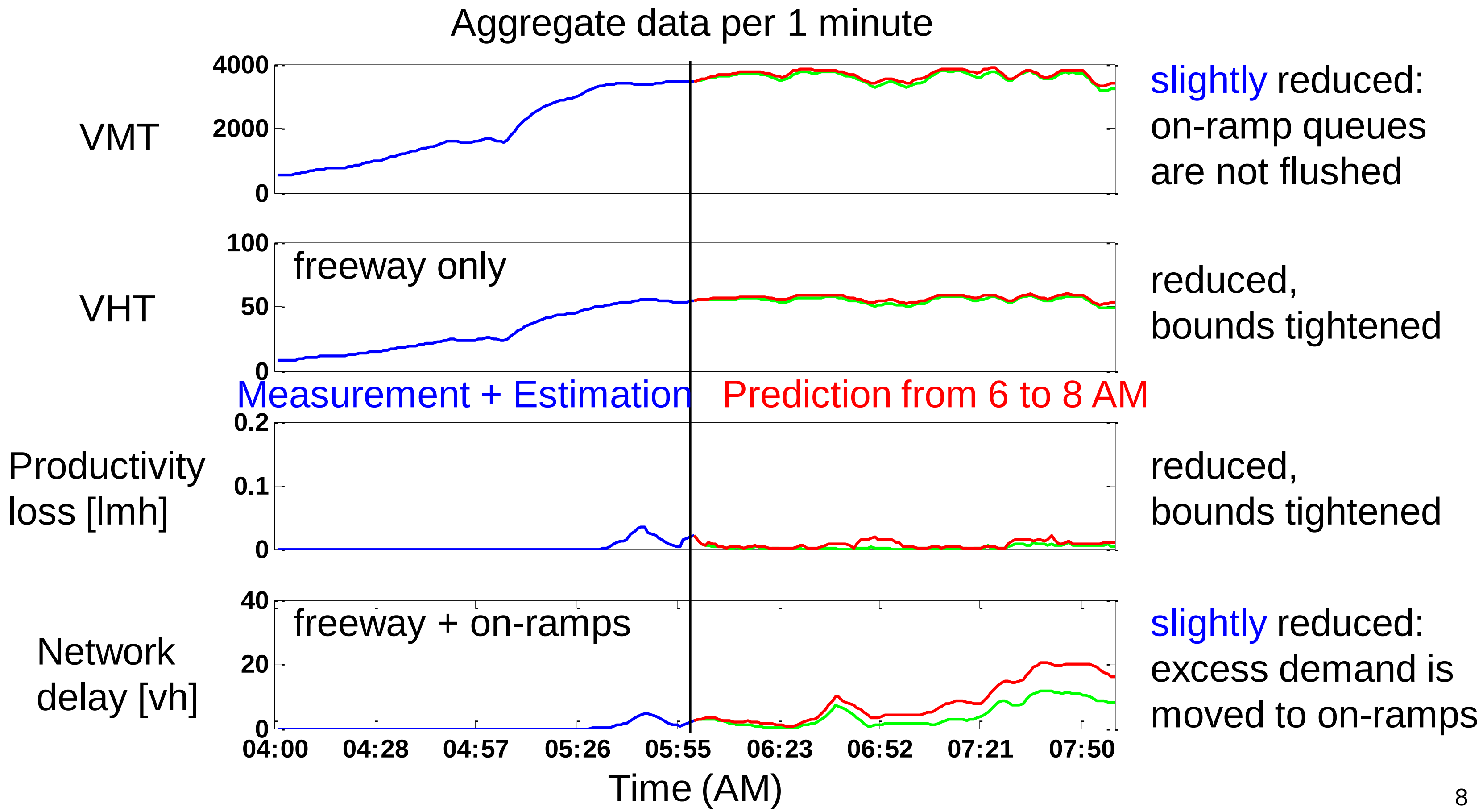




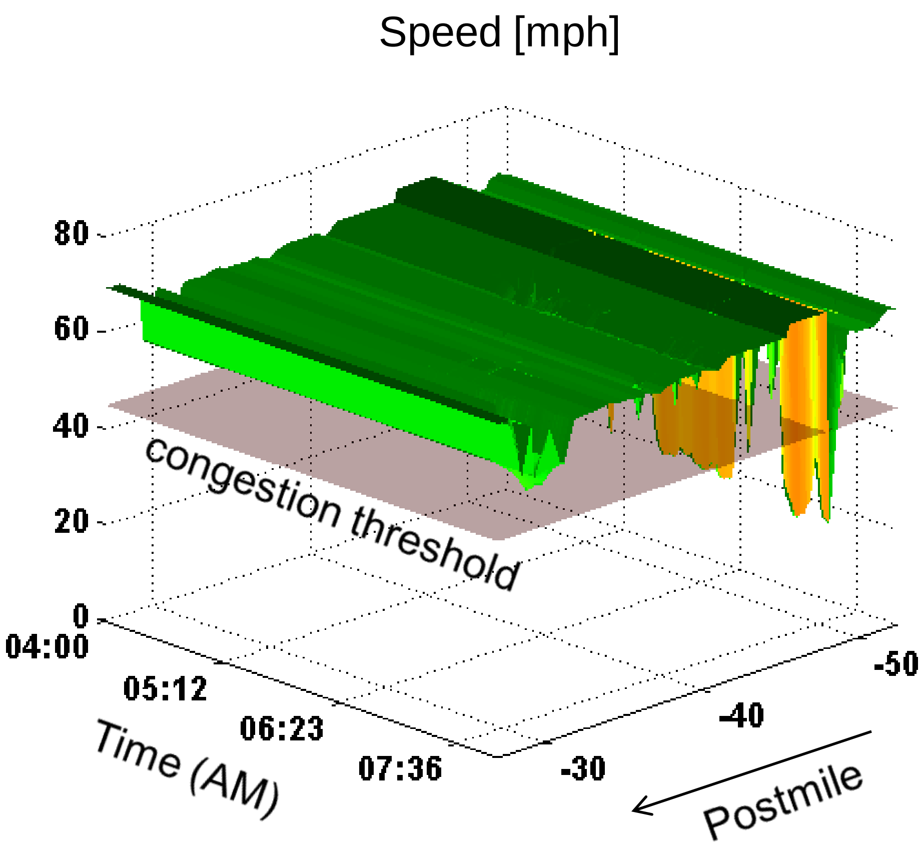


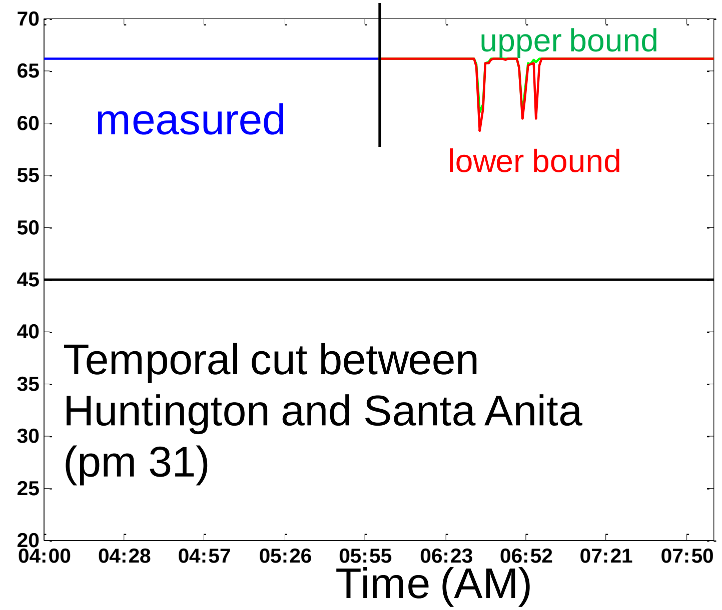
Congestion alarm

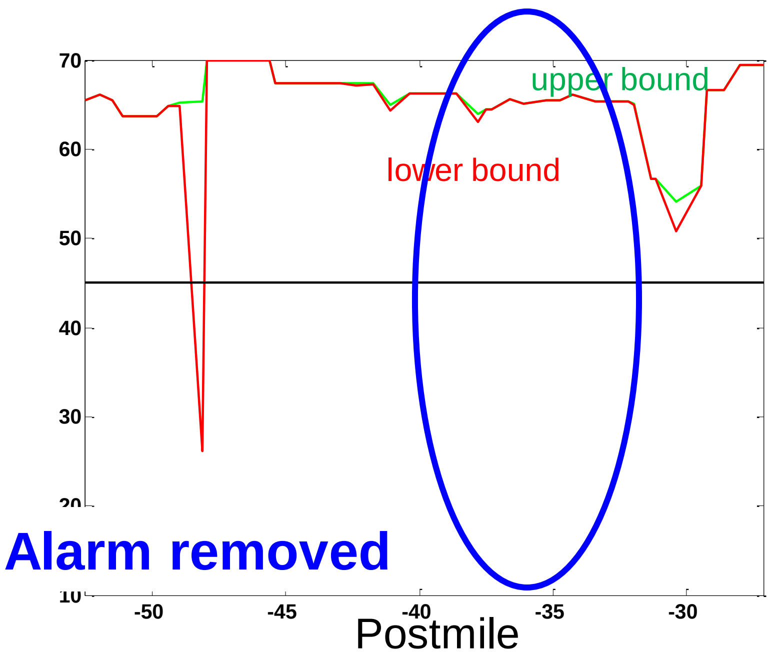
Predicted impact of ALINEA: 6-8 AM



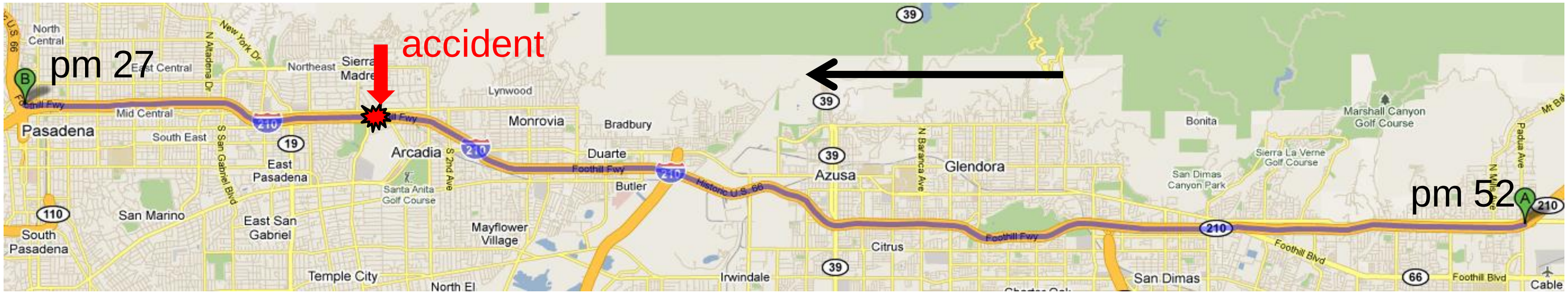
Forecast of speed under ALINEA





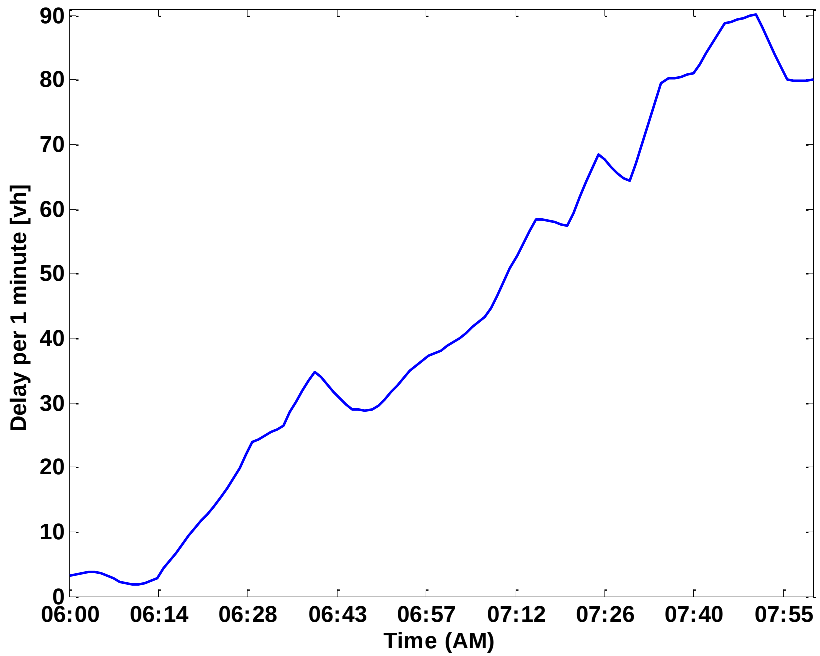


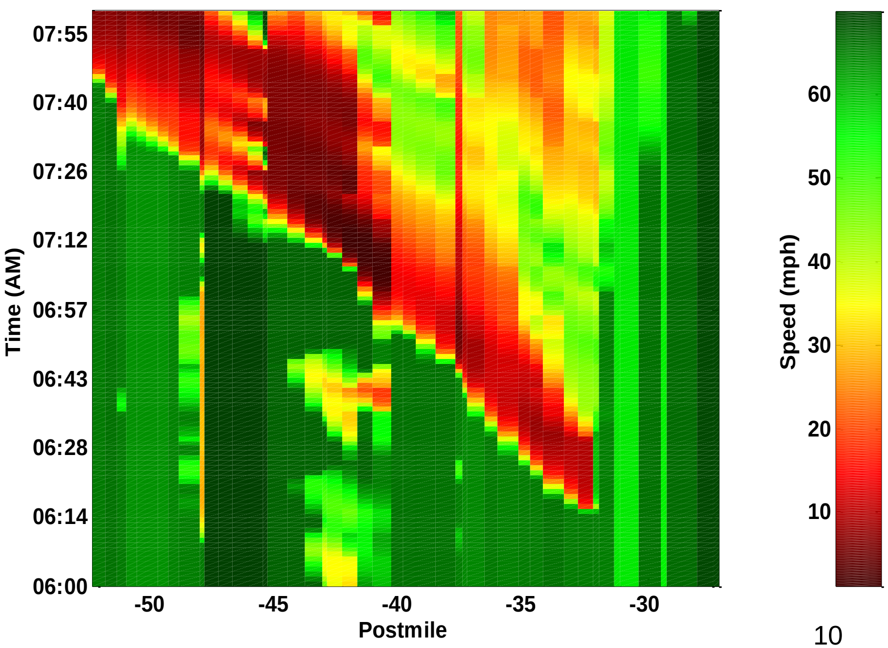
Scenario: accident near Baldwin



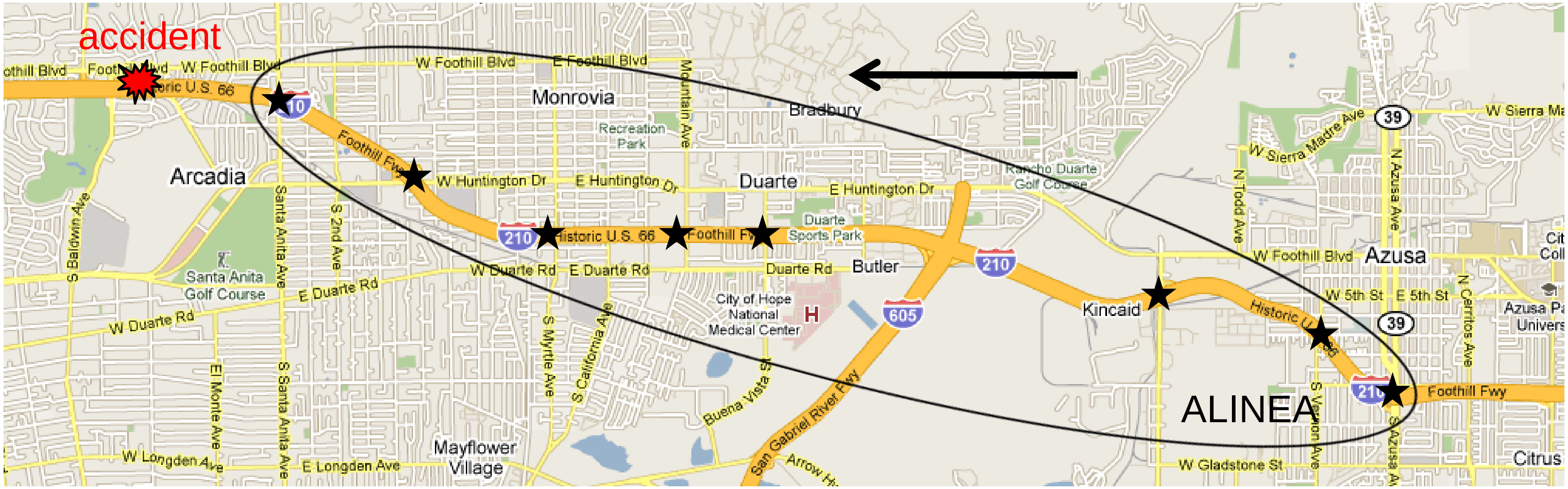
- 6.15 AM: freeway capacity is reduced by 50%
- 6.30 AM: road cleared, capacity is back to normal

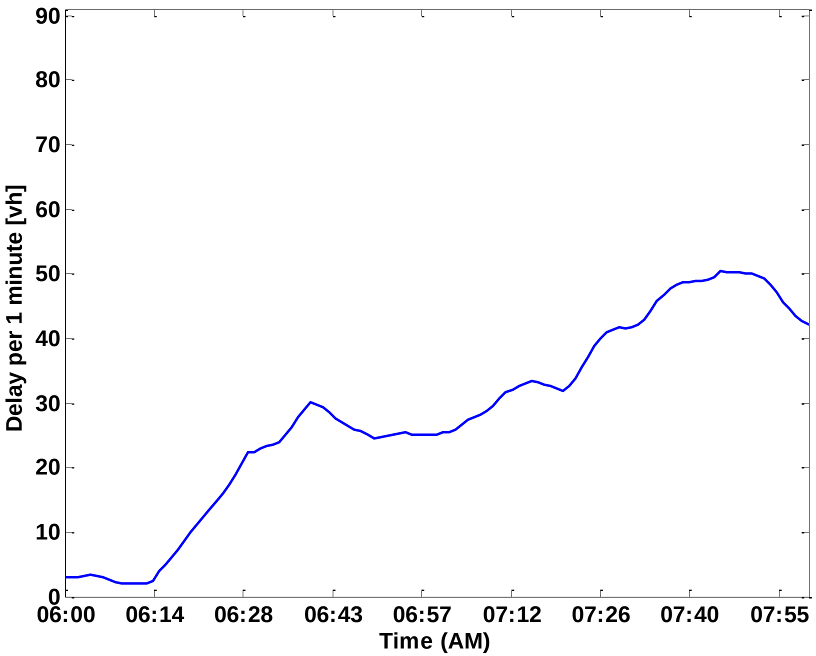
Worst case

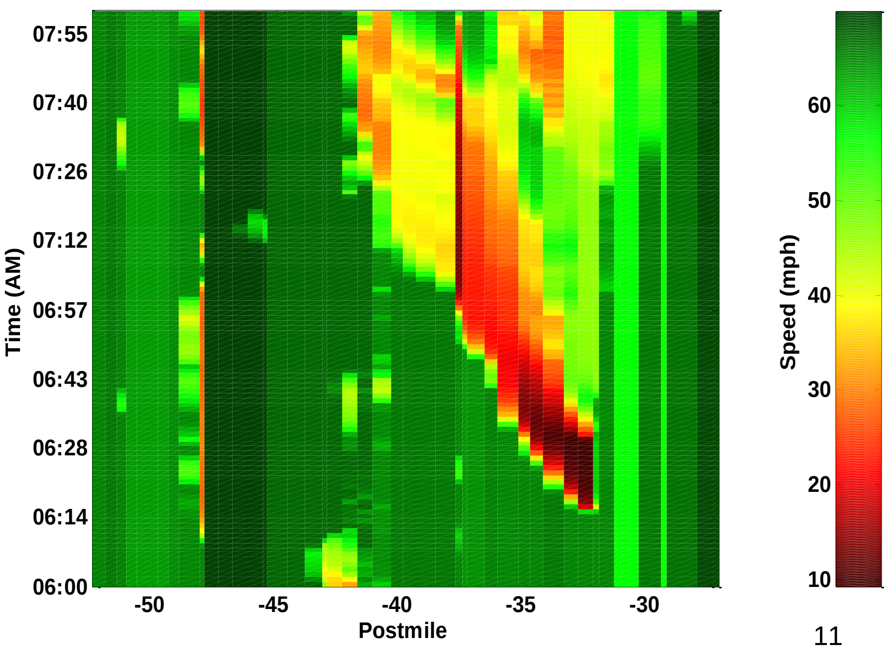




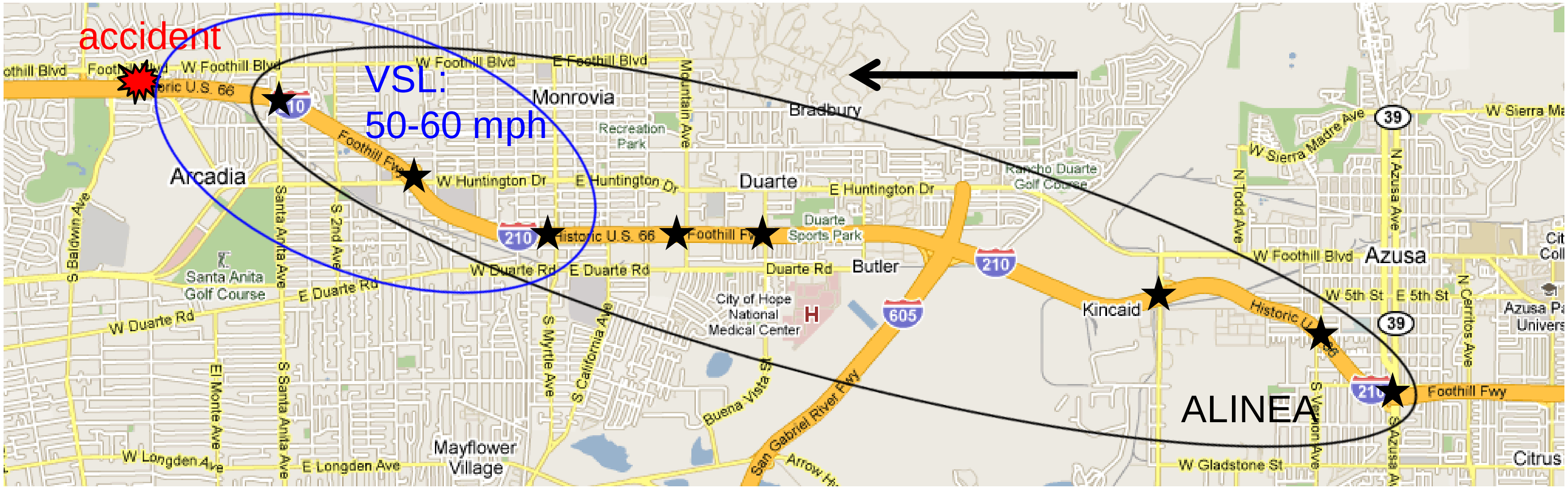
Strategy 1: ALINEA

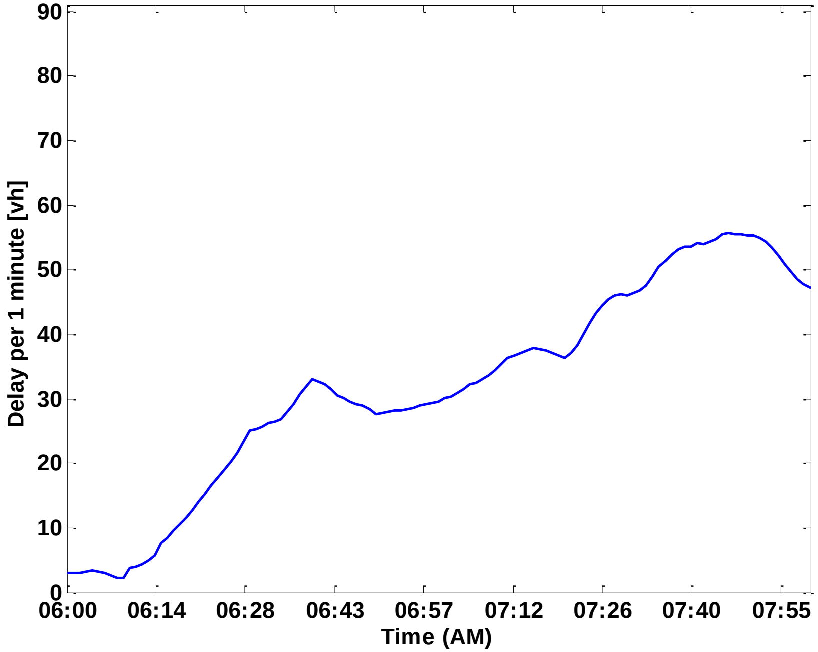


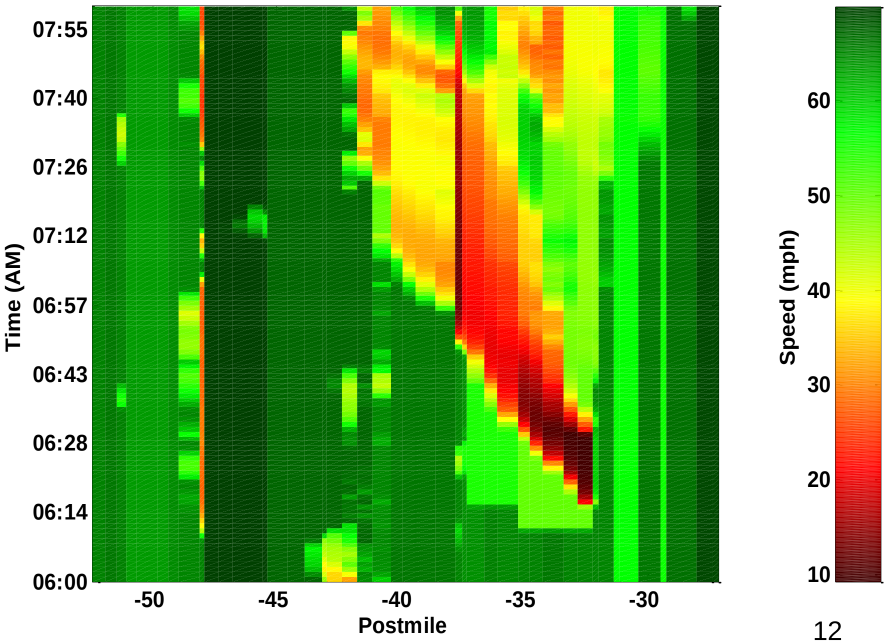




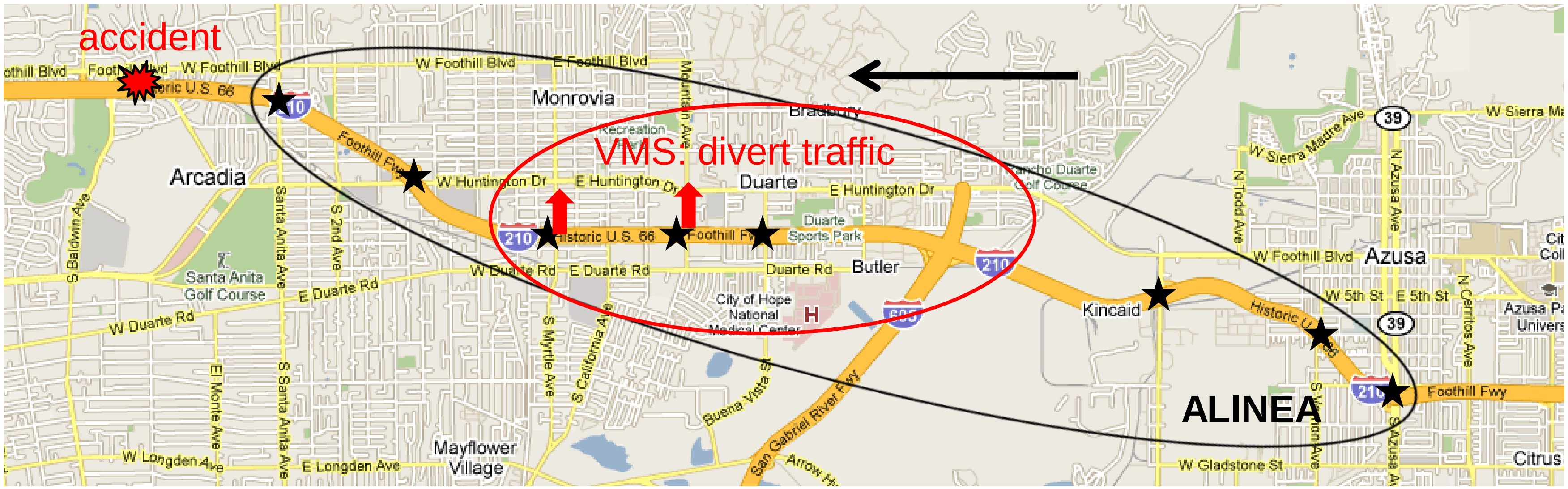
Strategy 2: ALINEA + VSL control

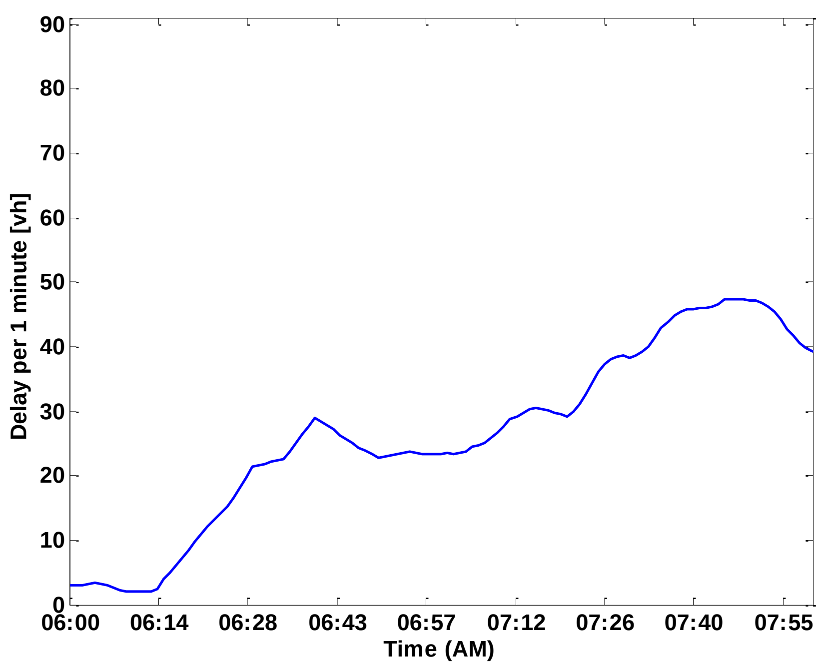


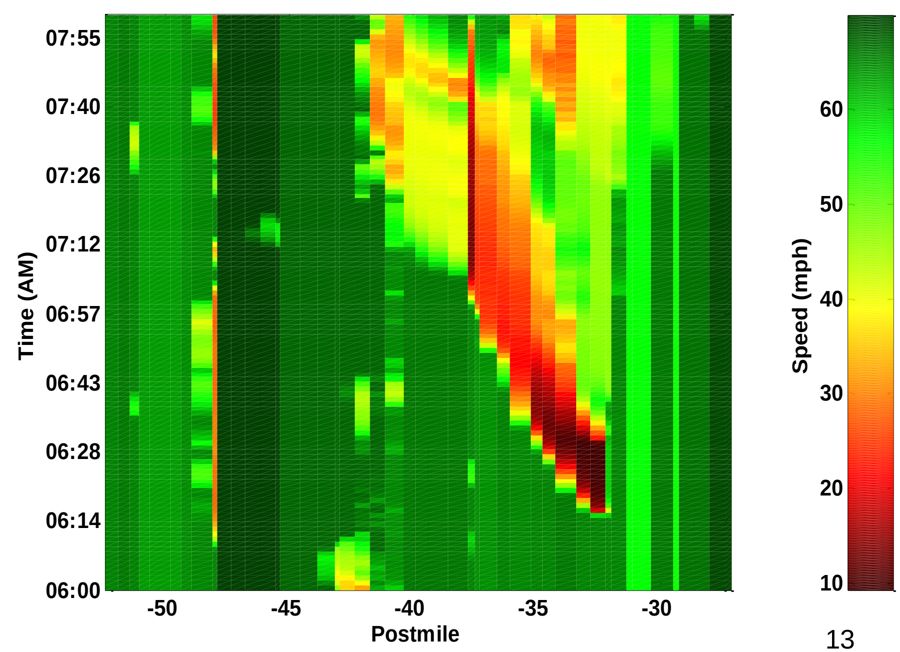




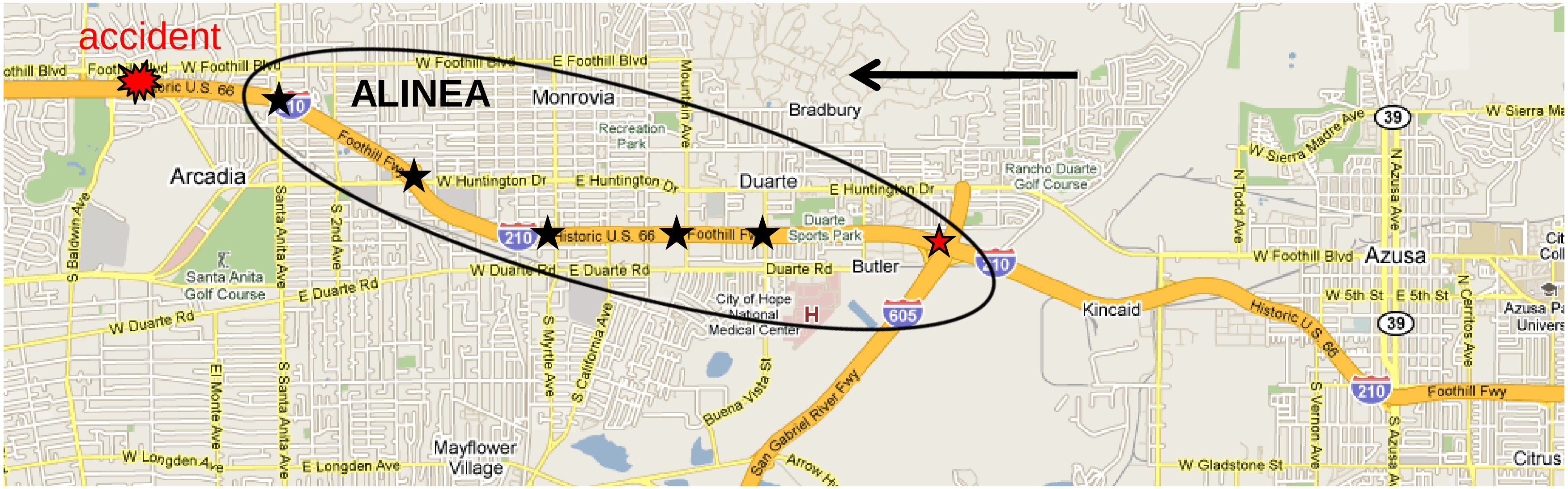
Strategy 3: ALINEA + VMS control

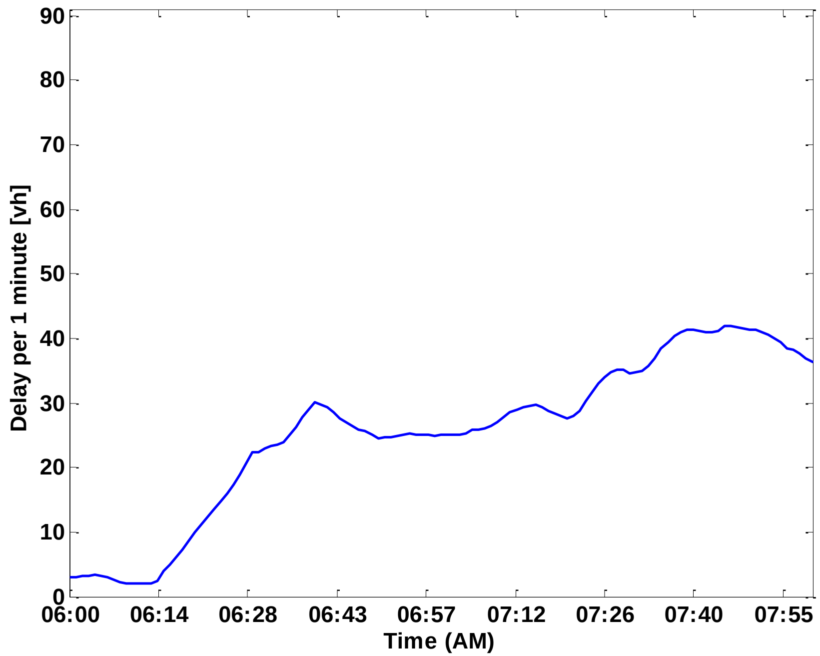


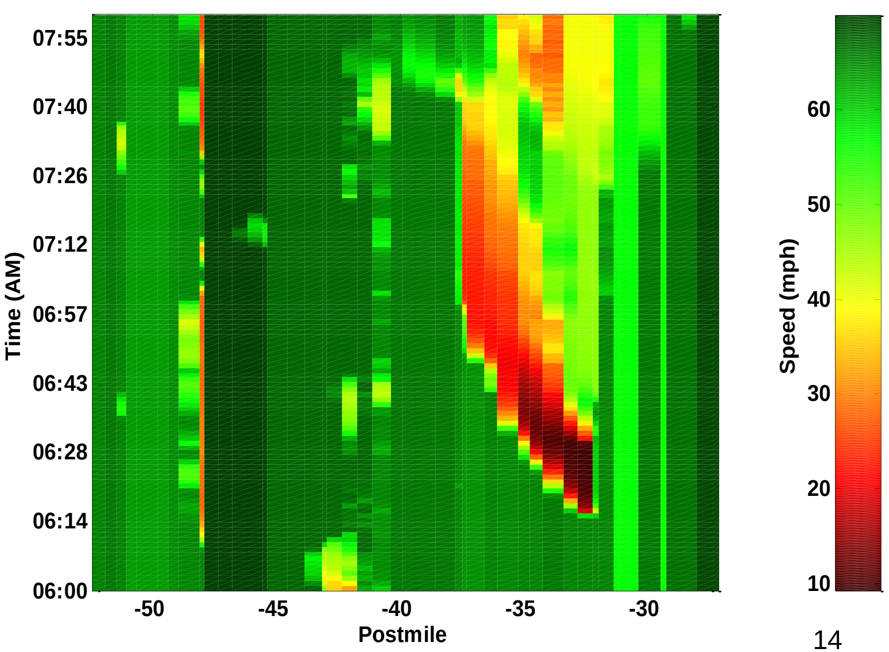




Strategy 4: ALINEA + metering at I-605 N







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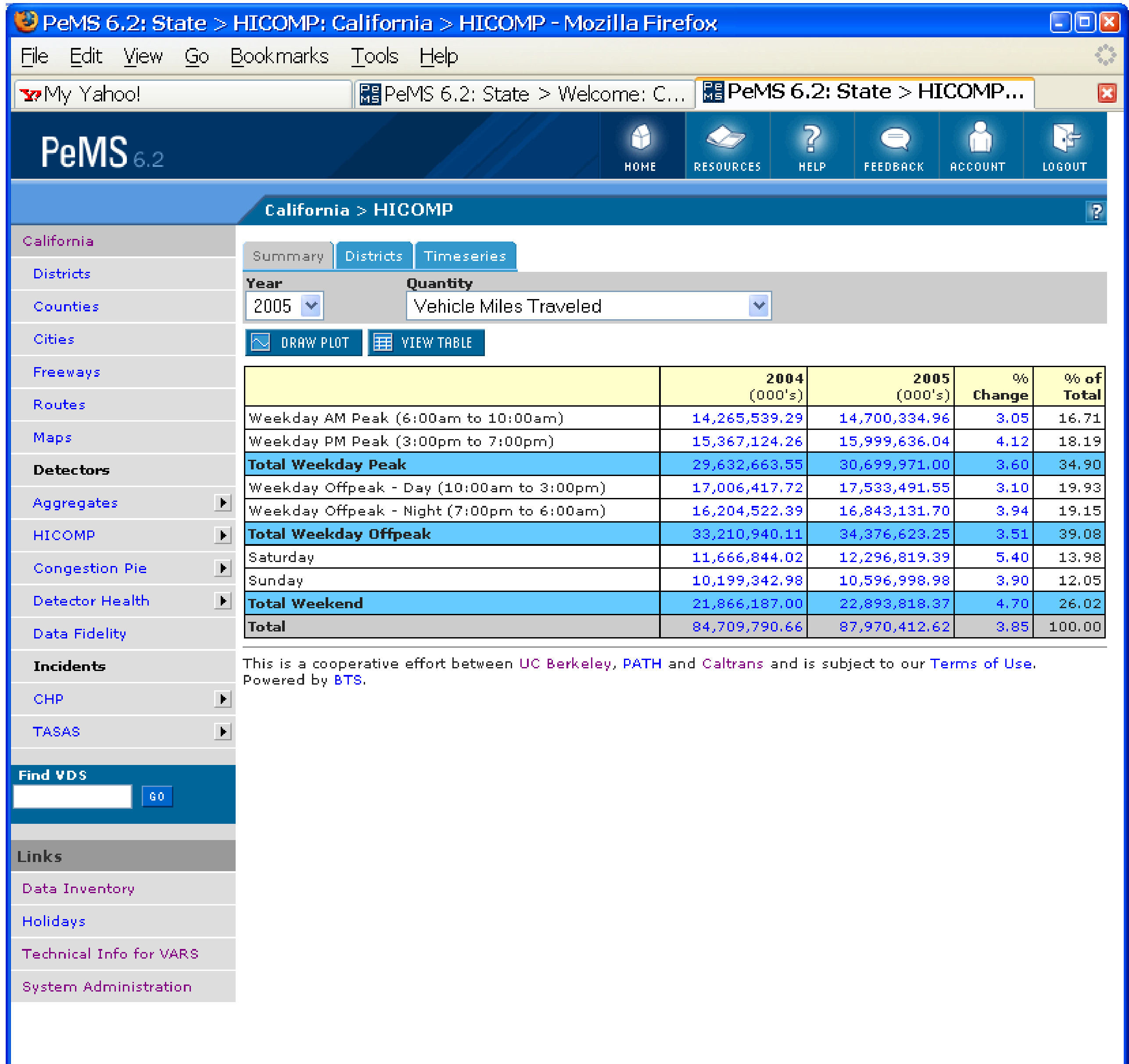
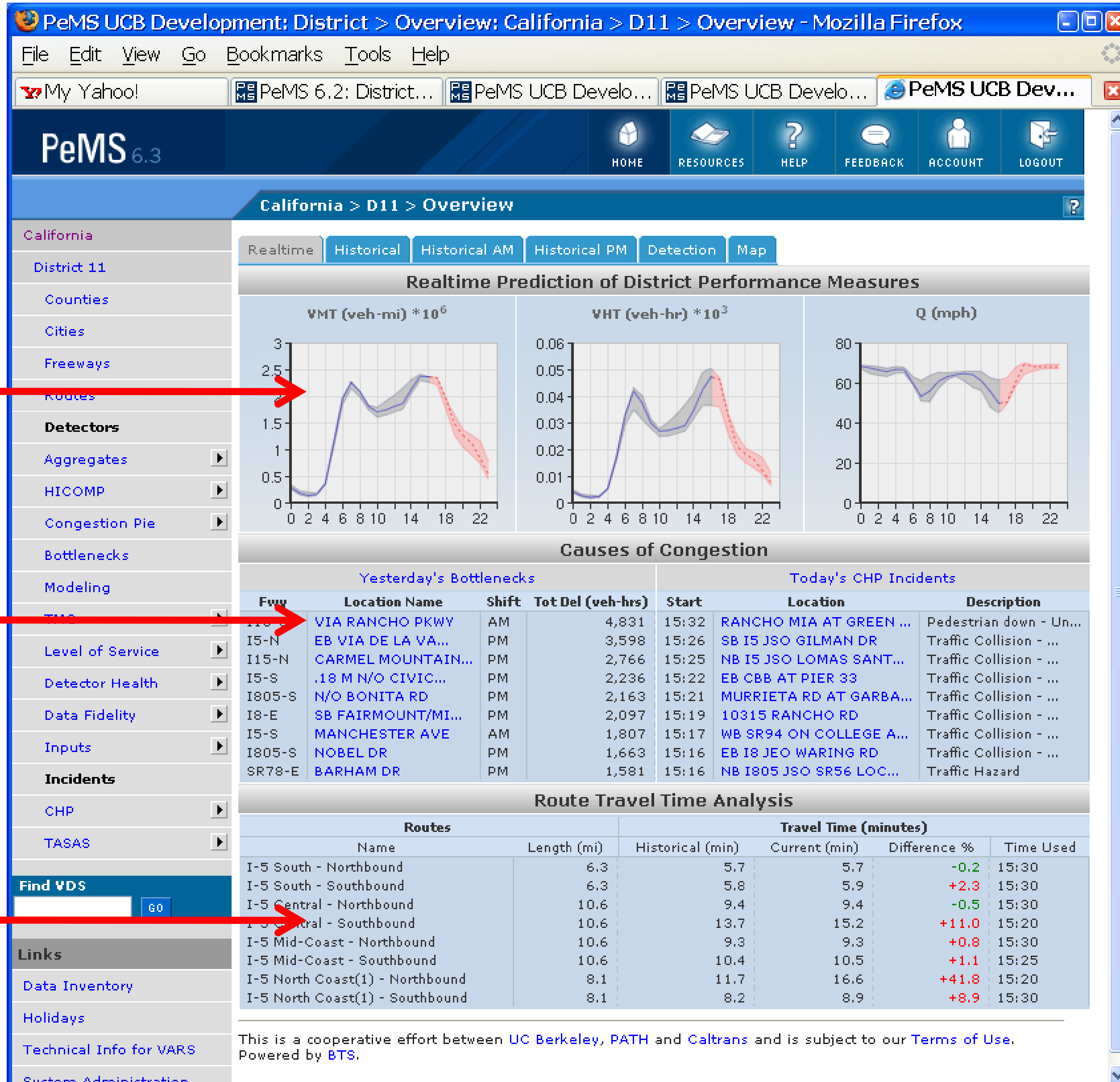
What is PeMS?

- PeMS archives freeway data and incident reports since 2000 from
  - 22,000 sensors
  - 50 Billon samples/year
  - 10TB of data
  - Now extended to urban streets, transit
- Processes data in real-time for performance measurement calculations
- All data online, accessed via browser



Real time dashboard

- Caltrans D11
- Snapshot at current time
- Top: Performance measures
  - Measured until now
  - Historical bounds
  - Predicted for rest of day
- Middle: Causes of congestion
  - Major bottlenecks
  - List of incidents from CHP
- Bottom: Mobility analysis
  - Historical travel time
  - Latest available travel time
  - Difference



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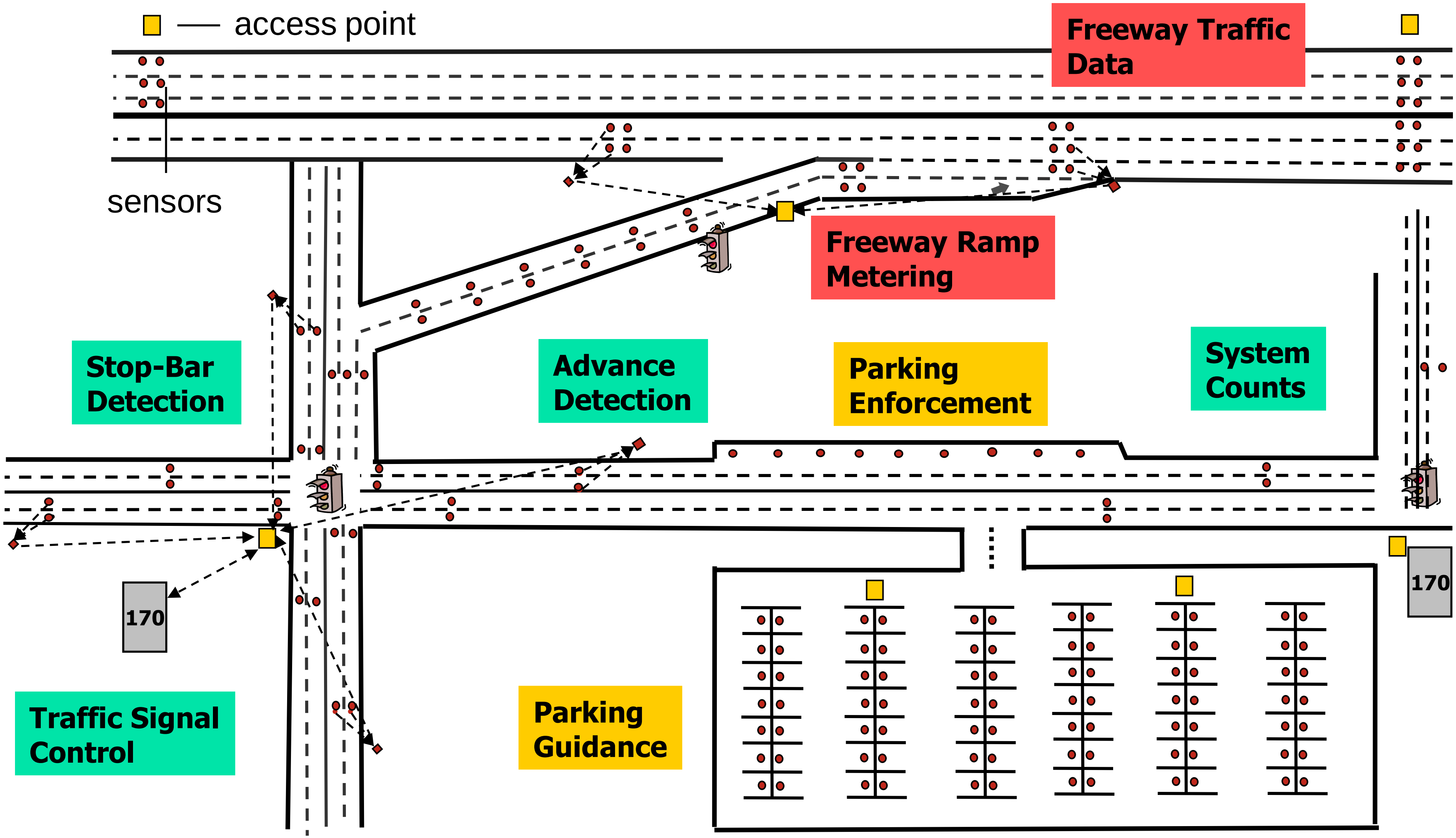
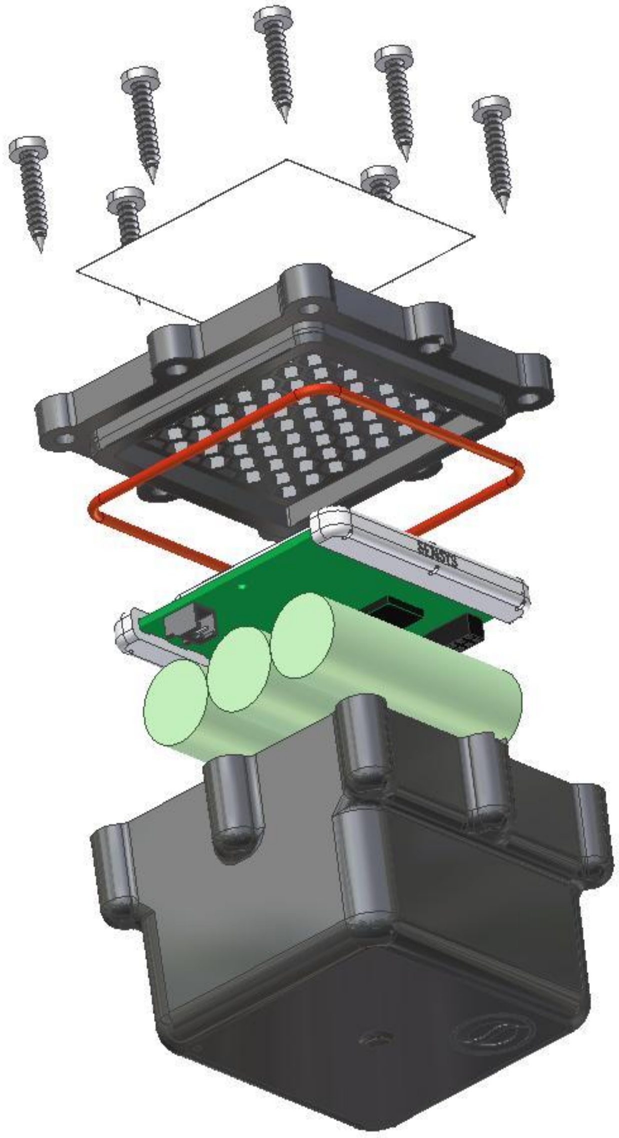
Traffic Sensing Infrastructure



In-Pavement Wireless Vehicle Sensor

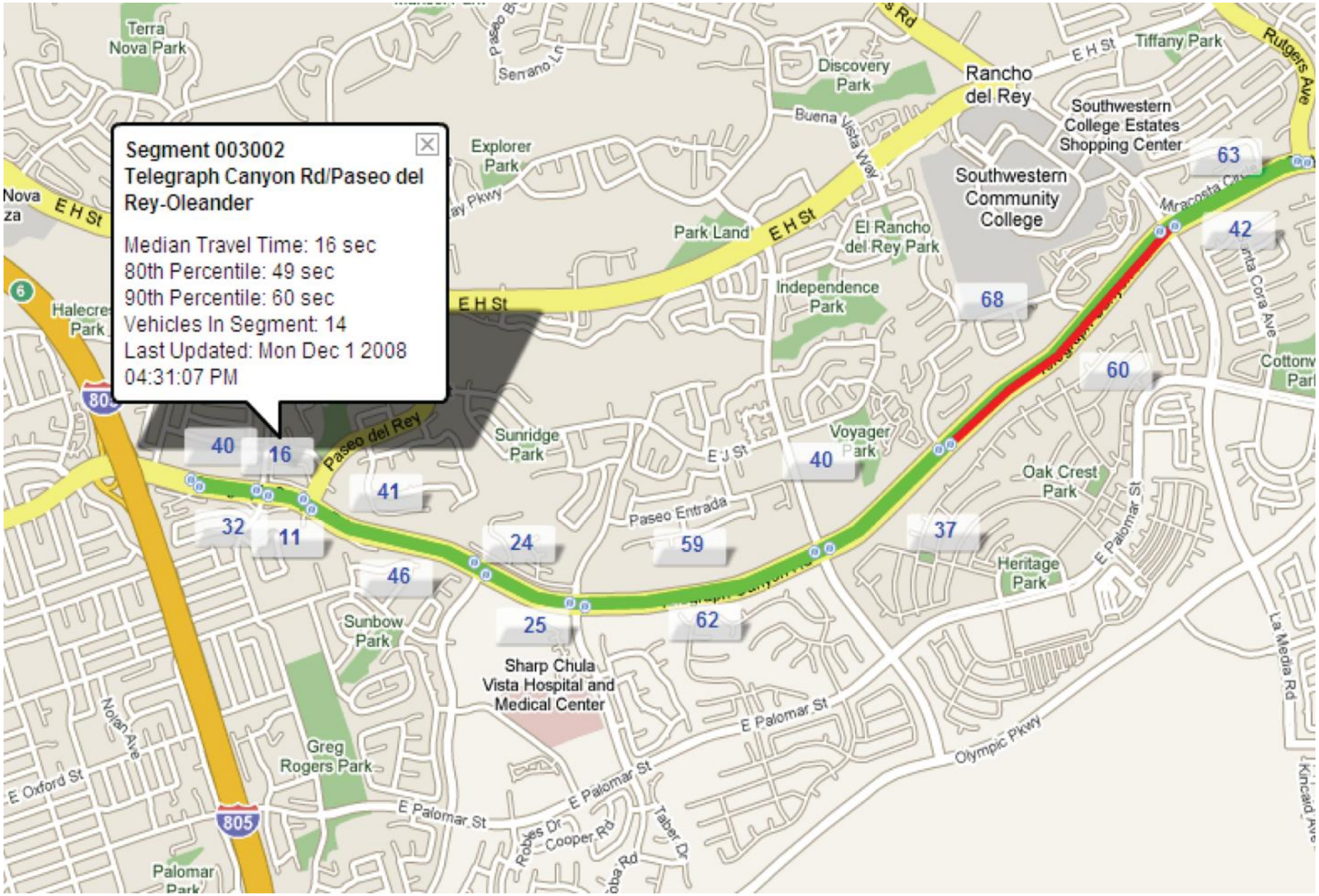
- Ultra-low power wireless communications protocol
- Accurate 3-axis magnetometers
- Self-calibrating, self-tuning
- Unique network address for each sensor
- Downloadable firmware
- Installed in minutes
- 10 year battery



Los Angeles Dodger Stadium

Travel Time to the Gate on Game Day

Chula Vista installation (San Diego County)



- 8-link
- 9-signal
- 3.3-mile

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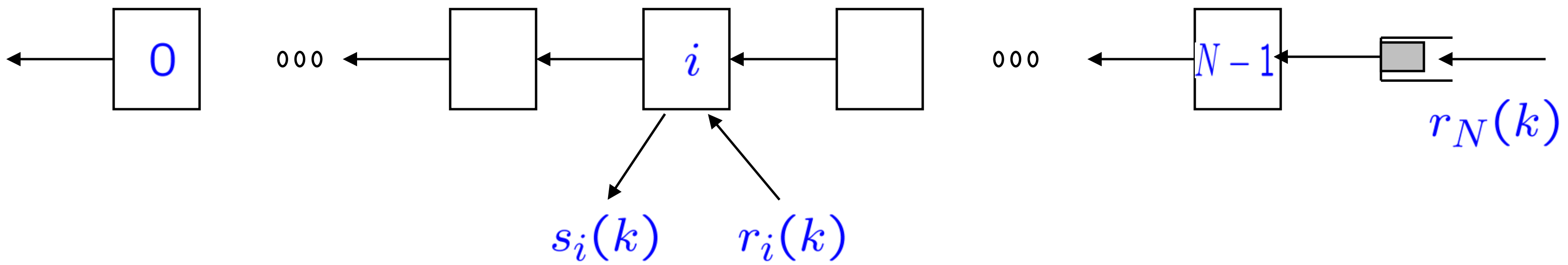
Freeway structure

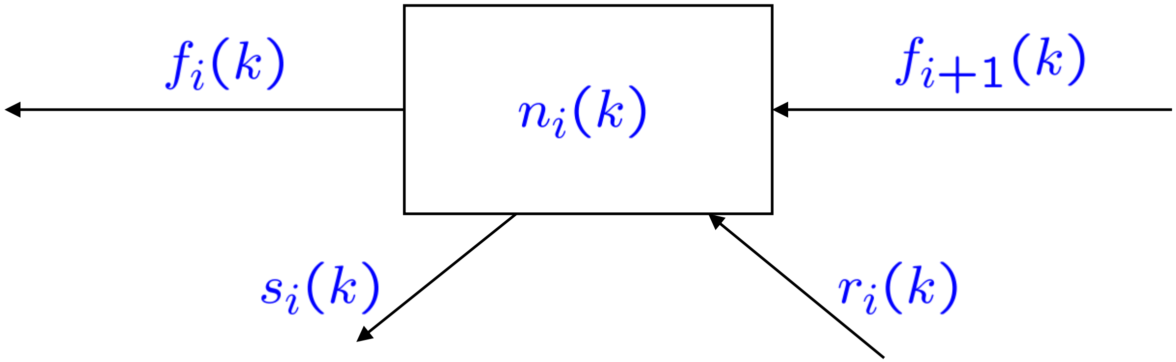


Freeway has N sections (cells), $0, \cdots, N-1$

Each section has one on-ramp and off-ramp

Two boundary conditions:
(1) Upstream section has specified inflow $r_N(k)$
(2) Downstream of section 0 is uncongested or has specified flow

Flow conservation within cell



$$n_i(k+1) = n_i(k) - [f_i(k) + s_i(k)] + [f_{i+1}(k) + r_i(k)]$$

Off-ramp flows are given by split-ratios:

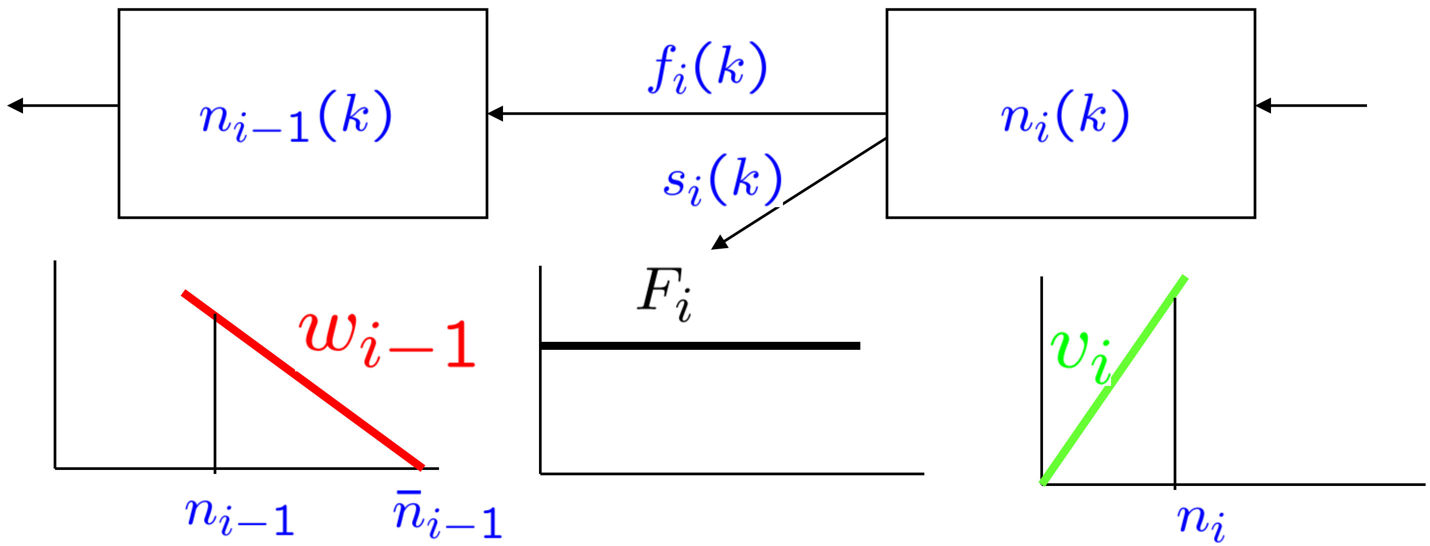
$$s_i(k) = \beta_i[s_i(k) + f_i(k)] = \beta_i \bar{\beta}_i^{-1} f_i(k). \; (\bar{\beta}_i = 1 - \beta_i)$$

Off-ramp is uncontrained.

1 mile sections, so n_i = density = # vehicles,

Flow($\frac{veh}{hour}$)= speed ($\frac{mile}{hour}$) $\times$ density($\frac{veh}{mile}$)

Determination of inter-cell flow



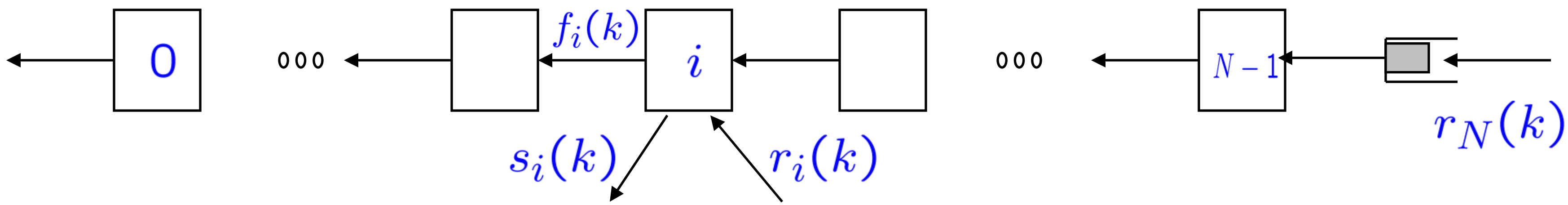
$f_i(k) \leq v_i n_i(k) - s_i(k)$ – demand

$f_i(k) \leq F_i$ – capacity

$f_i(k) \leq w_{i-1}(\bar{n}_i - n_{i-1}(k))$ – supply

$$f_i(k) = \min\{v_i n_i(k) - s_i(k), w_{i-1}[\bar{n}_{i-1} - n_{i-1}(k)], F_i\}$$

CTM model



$$
\begin{aligned}
n_i(k+1) &= n_i(k) - f_i(k)/\bar{\beta}_i + f_{i+1}(k) + r_i(k), 0 \le i \le N-1, \\
f_i(k) &= \min\{\bar{\beta}_i v_i n_i(k), w_{i-1}[\bar{n}_{i-1} - n_{i-1}(k)], F_i\}, 1 \le i \le N, \\
f_0(k) &= \min\{\bar{\beta}_0 v_0 n_0(k), F_0\}, \\
n_N(k+1) &= n_N(k) - f_N(k) + r_N(k).
\end{aligned}
$$

Suppose demand $r_i(k) \equiv r_i$. This gives a N-dimensional time-invariant nonlinear difference equation. Call $r = (r_0, \cdots, r_N)$ the demand.

Dynamics

Write dynamics as $n(k+1) = g(n(k))$.

Theorem (1) g is strictly monotone: $n < n' \Rightarrow g(n) < g(n')$. [$x < y$ means $x \leq y, x \neq y$]

(2) Let $\hat{n}(k)$ be trajectory starting with empty freeway and $\bar{n}(k)$ the trajectory starting with jammed freeway. For any trajectory $n(k)$

$$\hat{n}(k) \leq n(k) \leq \bar{n}(k), k \geq 0$$

(3) $n(0) \leq n^u \Rightarrow n(k) \rightarrow n^u$.

(4) $n(0) \geq n^{con} \Rightarrow n(k) \rightarrow n^{con}$.

(5) Every equilibrium is stable; every trajectory converges to some equilibrium in $E(r)$.

Use in prediction

Write dynamics as $n(k+1) = g(n(k), d(k), C(k))$.

Suppose

$d_-(k) \leq d(k) \leq d_+(k)$, $C_-(k) \leq C(k) \leq C_+(k)$.

Suppose

$n_-(k) = g(n_-(k), d_-(k), C_+(k)$ and

$n_+(k) = g(n_+(k), d_+(k), C_-(k)$.

Then,

$n_-(k) \leq n(k) \leq n_+(k)$.

Conclusion

- Fast macroscopic models can be used in real-time operations to support strategic decisions
- Models must be automatically calibrated
- Scores of scenarios can be run in real time to estimate risk of events that may occur and countermeasures selected in advance
- Without data management is blind
- Data collection must be fully automatic
- Detection system must be reliable and accurate