



Risk-Aware Active Traffic Management

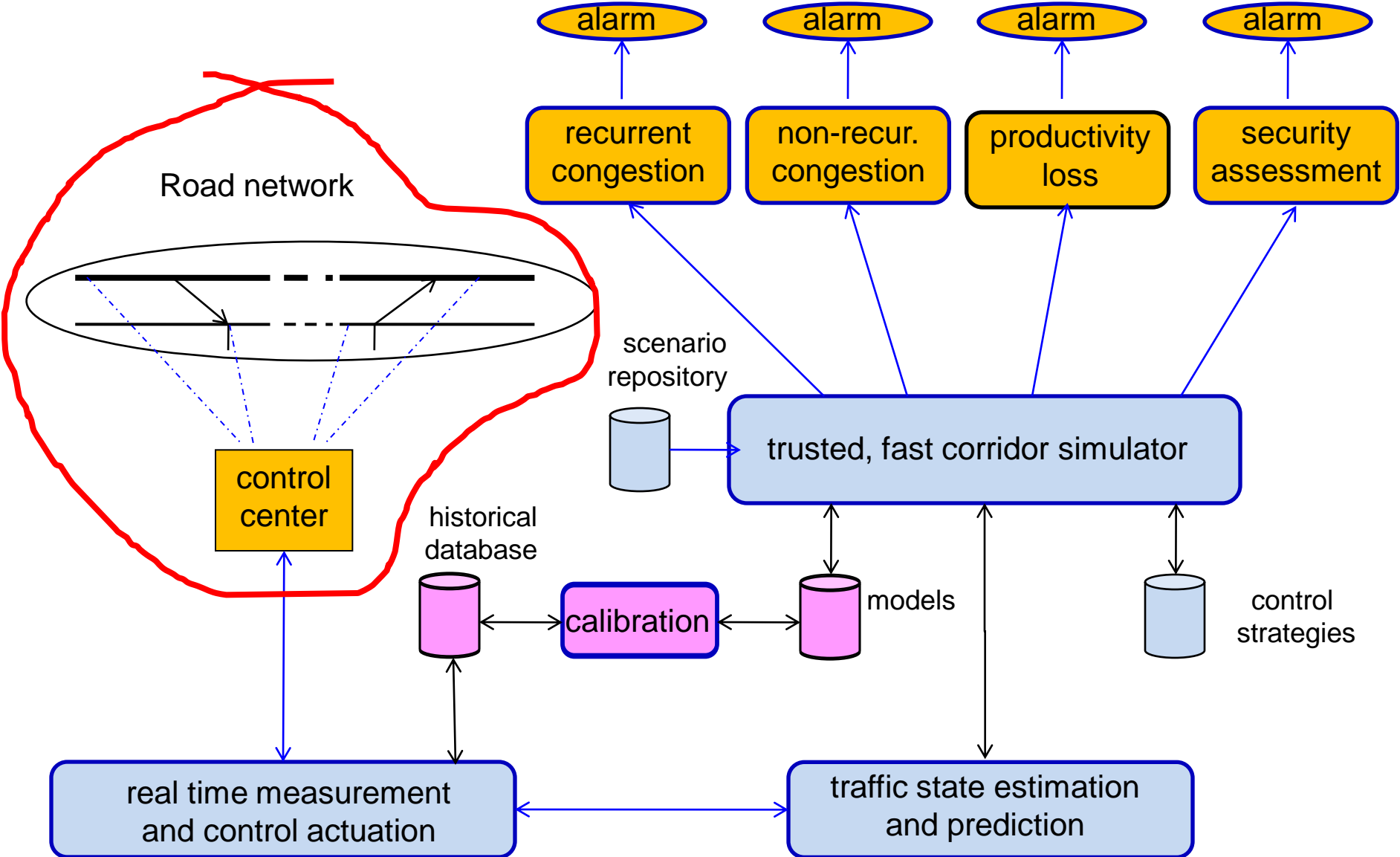
Alex A. Kurzhanskiy and Pravin Varaiya
University of California, Berkeley

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

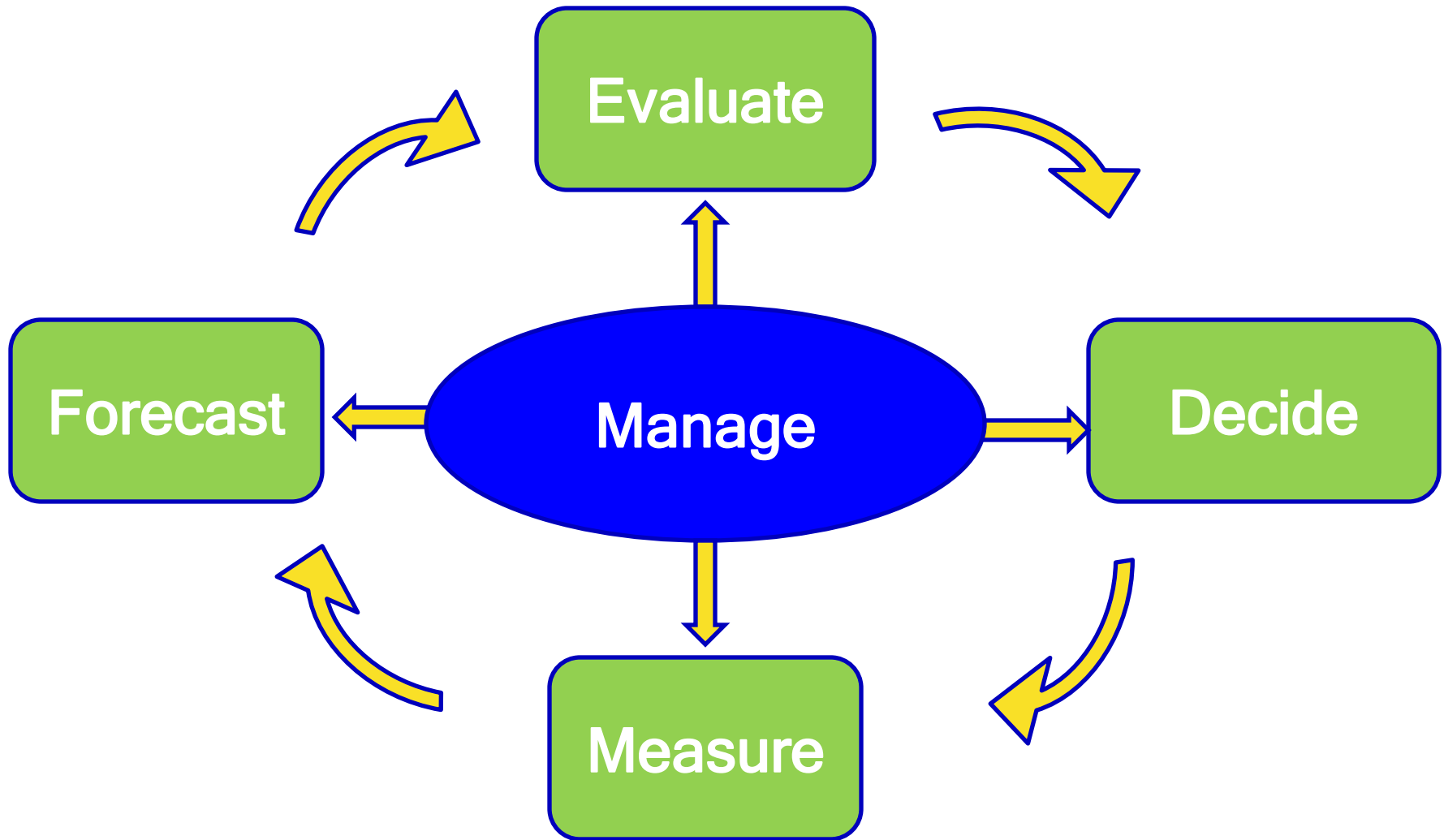
Outline

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

ATM workflow



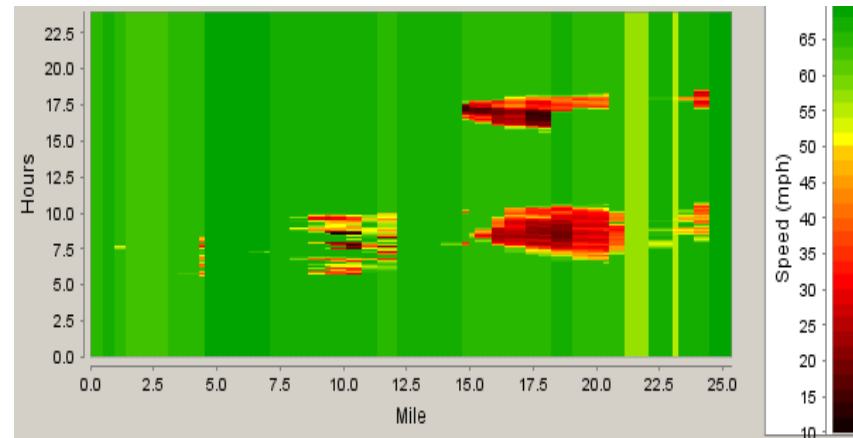
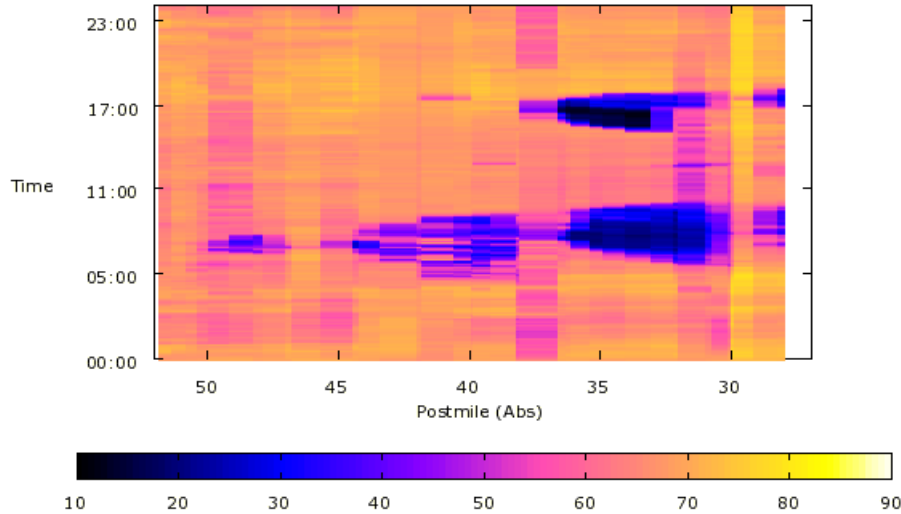
Active management



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



Aggregated Speed (mph) for I210-W (89% Observed)
07/15/2009 00:00-23:59
Traffic Flows from Left to Right

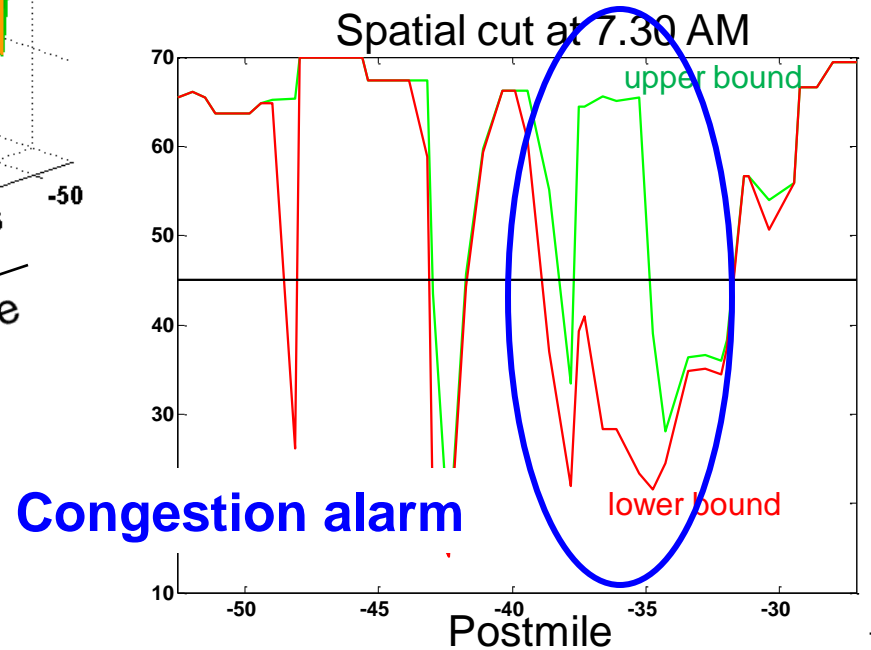
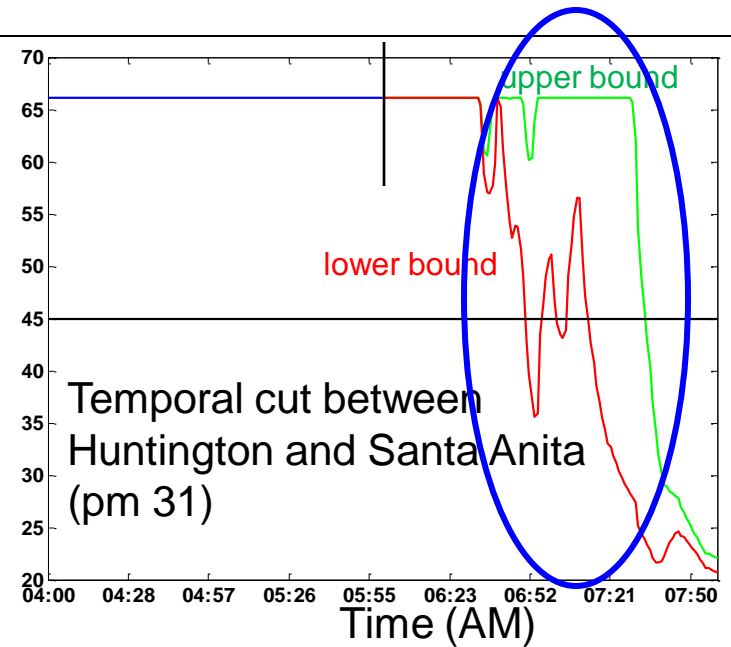
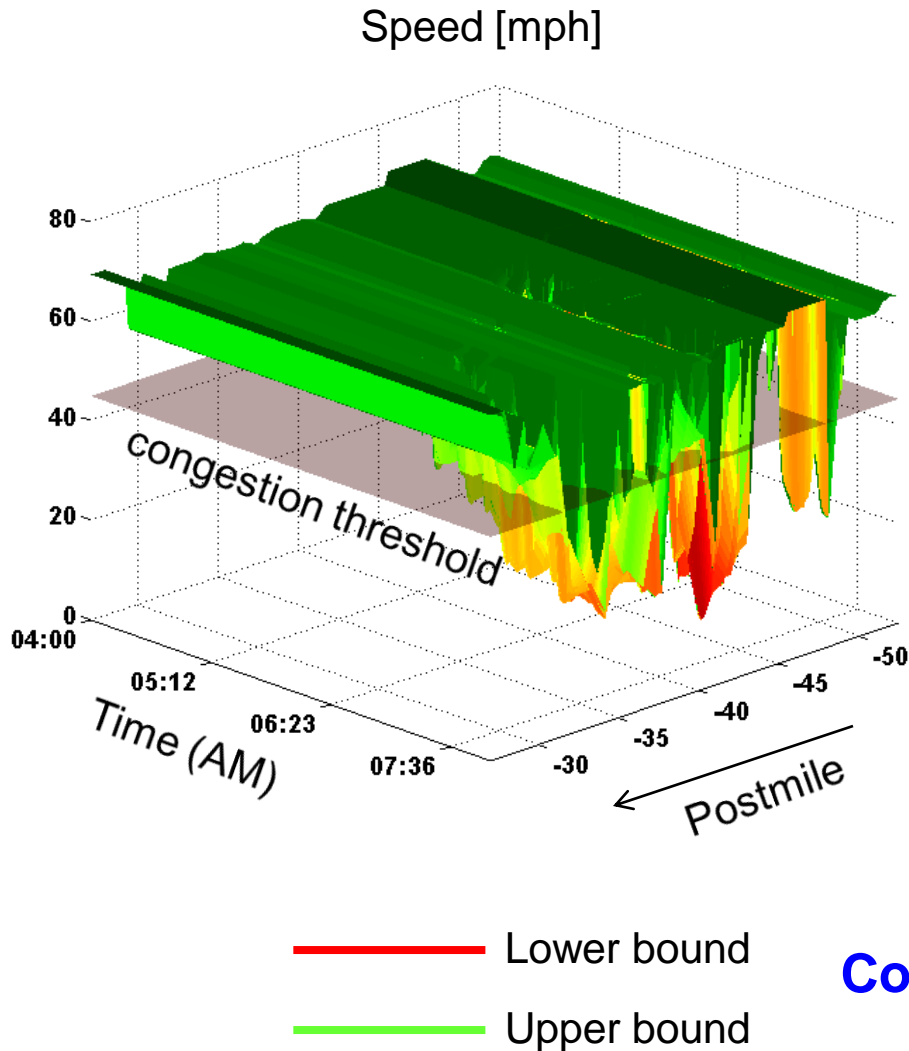


I-210 West on July 15, 2009: assumptions

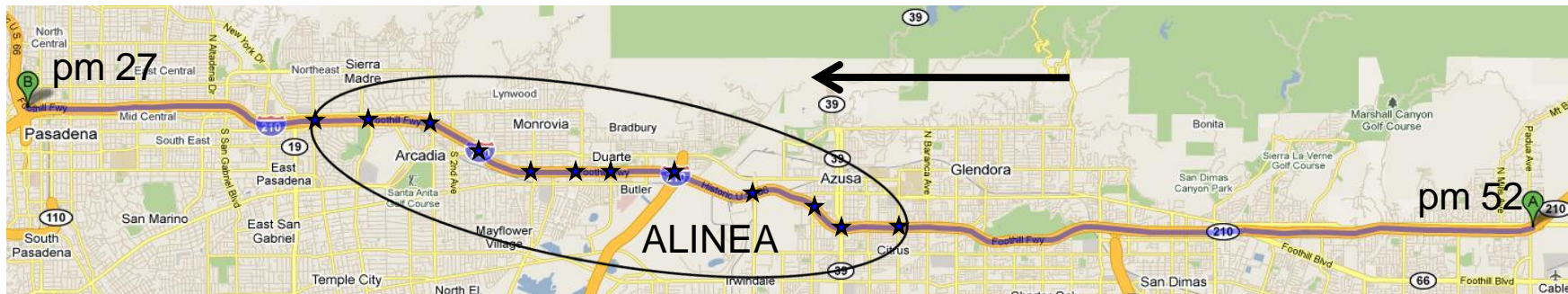


- ▶ Measure during 4AM-6AM
- ▶ Forecast 6AM-8AM, with +/- 2% demand uncertainty

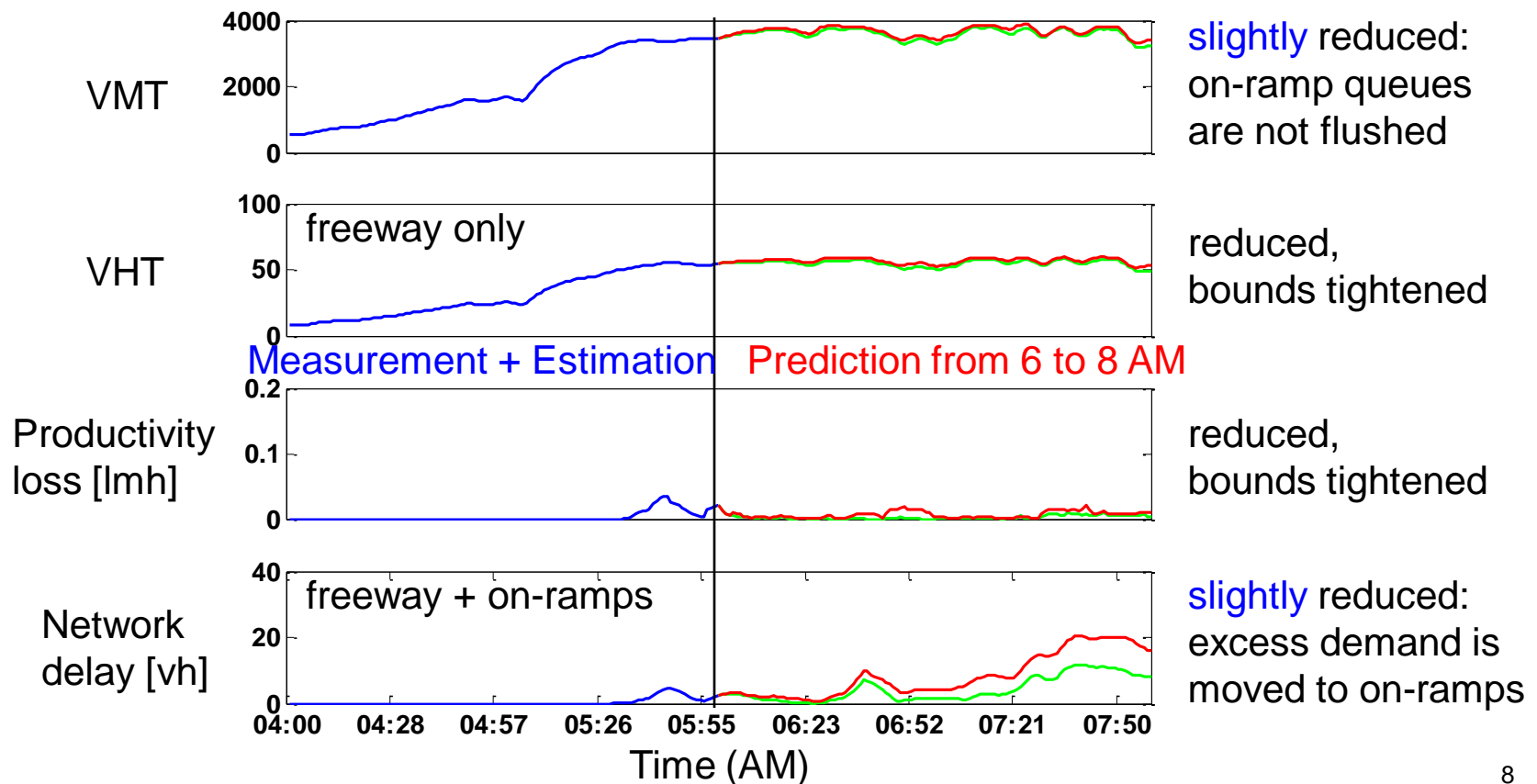
Forecast of speed



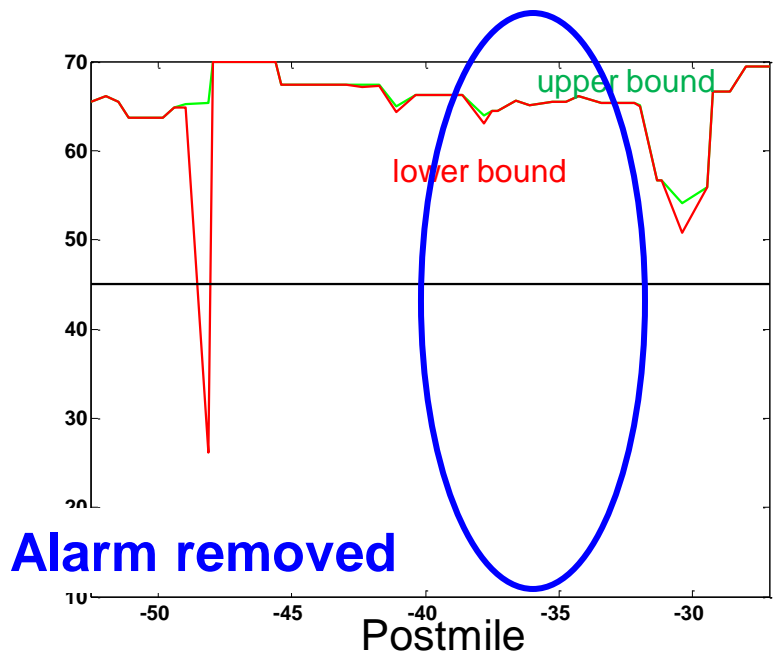
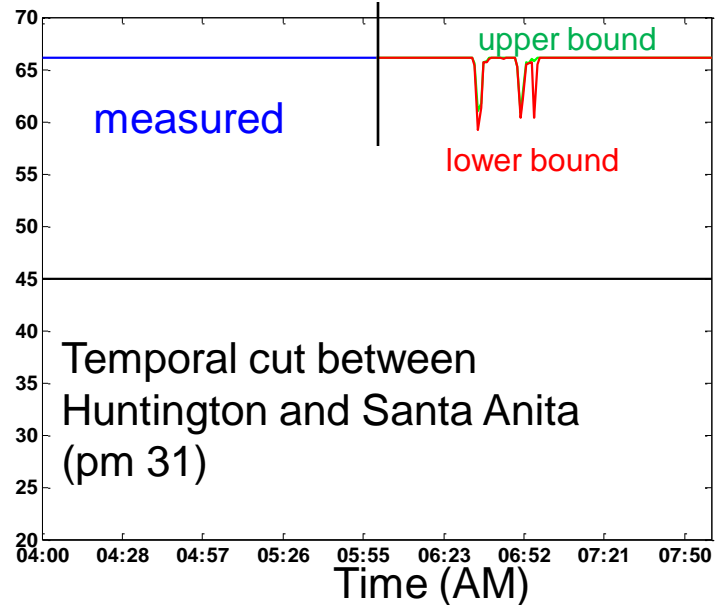
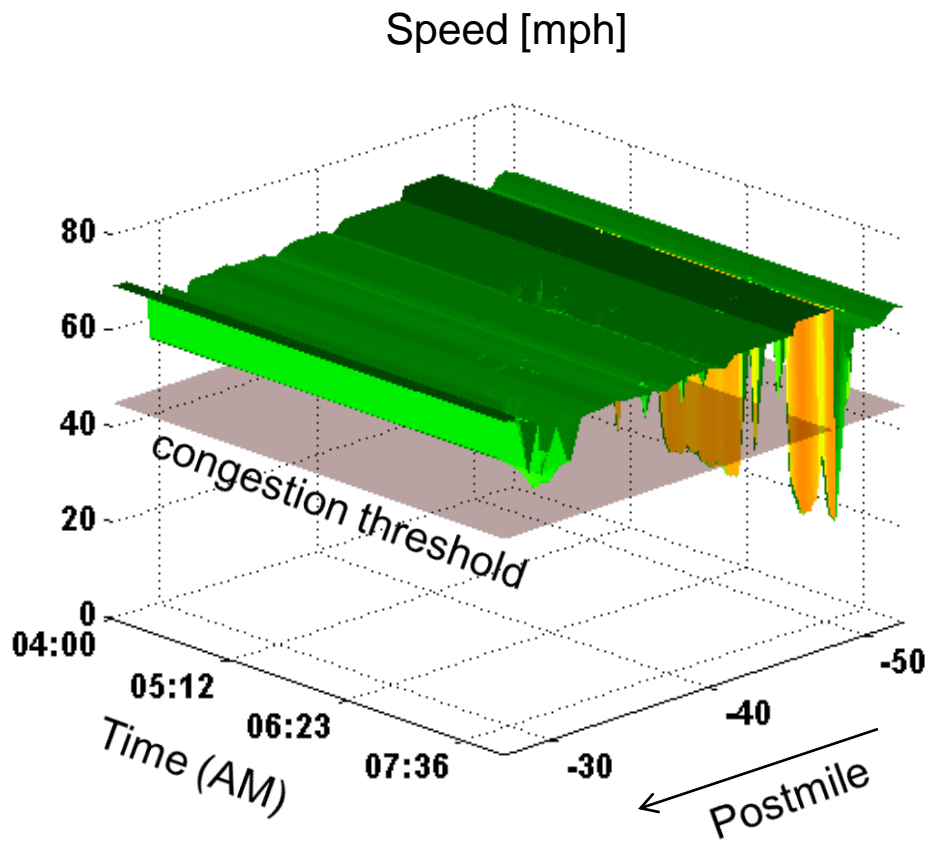
Predicted impact of ALINEA: 6-8 AM



Aggregate data per 1 minute



Forecast of speed under ALINEA

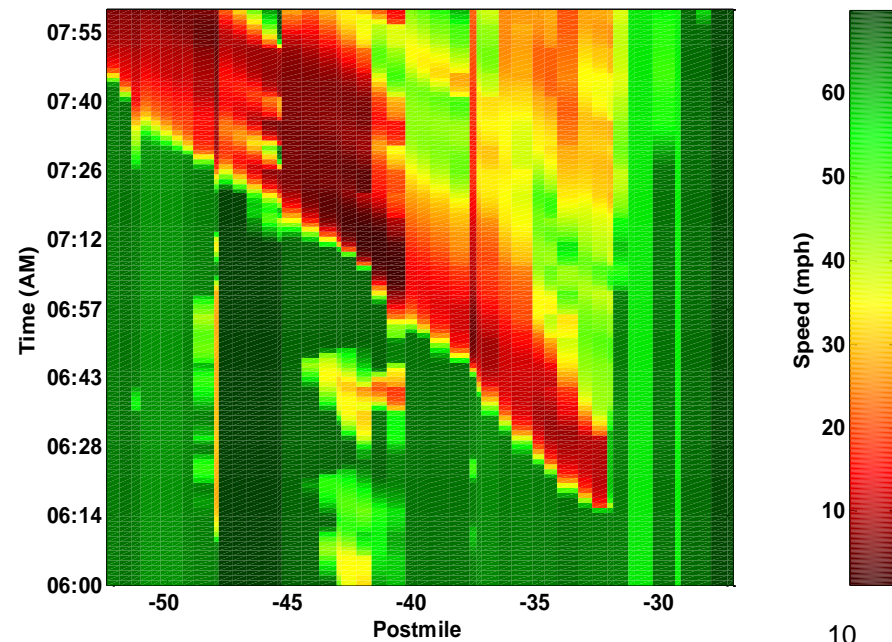
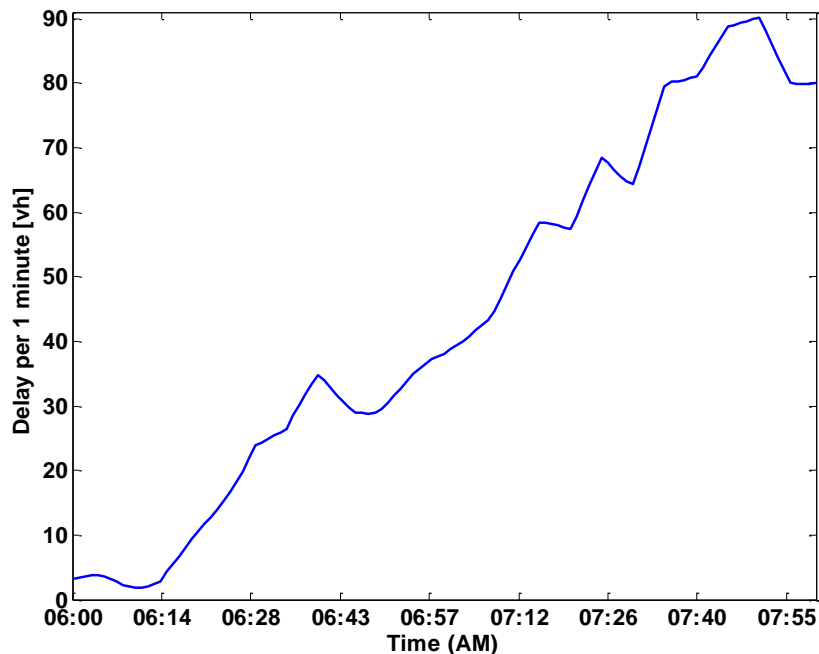


Scenario: accident near Baldwin

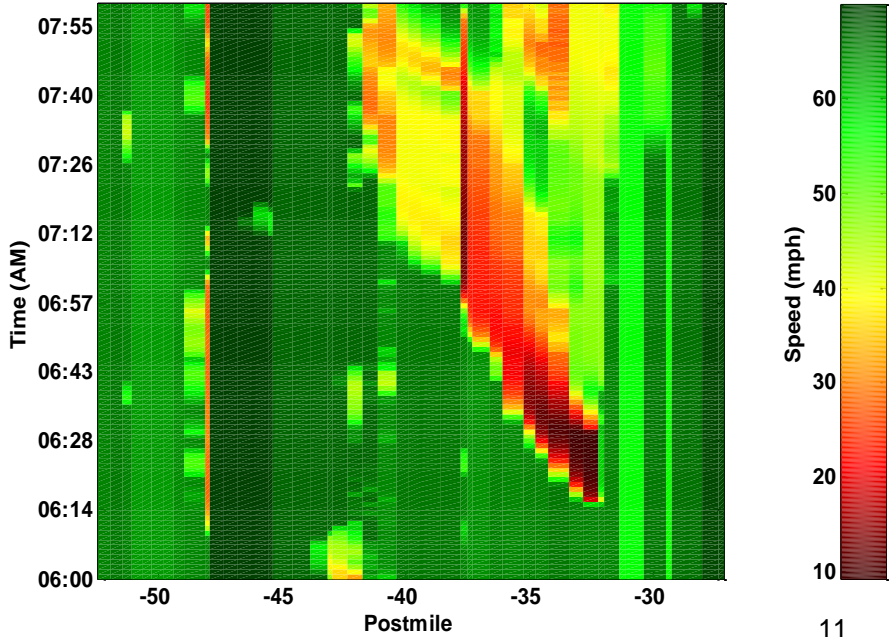
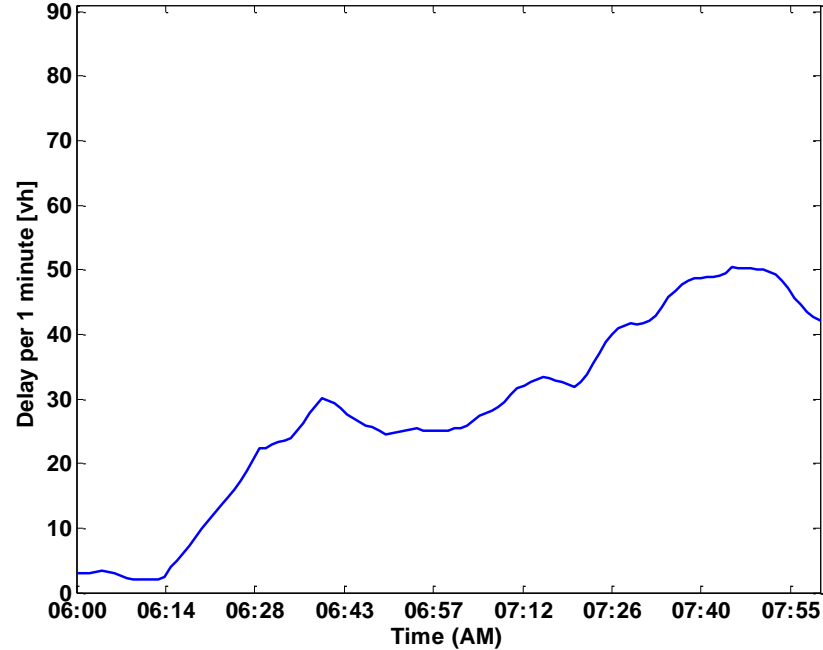
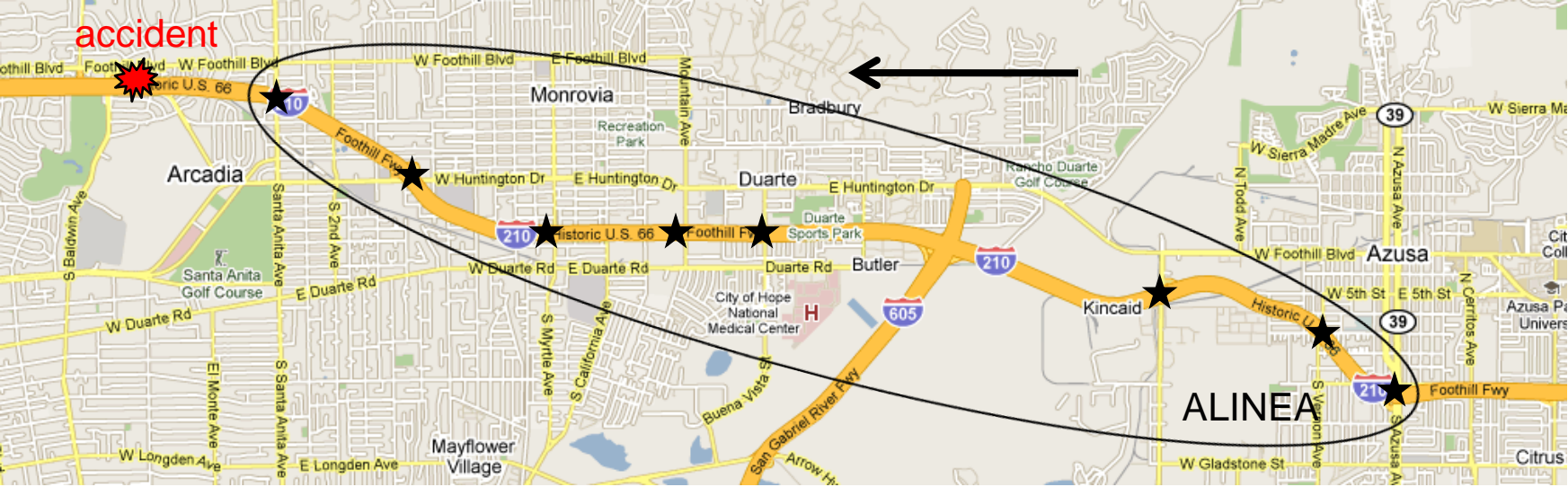


- ▶ 6.15 AM: freeway capacity is reduced by 50%
- ▶ 6.30 AM: road cleared, capacity is back to normal

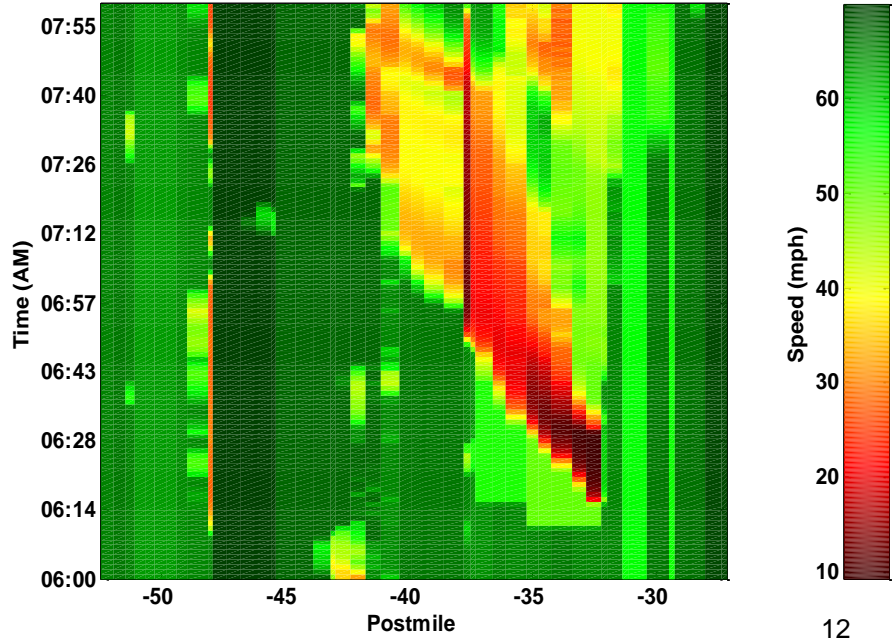
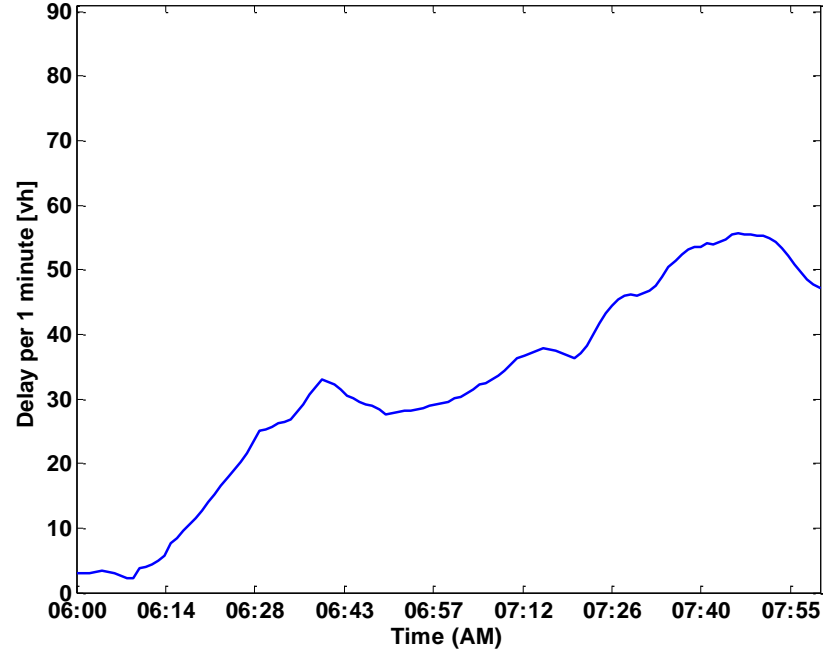
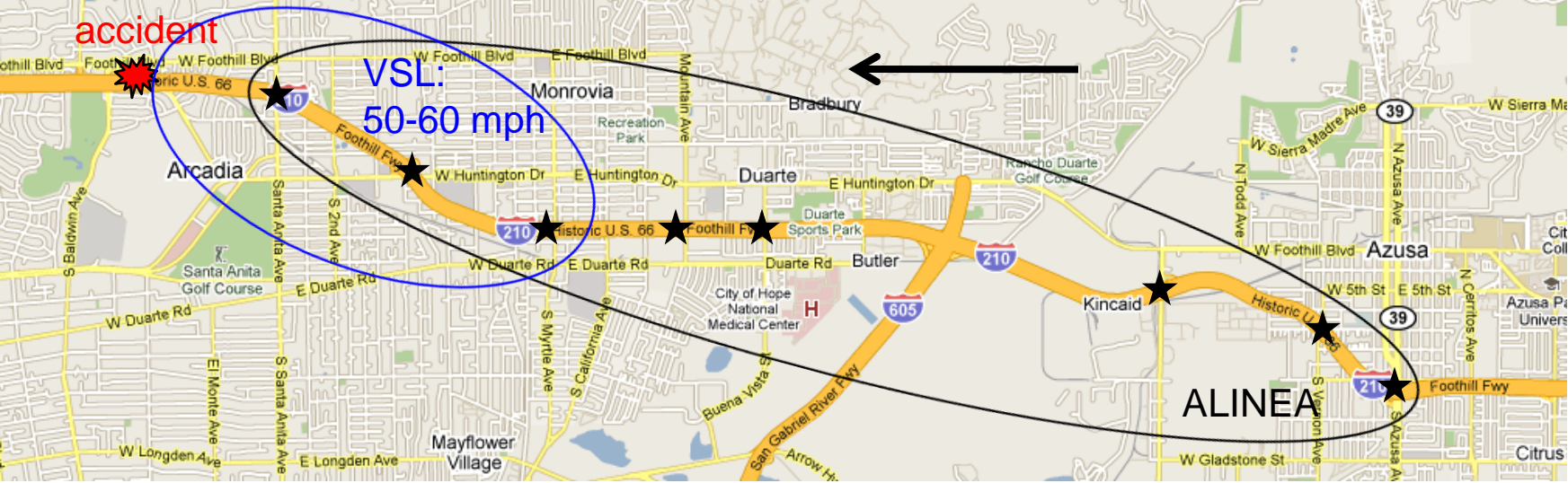
Worst case



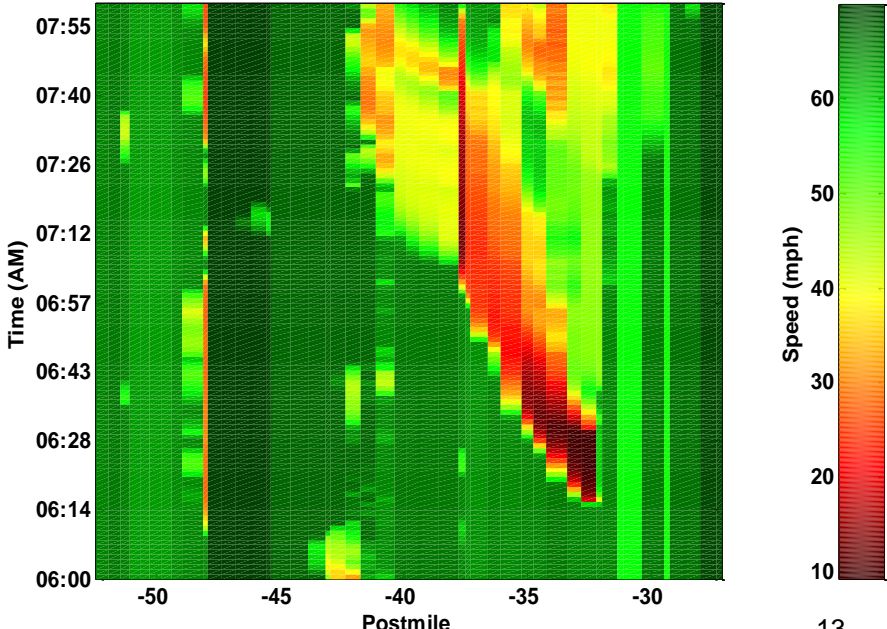
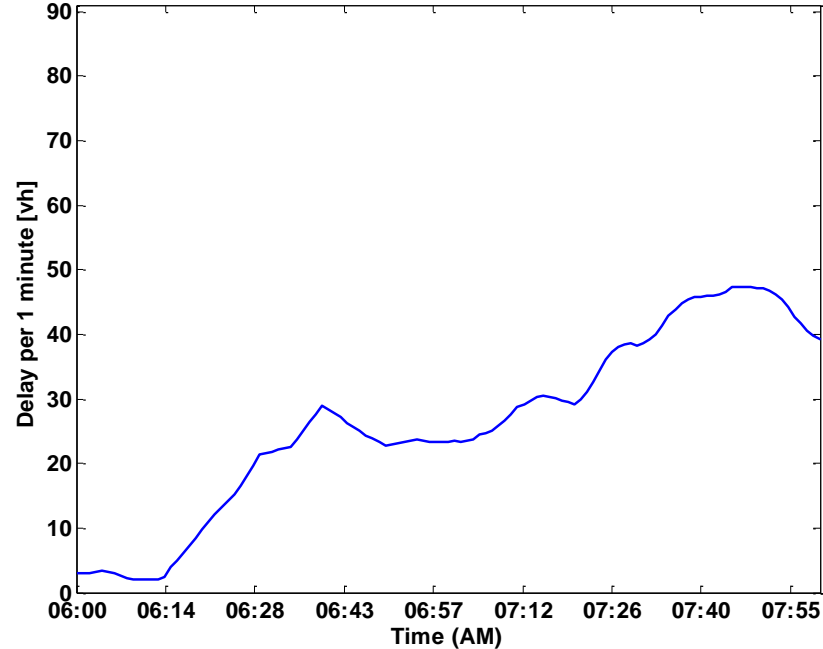
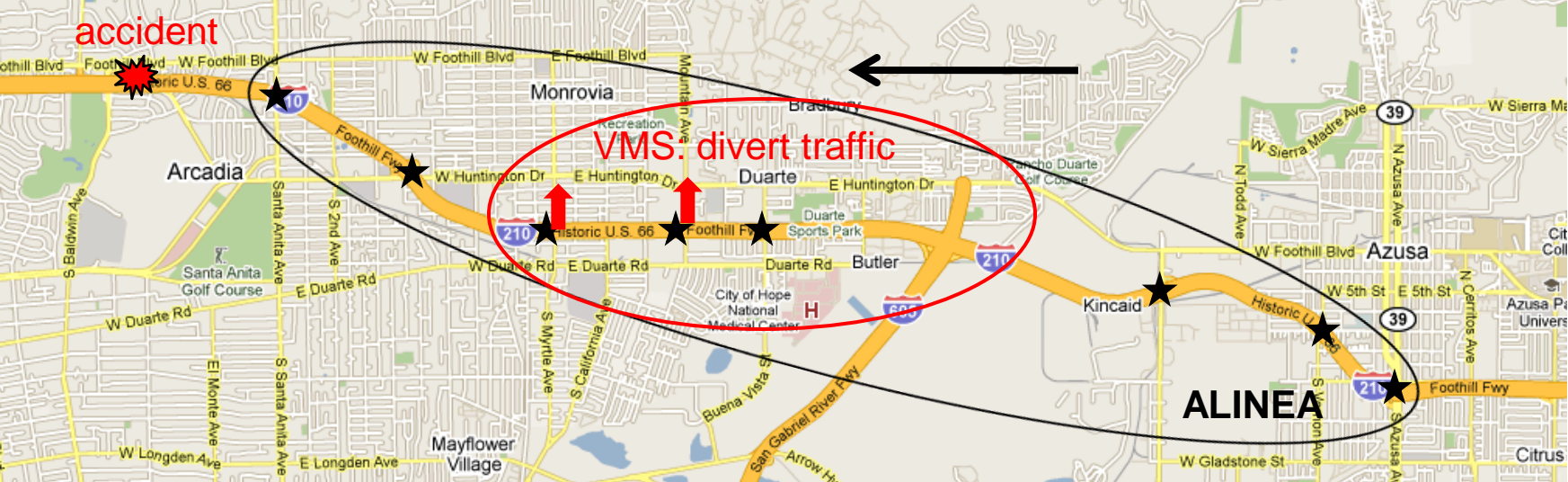
Strategy 1: ALINEA



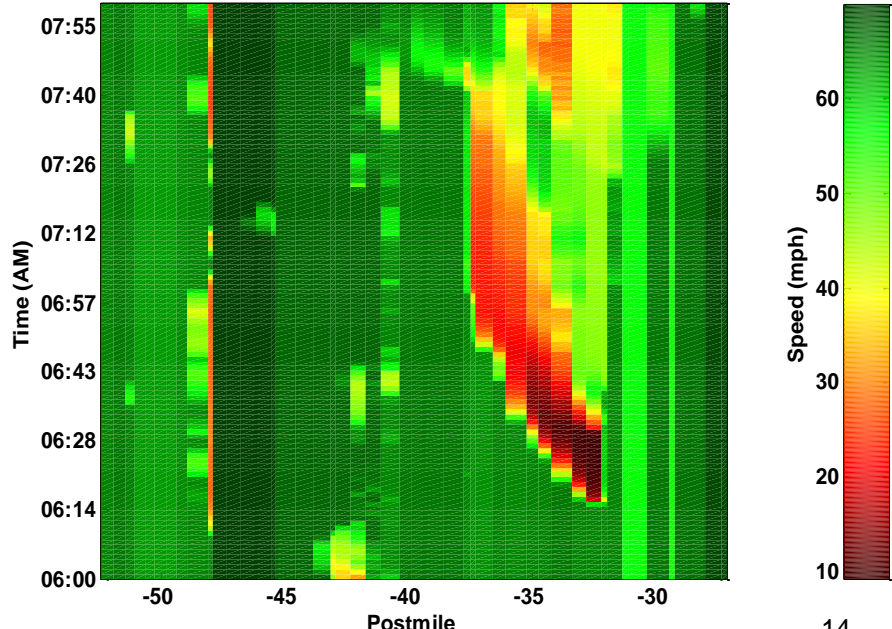
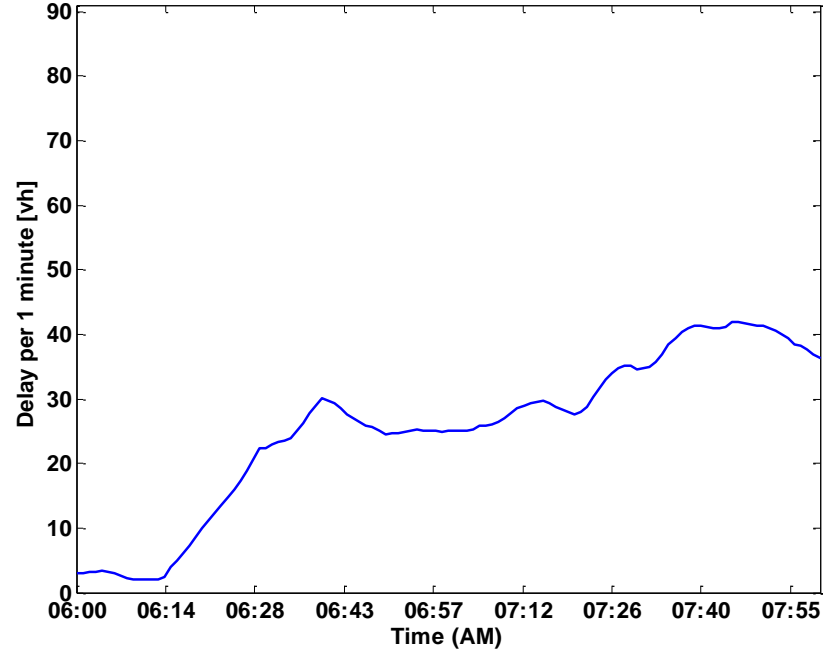
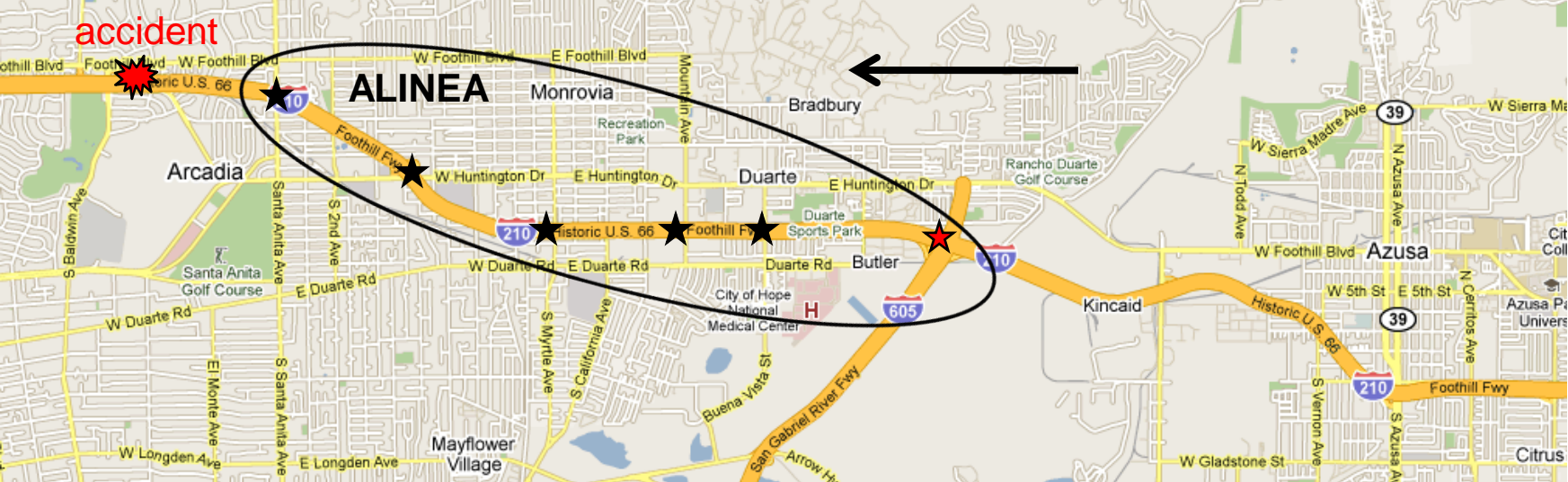
Strategy 2: ALINEA + VSL control



Strategy 3: ALINEA + VMS control



Strategy 4: ALINEA + metering at I-605 N



Outline

- ▶ What is ATM?
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What is PeMS?

- ▶ PeMS archives freeway data and incident reports since 2000 from
 - 22,000 sensors
 - 50 Billion 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

PeMS 6.2: State > HICOMP: California > HICOMP - Mozilla Firefox

PeMS 6.2

California > HICOMP

Summary | Districts | Timeseries

Year: 2005 | Quantity: Vehicle Miles Traveled

DRAW PLOT | VIEW TABLE

	2004 (000's)	2005 (000's)	% Change	% of Total
Weekday AM Peak (6:00am to 10:00am)	14,265,539.29	14,700,334.96	3.05	16.71
Weekday PM Peak (3:00pm to 7:00pm)	15,367,124.26	15,999,636.04	4.12	18.19
Total Weekday Peak	29,632,663.55	30,699,971.00	3.60	34.90
Weekday Offpeak - Day (10:00am to 3:00pm)	17,006,417.72	17,533,491.55	3.10	19.93
Weekday Offpeak - Night (7:00pm to 6:00am)	16,204,522.39	16,843,131.70	3.94	19.15
Total Weekday Offpeak	33,210,940.11	34,376,623.25	3.51	39.08
Saturday	11,666,844.02	12,296,819.39	5.40	13.98
Sunday	10,199,342.98	10,596,998.98	3.90	12.05
Total Weekend	21,866,187.00	22,893,818.37	4.70	26.02
Total	84,709,790.66	87,970,412.62	3.85	100.00

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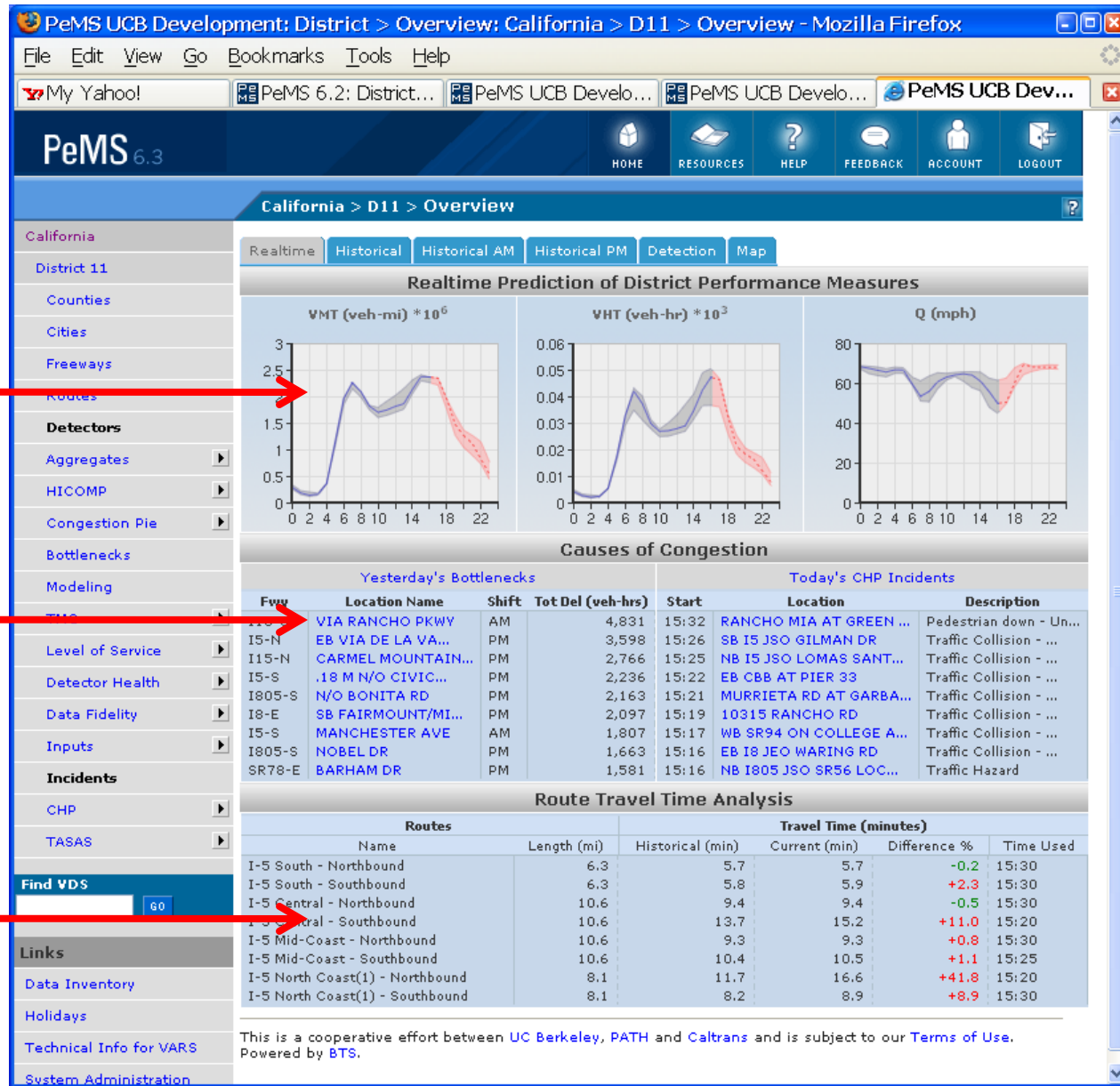
Find VDS

Links

- Data Inventory
- Holidays
- Technical Info for VARS
- System Administration

Real time dashboard

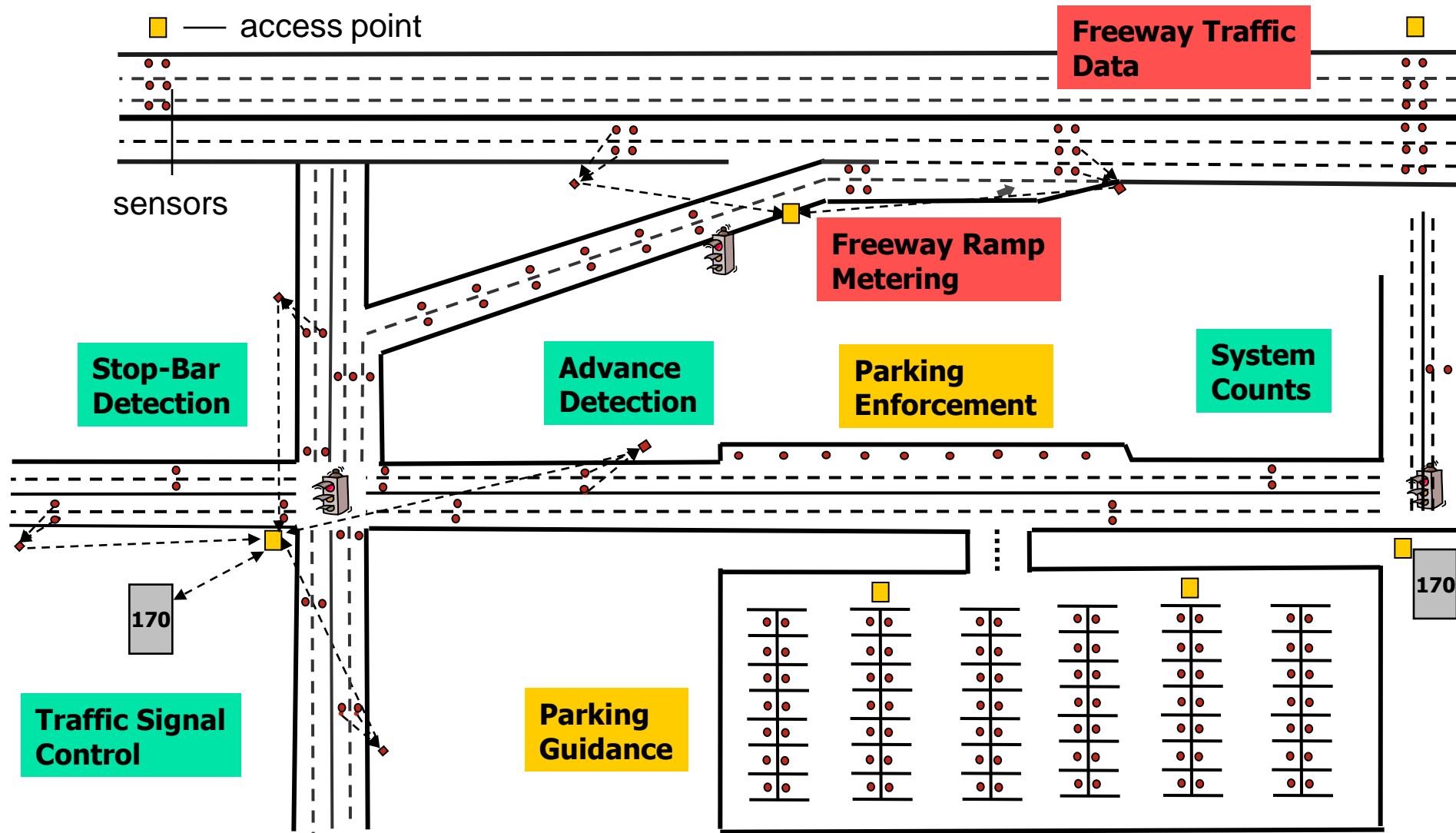
- ▶ Caltrans D11
- ▶ Snapshot at current time
- ▶ Top: Performance measures
 - Measured until now
 - Historical bounds
 - Predicted for rest of day
- ▶ Middle: Causes of congestion
 - Major bottlenecks
 - List of incidents from CHP
- ▶ Bottom: Mobility analysis
 - Historical travel time
 - Latest available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



Outline

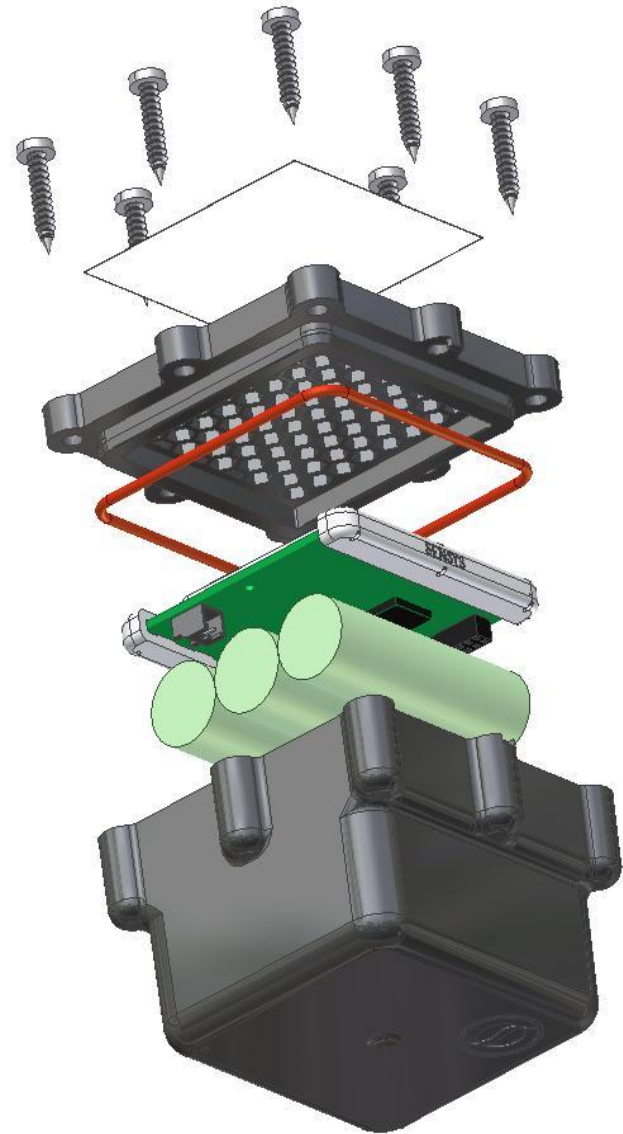
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Traffic Sensing Infrastructure



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

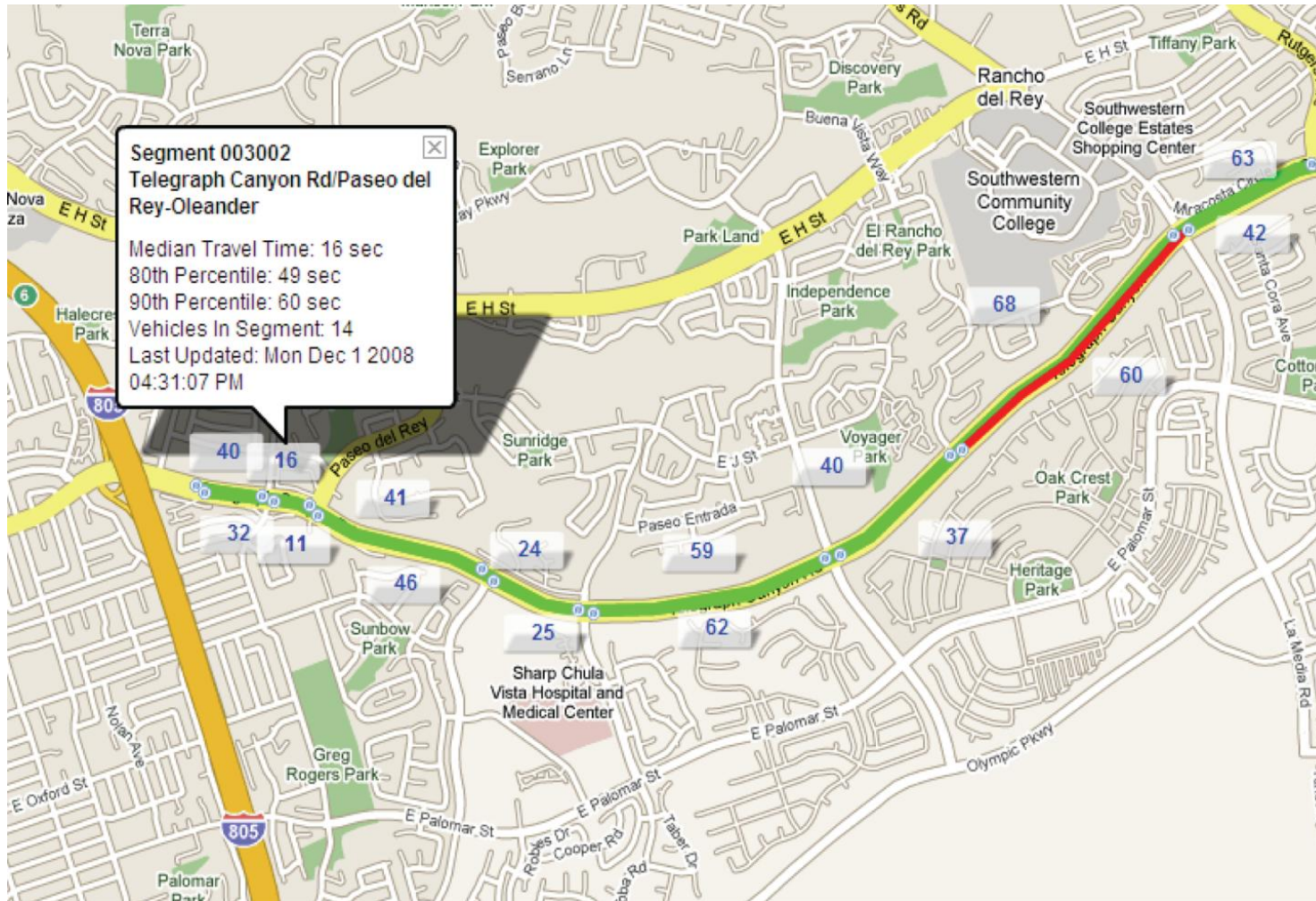


Los Angeles Dodger Stadium

Travel Time to the Gate on Game Day



Chula Vista installation (San Diego County)

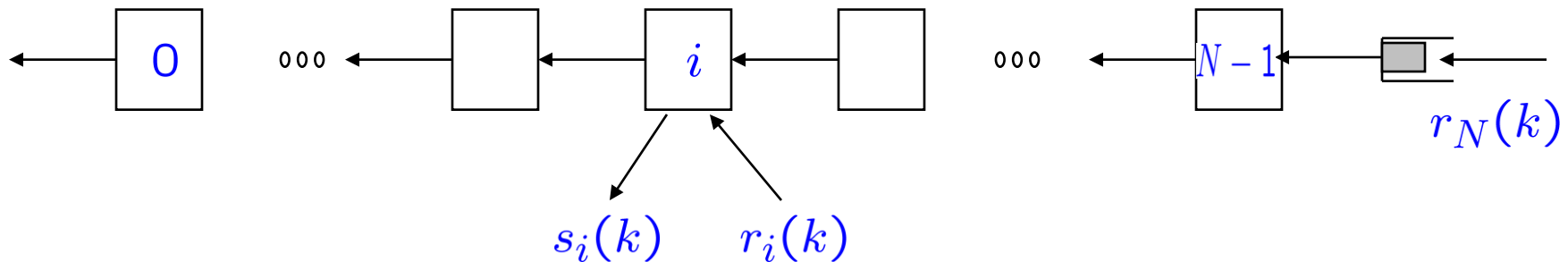


- 8-link
- 9-signal
- 3.3-mile

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Freeway structure



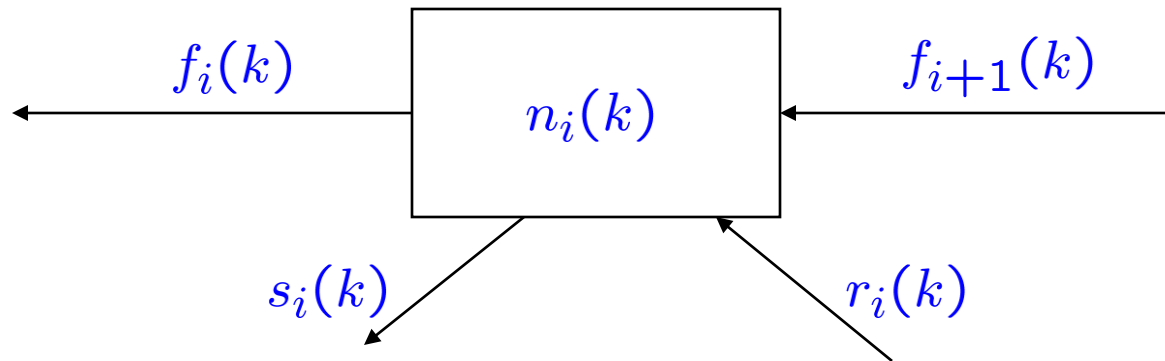
Freeway has N sections (cells), $0, \dots, N - 1$

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:

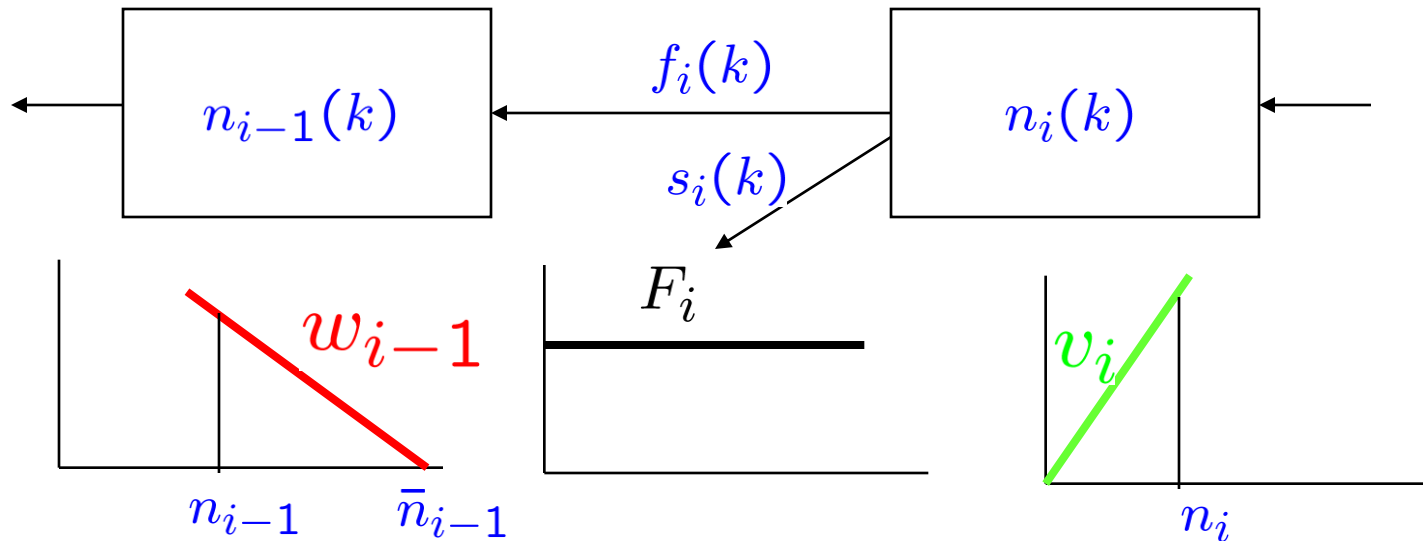
$$s_i(k) = \beta_i [s_i(k) + f_i(k)] = \beta_i \bar{\beta}_i^{-1} f_i(k). \quad (\bar{\beta}_i = 1 - \beta_i)$$

Off-ramp is unconstrained.

1 mile sections, so $n_i = \text{density} = \# \text{ vehicles}$,

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

Determination of inter-cell flow



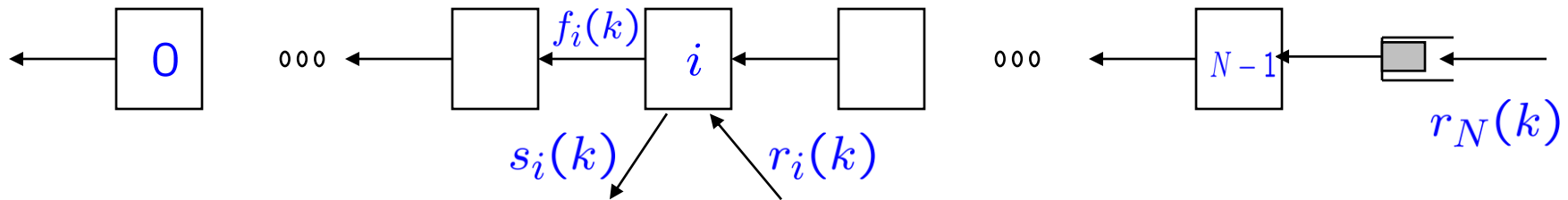
$$f_i(k) \leq v_i n_i(k) - s_i(k) \text{ - demand}$$

$$f_i(k) \leq F_i \text{ - capacity}$$

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

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

CTM model



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

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

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

Suppose

$$n_-(k) = g(n_-(k), d_-(k), C_+(k)) \text{ and}$$

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

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