



Constructing transportation system intelligence using PeMS

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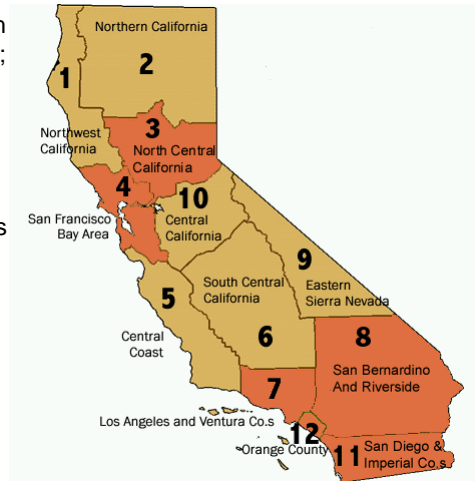
Outline

- ▶ Introduction to California Freeway Performance Measurement System (PeMS)
 - PeMS design principles
 - PeMS vision
- ▶ PeMS architecture
 - How PeMS works
 - Current uses of PeMS
- ▶ Future: A-PeMS, T-PeMS, S-PeMS



What is PeMS (Performance Measurement System)?

- ▶ PeMS collects loop detector data from District 3,4,7,8,11,12 and stores them; PeMS contains 2 TB of historical, and adds 2 GB of data each day—all data are online
- ▶ PeMS is accessed via a standard Internet browser and contains a series of built-in analytical capabilities to support a variety of uses
- ▶ PeMS production version being transferred to Caltrans



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PeMS design principles

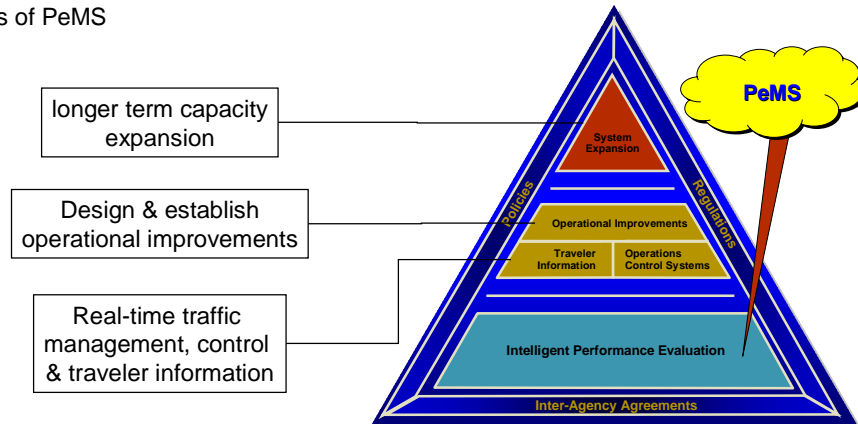
- ▶ **Divide and conquer**—break up more comprehensive performance measures into a set of small tasks. Example: Calculate all measures on basis of 5-minute-segments; use these to calculate measures for freeway, city, district, state
- ▶ **Back to basics**—start with simplest measures, before tackling more sophisticated ones. Example: Calculate travel times for each segment; use these to calculate travel time variability indexes
- ▶ **Use the Web**—rely on distributed data (under local control), but make them available over the Internet. Example: Each district assembles and maintains its own data; PeMS obtains copy and makes applications available over Internet. ATMS data only available by logging into ATMS database machine

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PeMS--element of Transportation Management System

► uses of PeMS



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PeMS role in TMS—user views

► Directors/Policy makers

- get high-level views of state-wide and district-wide performance
- can set measurable performance targets
- see opportunities for multimodal coordination

► Engineers

- detailed view by district, city, freeway, get segment
- use tools to analyze congestion, incident impacts, bottlenecks
- use lane closure forecasts to set performance-based contracts

► Planners

- get tools to analyze ramp metering
- use data to calibrate simulation models
- emergency planning aids

► Media

- get daily state-of-the-traffic report

► Public (customers)

- gets speed maps, travel time, route guidance, logistics assistance

► Researchers

- use database and development tools

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High-level views (1)

- ▶ PeMS statewide performance for 2001, 2002 shows year-over-year
 - 30% increase in demand (VMT)
 - 17% increase in travel time (VHT)
 - 151% increase in delay (VHT) due to increases in weekend (218%) and off peak weekday (56%) delay
- ▶ Note: PeMS will add incident statistics [here](#)
- ▶ Note: These numbers are not yet correct

California - Year to Year Comparison

Select Year Select Metric

2002

Vehicle Miles Traveled
Vehicle Hours of Delay
Vehicle Hours Traveled
Average Daily Traffic
Flow

Show Report

	2001 (000's)	2002 (000's)	% Change	% of Statewide
Weekday AM Peak 6:00am to 10:00am	80,252	84,158	4.87	-
Weekday PM Peak 3:00pm to 7:00pm	95,026	98,303	3.45	-
Total Weekday Peak	175,278	182,461	4.10	-
Weekday Offpeak - Day 10:00am to 3:00pm	87,839	93,627	6.83	-
Weekday Offpeak - Night 7:00pm to 6:00am	82,981	94,235	13.56	-
Total Weekday Offpeak	170,820	187,862	10.11	-
Weekend - Saturday	550,315	815,019	48.10	-
Weekend - Sunday	672,343	857,027	27.47	-
Total Weekend	1,222,658	1,672,046	36.76	-
Total	1,568,556	2,042,369	30.21	-

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High-level views (2)

- ▶ D3 performance for 2001, 2002 shows year-over-year
 - 3% increase in total delay
 - 6% increase in off peak weekday delay
 - 13% increase in VHT (from different menu choice)
- ▶ Note: These screen shots are part of PeMS Hicomp application report which can be generated at any time, for any period, district

District 3 - N. Central California

	2001 (000's)	2002 (000's)	% Change	% of Statewide
Weekday AM Peak 6:00am to 10:00am	1,829,874	1,896,457	3.64	50.03
Weekday PM Peak 3:00pm to 7:00pm	1,935,268	2,000,778	3.39	49.28
Total Weekday Peak	3,765,142	3,897,235	3.51	49.64
Weekday Offpeak - Day 10:00am to 3:00pm	2,113,511	2,246,031	6.27	48.52
Weekday Offpeak - Night 7:00pm to 6:00am	1,606,003	1,665,853	3.73	39.95
Total Weekday Offpeak	3,719,514	3,911,884	5.17	44.46
Weekend - Saturday	1,104,287	1,109,033	0.43	2.87
Weekend - Sunday	1,306,594	1,290,821	-1.21	3.15
Total Weekend	2,410,881	2,399,854	-0.46	3.01
Total	9,895,537	10,208,973	3.17	10.60

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High-level views (3)

- ▶ D11 director opens PeMS browser in his desktop to view current district-wide system performance

County	Cities	Fwys	Loops	Past Hour			Past Week		
				VMT	VHT	Delay	VMT (000's)	VHT (000's)	Delay (000's)
San Diego	11	22	285	12,015,173	234,903	14,698	1,744,142	33,418	2,300
Totals				12,015,173	234,903	14,698	1,744,142	33,418	2,300



High-level views (4)

- ▶ drills down to performance by freeway
- ▶ asks for trends in demand, congestion, incidents

Fwy	Loops	Dist. (mi)	Past Hour			Past Week		
			VMT	VHT	Delay	VMT (000's)	VHT (000's)	Delay (000's)
5-N	19	31.06	879,263	14,821		203,501	4,040	379
5-S	32	37.16	1,173,706	19,461		237,996	4,748	377
8-E	22	21.56	276,155	4,737		84,432	1,610	86
8-W	23	21.41	545,800	9,265		123,881	2,163	15
15-N	28	27.50	606,861	10,190		140,987	2,783	269
15-S	26	28.22	876,619	14,718		180,667	3,478	261
52-E	3	5.97	42,975	793		9,842	176	3
52-W	3	5.97	41,194	683		9,668	166	1
54-E	3	2.08	27,771	466		4,741	80	
54-W	3	2.00	24,469	416		4,626	79	0
56-E	2	1.01	2,448	41		946	16	0
56-W	2	0.99	3,914	64		889	15	
78-E	13	14.76	242,376	3,987		60,136	1,060	35
78-W	18	16.59	306,278	5,014		65,756	1,104	7
94-E	11	11.56	139,178	2,425		38,984	697	9
94-W	17	7.48	168,734	2,863		34,174	589	2
125-N	5	9.50	44,718	756		9,965	168	0
125-S	5	6.49	53,990	882		12,648	212	4
163-N	7	8.32	73,263	1,245		22,936	401	7
163-S	10	8.34	147,595	2,453		40,395	702	4
805-N	15	16.80	525,315	8,913		97,893	1,767	33
805-S	18	16.93	464,059	7,725		99,414	1,972	158
Totals			6,666,681	111,918	0	1,484,477	28,025	1,650



High-level views (5)

- ▶ checks current worst conditions in district
- ▶ finds condition on 5-N is worse than normal and emails analyst asking whether this is due to
 - incident
 - special event, or
 - random increase in recurrent congestion

Slowest Speeds		
Fwy	City (Postmiles)	Speed
5-N	SAN DIEGO (51.92 - 56.92)	21
5-S	ENCINITAS (51.11 - 56.11)	32
5-S	SOLANA BEACH (51.11 - 56.11)	33
5-S	ENCINITAS (56.11 - 61.11)	35
5-S	SAN DIEGO (51.11 - 56.11)	43

Greatest Flow		
Fwy	City (Postmiles)	Flow
15-N	SAN DIEGO (18.2 - 23.2)	37980
15-S	SAN DIEGO (9.63 - 14.63)	33900
15-S	SAN DIEGO (19.63 - 24.63)	33612
8-W	LA MESA (10.41 - 15.41)	31620
15-N	SAN DIEGO (8.2 - 13.2)	29616

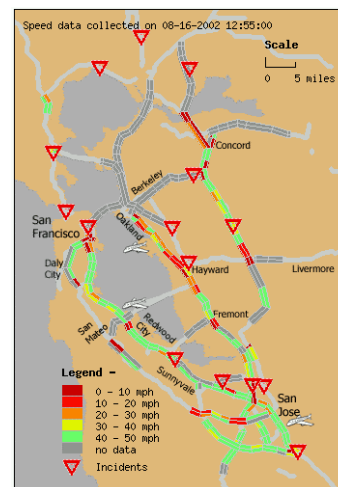
Most Delay		
Fwy	City (Postmiles)	Delay
5-N	SAN DIEGO (51.92 - 56.92)	207
5-S	ENCINITAS (51.11 - 56.11)	157
5-S	ENCINITAS (56.11 - 61.11)	136
5-S	SOLANA BEACH (51.11 - 56.11)	15

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Analyst (1)

- ▶ checks in PeMS' CHP database for significant incidents on I5-N during past hour, finds none
- ▶ Note: this is Bay Area (not D11) map

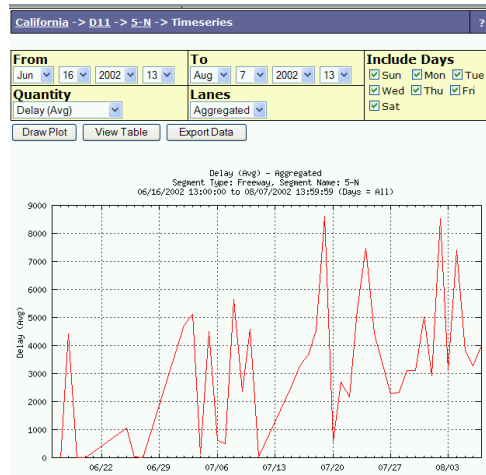


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Analyst (2)

- ▶ examines delay on I5-N over past two months and observes growing trend
- ▶ believes this may be end of summer effect ...
- ▶ but PeMS doesn't yet have D11 data for previous years to answer if traffic increases in August each year

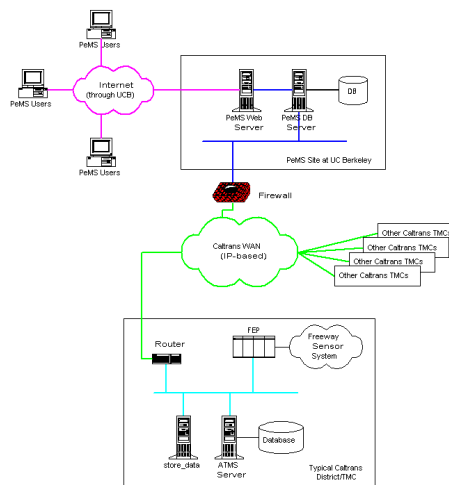


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Communications architecture

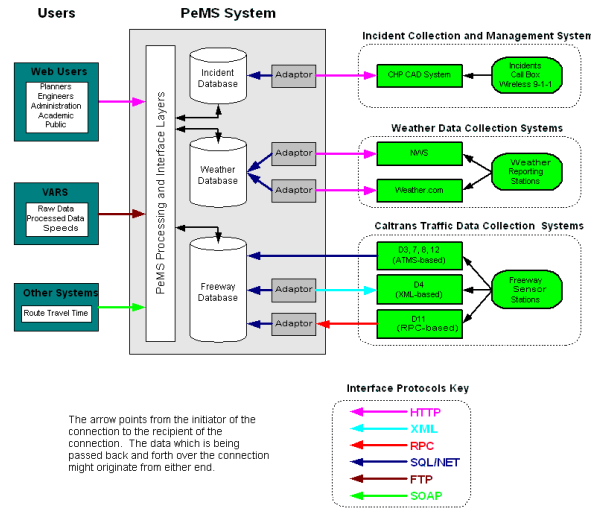
- ▶ PeMS collects and stores data in a central database; also obtains and stores CHP-published incident data
- ▶ The central database is currently located on the UC Berkeley campus, but it can be accessed from anywhere via the Internet
- ▶ Data are sent from the TMCs to UC Berkeley over the Caltrans wide area network (WAN)
- ▶ PeMS users have different levels of access to the data, depending on needs



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Software architecture (1)

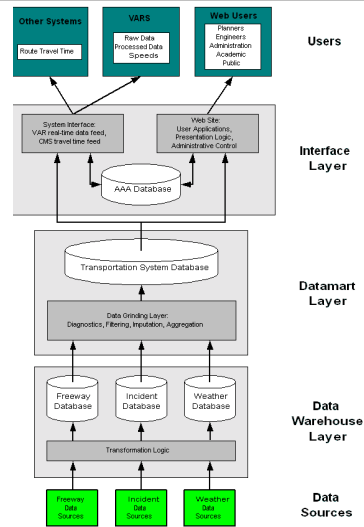


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Software architecture (2)

- ▶ Warehouse layer converts to common formats and stores bulk data
- ▶ Datamart layer calculates g-factors and speed, performs diagnostics, does aggregation, computes performance measures (delay, VMT, VHT, etc)
- ▶ Interface layers distribute data via web or SOAP



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Uses of PeMS

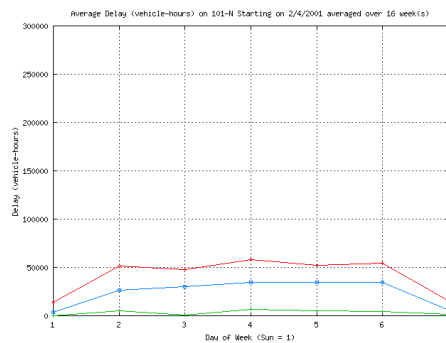
- ▶ Congestion measurement
- ▶ LoS determination
- ▶ Impact of incidents
- ▶ Bottleneck identification
- ▶ Bottleneck analysis
- ▶ Maximum flow or capacity estimation
- ▶ Gains from ramp metering
- ▶ (In)efficiency of freeway operations
- ▶ Truck counts
- ▶ Travel time variability
- ▶ Changeable message signs
- ▶ How good are PeMS data
- ▶ Sensor health and diagnosis
- ▶ Correcting sensor data

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Congestion measurement (1)

- ▶ PeMS chart of min, max, avg congestion on 101-N by day of week over 16-week period shows HICOMP report is unreliable
- ▶ need for statistically robust measures



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Congestion measurement (2)

$$D(s,t) = \sum_{\sigma \in s, \tau \in t} \max\{VHT(\sigma, \tau) - \frac{VMT(\sigma, \tau)}{V_r}, 0\}$$

- ▶ $D(s,t)$ is the additional vehicle-hours traveled driving below V_r mph over segment s and time duration t
- ▶ The segment may be a portion of freeway, a district, county, or user-defined segment; time duration is user-defined interval

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Congestion measurement (3) I-210 (peak hours, Feb-April '02)

- ▶ For 60 mph reference, **non-recurrent congestion is 13% of total congestion**; and accidents account for 72% of non-recurrent congestion
- ▶ For 35 mph reference, **non-recurrent congestion is 17% of total**
- ▶ **Incidents limited to those reported by CHP**

A. Reference Speed = 60 mph

I	$P(I)$	$E(D/I)$	σ	Error	Max D	Count
Total	1.00	368.75	290.67	18.53	1457.75	246
$I=0$	0.66	322.00	255.00	19.97	1098.50	163
$I=inc$	0.34	460.56	384.50	42.20	1457.75	83
$I=non$	0.15	410.58	304.67	50.09	1271.00	37
$I=acc$	0.19	500.75	352.75	52.01	1457.75	46

B. Reference Speed = 35 mph.

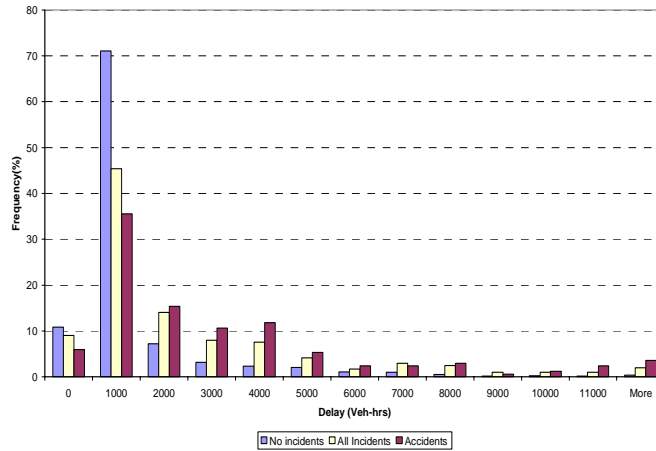
I	$P(I)$	$E(D/I)$	σ	Error	Max D	Count
Total	1.00	214.42	196.50	12.53	1104.25	246
$I=0$	0.66	177.83	166.42	13.03	806.17	163
$I=inc$	0.34	286.19	234.20	25.71	1104.25	83
$I=non$	0.15	251.92	205.17	33.73	842.83	37
$I=acc$	0.19	313.75	246.58	36.36	1104.25	46

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Congestion measurement (4)

- ▶ Probability distributions of congestion. Note importance of large tails



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Congestion measurement (5) I-880 FSP

- ▶ Non-recurrent congestion is 30% of total congestion, both before and after introduction of FSP
- ▶ Complete set of incidents: CHP, FSP, probe vehicles
- ▶ Same results when minor incidents (lasting less than 10 min are eliminated. This suggests that CHP incidents account for most delay-causing incidents

TABLE 2. SUMMARY STATISTICS-- CONGESTION DELAY I-880 (Reference Speed = 60 mph)

A. Before

<i>l</i>	<i>P(l)</i>	<i>E(D/l)</i>	σ	<i>Error</i>	<i>Max D</i>	<i>Count</i>
Total	1.00	40.45	46.04	2.71	286.30	288
<i>l</i> = 0	0.22	28.30	28.07	3.54	167.30	63
<i>l</i> = inc	0.78	43.85	49.44	3.30	286.30	225
<i>l</i> = non	0.63	35.91	45.17	3.35	286.30	182
<i>l</i> = acc	0.15	77.47	53.05	8.09	207.61	43

B. After

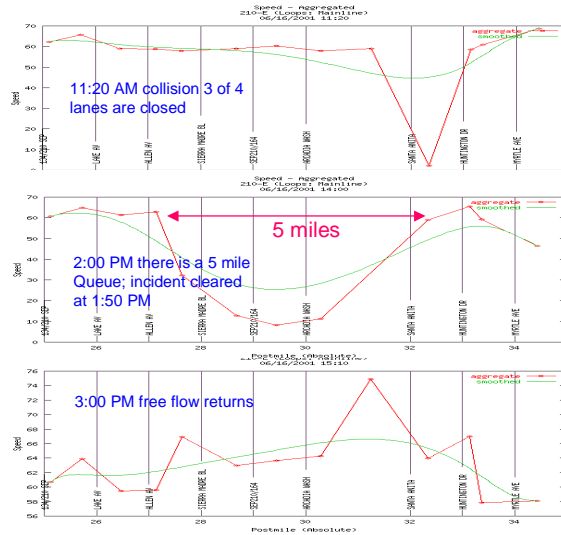
<i>l</i>	<i>P(l)</i>	<i>E(D/l)</i>	σ	<i>Error</i>	<i>Max D</i>	<i>Count</i>
Total	1.00	47.94	49.86	2.91	244.31	293
<i>l</i> = 0	0.29	30.86	31.77	3.43	123.91	86
<i>l</i> = inc	0.71	49.91	49.14	3.42	244.31	207
<i>l</i> = non	0.57	43.82	47.49	3.69	240.10	166
<i>l</i> = acc	0.14	74.51	48.57	7.59	244.31	41

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Incident impact (1)

- ▶ Free flow at 11:00 AM, 6/16/01, on 210-E
- ▶ Major incident at 11:20 AM
- ▶ Incident clears at 1:50 PM. There is a 5-mile queue at 2:00 PM. Free flow is restored at 3:00 PM
- ▶ Discharge rate was 300 vph for 10 min after incident, increasing to 1400 vph or 17 percent of capacity of 8400 vph, higher than 13 percent reported in HCM2000
- ▶ Queued vehicles discharged at 7400 vph, 12 percent lower than 8400 vph capacity

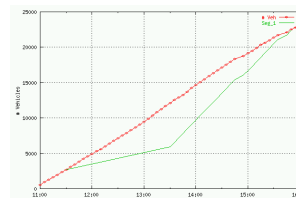


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Incident impact (2) what if

- ▶ Check effect of similar incident on other days, segments
- ▶ Specify incident duration, capacity during incident, discharge capacity; PeMS uses demand on that day to compute delay and queue length
- ▶ Evaluate benefit of reduced incident clearance time
- ▶ The 'lane closure' application could be used to choose time and performance-based construction contract



Summary of capacity-exceeding segments:

Seg #	Incident Start Time	Delay Start Time	Delay End Time	Segment Delay Duration (minutes)	Incident Capacity (veh/hr)	Max Flow During Segment (veh/hr)	Max Individual Delay (minutes)	Max Queue Length (miles)	Total Delay (veh-hrs)
1	06/15/2001 11:30:00	06/15/2001 11:30:00	06/15/2001 16:45:00	270	1600	6840	65.8 at 06/15/2001 12:10:00	7.1	13911.5
									Sum: 13911.5

Summary of capacity-exceeding segments:

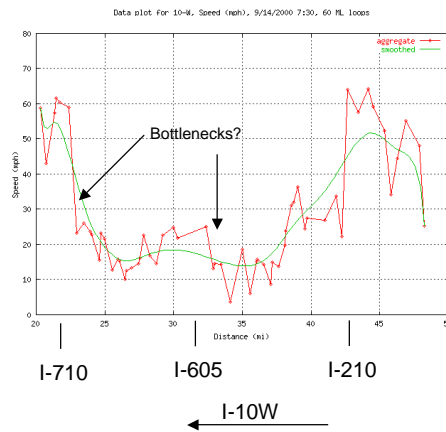
Seg #	Incident Start Time	Delay Start Time	Delay End Time	Segment Delay Duration (minutes)	Incident Capacity (veh/hr)	Max Flow During Segment (veh/hr)	Max Individual Delay (minutes)	Max Queue Length (miles)	Total Delay (veh-hrs)
1	06/17/2001 11:30:00	06/17/2001 11:30:00	06/17/2001 15:35:00	255	1600	6600	75.7 at 06/17/2001 12:15:00	7.35	13025.6
									Sum: 13025.6

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Identifying bottlenecks (1)

- ▶ Select freeway section, time, and variable (eg speed)
- ▶ Plot shows average speed on I-10W from pm 20 to 50 at 7.30 am on September 14, 2000
- ▶ Two potential bottlenecks at pm 23 and 32 where speed drops sharply

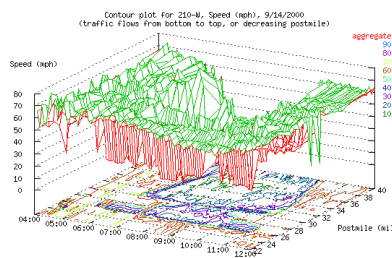


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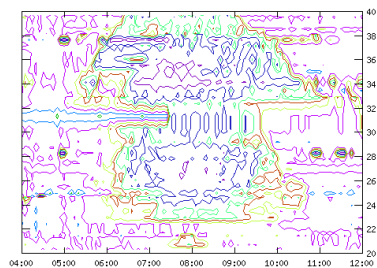


Identifying bottlenecks (2)

- ▶ Bottleneck confirmed from PeMS contour map application
- ▶ Repeat confirmation for other days
- ▶ Engineer can focus on causes (geometry, interchanges, demand) and measures to alleviate bottleneck



Contour plot for 10-W, Speed (mph), 9/14/2000
(traffic flows from bottom to top, or decreasing postmile)

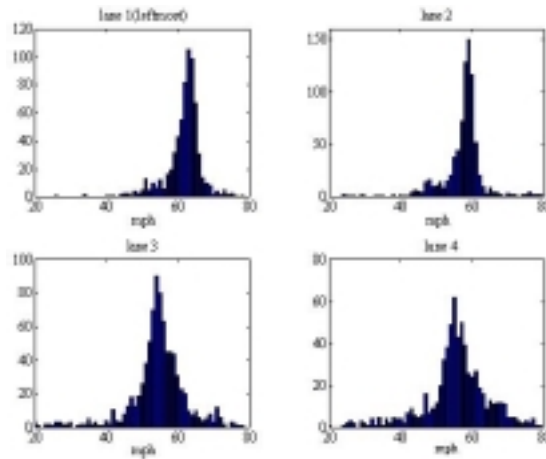


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Maximum flow occurs at 60 mph (1)

- ▶ Highway Capacity Manual gives speed-flow curve with max flow between 35-50 mph
- ▶ Flow at 3,363 detectors in D7 on Sept 1, 2000, between midnight and noon shows max flow at 60 mph
- ▶ So congestion should be defined as extra delay driving below 60 mph

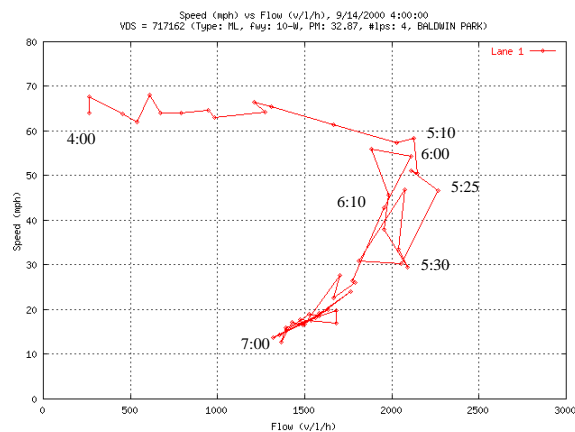


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Maximum flow occurs at 60 mph (2)

- ▶ Speed-flow plot in one section
- ▶ Speed below 50 mph cannot be sustained
- ▶ Ramp-metering will be effective only if it maintains free flow

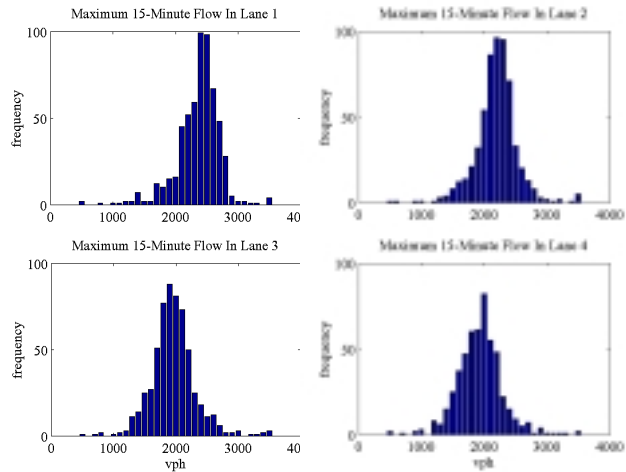


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Maximum sustainable flow is 2000-2400 vph (3)

- ▶ Lane-by-lane distributions of maximum flows recorded in Los Angeles
- ▶ Planning studies can be based on empirically based capacity

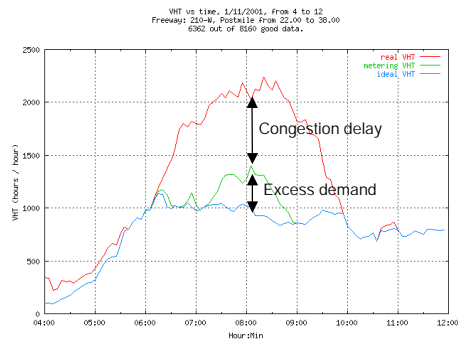


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Potential gains from ramp metering

- ▶ Select freeway section I-210W, pm 22 to 38, Jan 11, 2001, 4.00 am to noon
- ▶ Hypothesis: if flow is maintained below max observed flow (less 3%), then speed will be 60 mph
- ▶ Ramp-metering imposes this policy
- ▶ Application calculates total delay, and delay at ramps
- ▶ Calculates ramp queues
- ▶ For LA, annual congestion delay estimated at 75 million vehicle-hours of which 50 million is eliminated by this policy



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Inefficiency of traffic operations (1)

- ▶ Earlier figure shows at 7.00 am flow is 1300 v/h/ln and speed is 15 mph. So efficiency is

$$\eta = \frac{Flow \times Speed}{MaxFlow \times SpeedAtMaxFlow(60)} = 13\%$$

- ▶ Formula based on queuing system. Customer is vehicle, service is transport across segment, service time is

$$\frac{SegmentLength}{Speed}$$

- ▶ *Flow* customers served in parallel, so throughput--number of customers served per unit time--is

$$\frac{Speed}{SegmentLength} \times Flow$$

- ▶ Max throughput is

$$\frac{SpeedAtMaxFlow(60)}{SegmentLength} \times MaxFlow$$

- ▶ Efficiency is throughput/Max throughput

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Inefficiency of traffic operations (2)

- ▶ Estimate efficiency of all 291 segments of I-10W at time of worst congestion on Oct 1, 2000, midnight to noon

- ▶ 78 segments have efficiency under 40%, 65 between 40 and 80%, 46 have efficiency larger than 100 (speed at max flow larger than 60 mph)

- ▶ \$1 trillion dollar freeway system has very poor efficiency at time of greatest demand

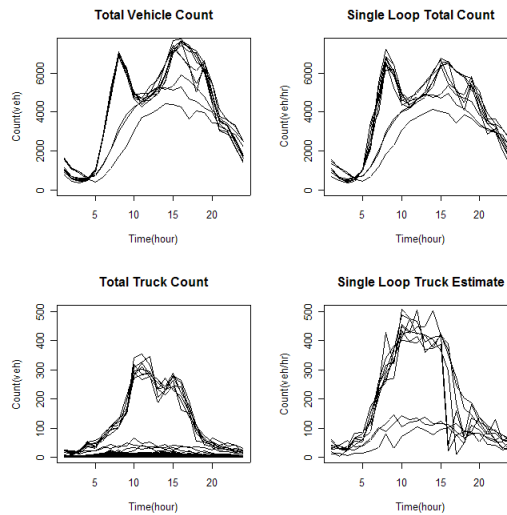


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Truck counts (1)

- ▶ Comparison of PeMS estimates of hourly total vehicle and truck counts using single loop data with WIM-AVC counts on I-91E, May 5-18, 2002
- ▶ PeMS overestimates trucks but shows same trends for weekdays and weekends
- ▶ Counts are based on PeMS' vehicle length estimates



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Truck counts (2)

- ▶ Comparison of PeMS estimates of daily truck counts by lane on I-880 over 10 Mondays, March 22-May 24, 1999, using single-loop and double-loop data with observed counts and AADT reports
- ▶ Error for total counts is 5.7% for single loop and 3.3% for double loop estimates

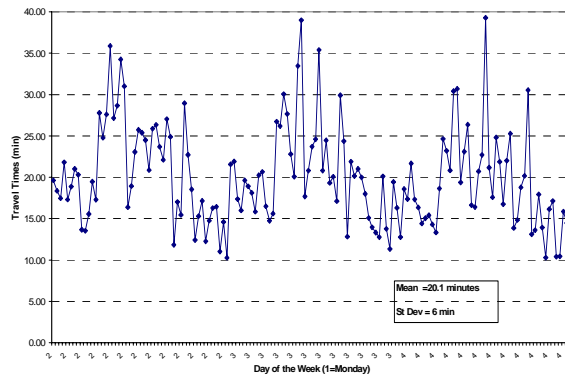
	Observed		Single-Loop Algorithm		Double-loop Algorithm	
	Volume (veh/day)	Raw and Percent Truck Volume	Estimated Raw and Percent Truck Volume	Error and Percent Error	Estimated Raw and Percent Truck Volume	Error and Percent Error
Lane 1 (HOV)	11,493	- ¹	-	-	-	-
Lane 2	25,846	255 (1.0%)	0 (0%)	255 (-100%)	121 (0.5%)	-134 (-53%)
Lane 3	24,169	1,437 (5.9%)	1,217 (5.0%)	-220 (-15.3%)	1,344 (5.6%)	-94 (-6.5%)
Lane 4	23,546	2,037 (8.7%)	2,098 (8.9%)	62 (3.0%)	2,153 (9.1%)	116 (5.7%)
Lane 5	13,621	981 (7.2%)	884 (6.5%)	-97 (-9.9%)	936 (6.9%)	-45 (-4.5%)
Total	98,677	4,710 (4.8%)	4,200 (4.3%)	-255 (5.7%)	4,553 (4.6%)	-157 (3.3%)
Caltrans Report- ²	127,500	6,126 (4.8%)	-	-	-	-

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Travel time variability (1)

- ▶ Travel time variability along I-210 corridor by day of week

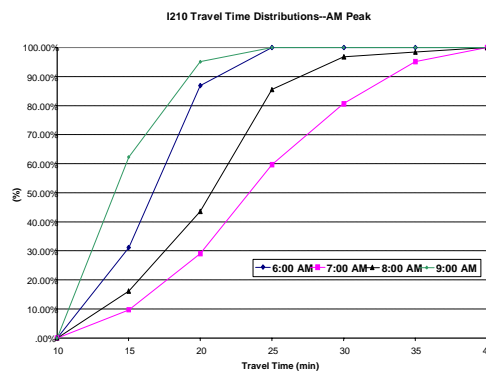


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Travel time variability (2)

- ▶ Travel time distribution by departure time
- ▶ Average travel time under free-flow is 13 min
- ▶ Increases to 23 minutes under congestion
- ▶ 90th percentile travel time increases by 15 min from 18 to 33 min

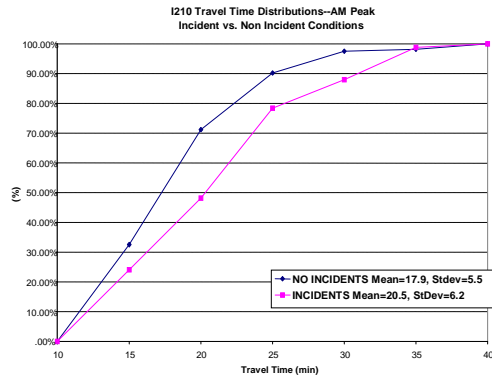


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Travel time variability (3)

- ▶ Travel time distribution during incident-free peak periods and periods with incidents
- ▶ Average travel time during incidents increases by 17%, 90th percentile increases by 8 min

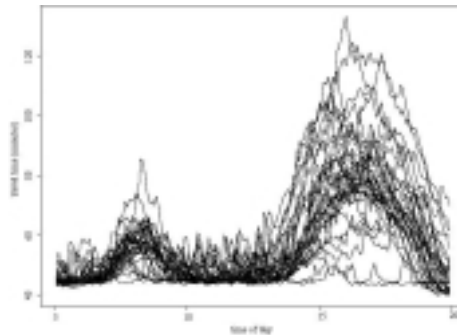


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Travel time variability (4)

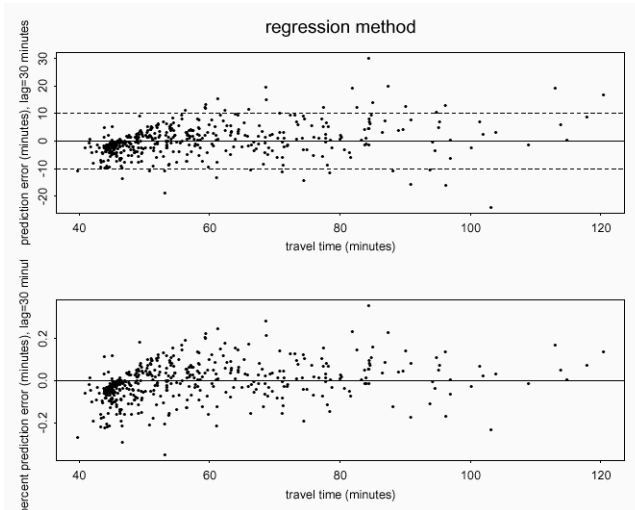
- ▶ Travel times for 20 days in October, 2000, on I-10E, between pm 1.3 and 48.5, starting every 5-min, between 5 am and 8 pm
- ▶ Unconditional distribution shows large variation
- ▶ 90% confidence interval for trip starting at 5 pm is between 55 and 110 min
- ▶ Travel time distribution, conditioned on current and past values, shows much smaller variation
- ▶ Permits prediction of travel time



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Travel time prediction—30 min forecast

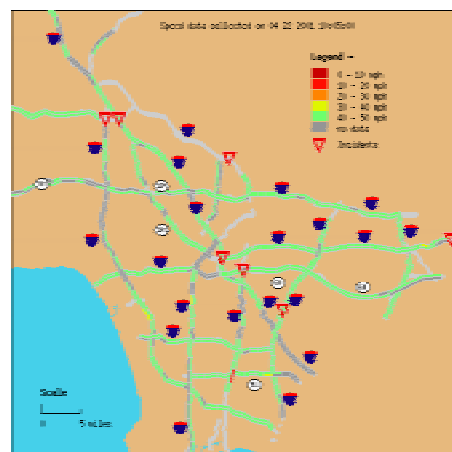


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Traveler information

- ▶ Speed maps, now common on the Internet and via cable TV, are available at PeMS website
- ▶ The map also shows incidents. Clicking on an incident icon gives a description



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Traveler information

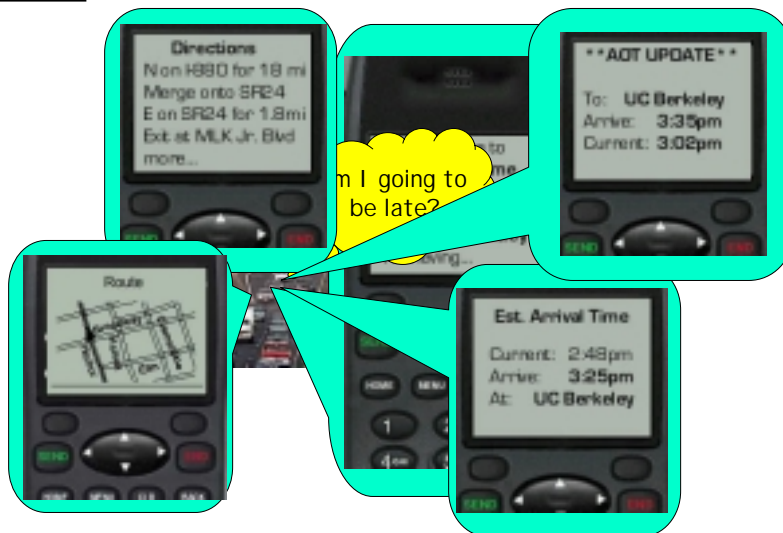
- ▶ PeMS provides travelers in LA travel time estimates and predictions from designated origin to destination for 15 shortest-distance routes
 - Exhibit shows an example
 - Travel times will also be provided for HOV vehicles



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Traveler information scenario



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A possible use

Karl,

I'd like to use [information on average speed throughout the day along the SD I-15 corridor to help us recommend and set shift change times for our plant in Rancho Bernardo](#). Ideally I'd like to graph the average speed every few minutes throughout the day at each ramp along the San Diego county I-15 corridor. I created a public account (MartinJD) on your server but have been unable to find any way of displacing this information or the raw data. Can you help?

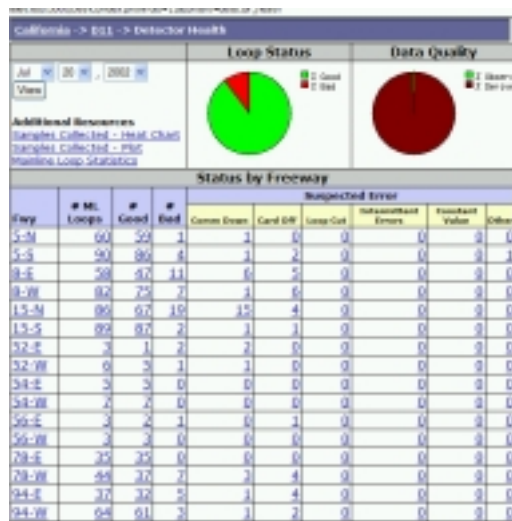
Thanks,--Jon

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D11 loop detector quality

- ▶ For each day, and each freeway PeMS gives
 - number of 'good' vs 'bad' loops
 - diagnosis of 'bad' loops
- ▶ Several additional charts give different views of loop detector system performance



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Future developments

- ▶ PeMS has just started A-PeMS, PeMS extension to include arterial data in LA
- ▶ PeMS will receive Caltrans-MTC ETC tag data for 24-hour trips. This will provide a unique data set for calculating O/D and multi-purpose trip data, demand for special events

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Appendix 1: How to Access PeMS

- ▶ Go to the following URL:
<http://pems.eecs.Berkeley.edu>
- ▶ You need a username and password
- ▶ You can get these at the PeMS web site
 - Select “Login” and then “Apply for an Account”
 - Fill out the online form and select “Apply”



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Conclusion

- ▶ The integration of IT at all levels of the transportation system can greatly enhance freeway system productivity
- ▶ Examples from Los Angeles illustrate opportunities to improve system management and assist travelers
- ▶ Integration of IT requires reengineering the operations, planning, and investment procedures constituting today's transportation system

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Berkeley Highway Lab

- ▶ 12 cameras with overlapping fields of view covering 1.5 miles of I-880
- ▶ Video data are processed to obtain position and speed of every vehicle
- ▶ Left movie is feature tracker; right movie is grouper



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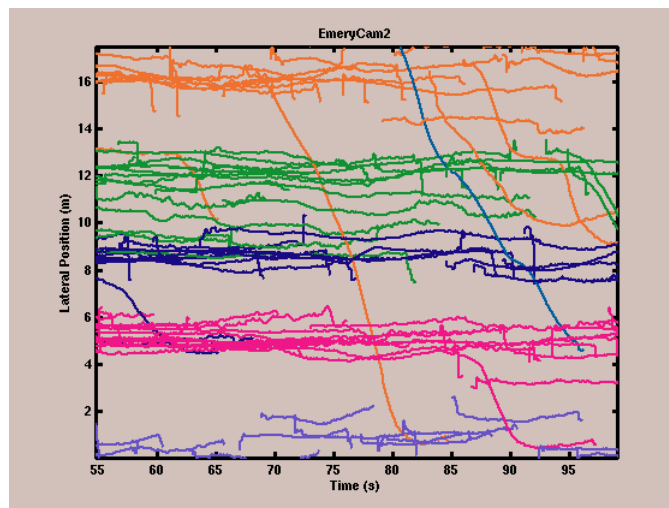
Lane-changing maneuver and shockwave



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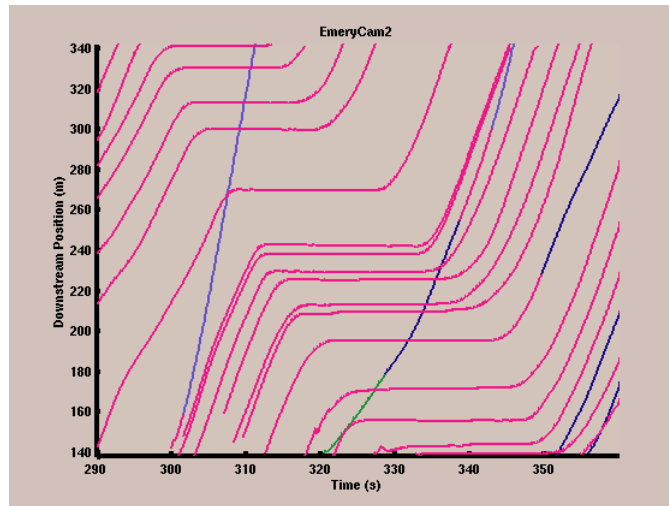
Lane changing



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Shockwave



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PeMS Publications 2002 (1)

- ▶ [California's performance measurement system: Improving freeway efficiency through transportation intelligence](#), by P. Varaiya, July 2001, appears in TR News, 218, Jan-Feb 2002. [pdf, 262K]
- ▶ [Detecting errors and imputing missing data for single loop surveillance systems](#), by C. Chen, J. Kwon, A. Skabardonis, P. Varaiya, 82nd Annual Meeting of the Transportation Research Board, August 2002. [pdf, 696K]
- ▶ [Estimation of truck traffic volume from single loop detector using lane-to-lane speed correlation](#), by J. Kwon, P. Varaiya, A. Skabardonis, 82nd Annual Meeting of the Transportation Research Board, August 2002. [pdf, 384K]
- ▶ [Joint estimation of the traffic speed and mean vehicle length from single-loop detector data](#), by J. Kwon. Submitted to the 82nd Annual Meeting of the Transportation Research Board, August 2002. [pdf, 247K]
- ▶ [Measuring recurrent and non-recurrent traffic congestion](#), by A. Skabardonis, P. Varaiya, K. Petty, 82nd Annual Meeting of the Transportation Research Board, August 2002. [pdf, 391K]

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2002(2)

- ▶ [The quality of loop data and the health of California's freeway loop detectors](#), by C. Chen, J. Kwon and P. Varaiya, July 2002. [pdf, 454K]
- ▶ [A simple and effective method for predicting travel times on freeways](#), by J. Rice and E. van Zwet, Submitted to IEEE Transactions on Intelligent Transportation Systems, August 2002. [pdf, 278K]
- ▶ [Statistical methods for estimating speed using single-loop detectors](#), by C. Chen, Z. Jia, J. Kwon, E. van Zwet, Submitted to the 82nd Annual Meeting of the Transportation Research Board, August 2002. [pdf, 295K]
- ▶ [Travel time reliability as a measure of service](#), by C. Chen, A. Skabardonis, P. Varaiya, 82nd Annual Meeting of the Transportation Research Board, August 2002. [pdf, 306K]

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2001 (1)

- ▶ [Causes and cures of highway congestion](#), by C. Chen, Z. Jia and P. Varaiya, August 2001. IEEE Control Systems Magazine, 21(4), 26--33, Dec 2001. [pdf, 196K]
- ▶ [The Freeway-Congestion Paradox](#), by C. Chen and P. Varaiya, November 2001. Access 20, Spring 2002. [pdf, 172K]
- ▶ [Freeway performance measurement system \(PeMS\): An operational analysis tool](#), by T. Choe, A. Skabardonis and P. Varaiya. TRB 81st Annual Meeting, January 2002. [pdf, 520K]
- ▶ [Freeway performance measurement system: mining loop detector data](#), by C. Chan, K. Petty, A. Skabardonis, P. Varaiya, Z. Jia. 80th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan 2001. [pdf, 259K]
- ▶ [Maximum flow in D12 occurs at 60 mph](#), by C. Chen and P. Varaiya, October 2001. [pdf, 91K]

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- ▶ [Maximum throughput in LA freeways occurs at 60 mph v.4](#), by Z. Jia, P. Varaiya, C. Chao, K. Petty, A. Skabardonis. Jan 16, 2001. [pdf, 105K]
- ▶ [A New Methodology for Evaluating Incident Detection Algorithms](#), K. Petty, M. Ostland, J. Kwon, J. Rice and P. Bickel, (in press) Transportation Research, Part C. [pdf, 239K]
- ▶ [The PeMS algorithms for accurate, real-time estimates of g-factors and speeds from single-loop detectors](#), by Z. Jia, C. Chen, B. Coifman, P. Varaiya. Feb 12, 2001. Submitted to IEEE 4th International ITS Conference. [pdf, 223K]
- ▶ [Traffic Flow on a Freeway Network](#), P. J. Bickel, C. Chen, J. Kwon, J. Rice, P. Varaiya and E. van Zwet, To appear in the Proceeding of MSRI Workshop on Nonlinear Estimation and Classification, Berkeley, California, March 19-29, 2001, Springer. [pdf, 371K]
- ▶ [Wireless content delivery and user profiling](#), by C-K Ng and C. Chen. Feb 12, 2001. Submitted to IEEE 4th International ITS Conference. [pdf, 217K]

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- ▶ [Calculus of Statistical Efficiency in a General Setting: Kernel Plug-in Estimation for Markov Chains: Hidden Markov Modeling of Freeway Traffic](#), J. Kwon. Dept of Statistics, University of California, Berkeley, California Committee: Peter J. Bickel (chair), John Rice, David Brillinger. Fall 2000. [pdf, 581K]
- ▶ [Congestion, excess demand, and effective capacity in California freeways](#), by Z. Jia, P. Varaiya, C. Chen, K. Petty and A. Skabardonis. Dec 9, 2000. [pdf, 356K]
- ▶ [Optimal ramp metering policy](#), by C. Chen, P. Varaiya. Nov 9, 2000.
- ▶ [Day-to-Day Travel Time Trends and Travel Time Prediction from Loop Detector Data](#), by J. Kwon, B. Coifman, and P. Bickel. Transportation Research Record no. 1717, Transportation Research Board, pp. 120-129. 2000. [pdf, 278K]

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1999

- ▶ [Freeway performance measures: calculations with loop detectors](#), by The PeMS Group, August 1999. [pdf, 125K]

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- ▶ [Accurate estimation of travel times from single-loop detectors](#), K. F. Petty, P. Bickel, M. Ostland and J. Rice, Y. Ritov, F. Schoenberg. Transportation Research, Part A (Policy and Practice), Jan. 1998, vol.32A, (no.1):1-17. [pdf, 337K]

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1997

- ▶ [How to measure transportation system performance](#), by P. Varaiya. December, 1997. [pdf, 4730K]
- ▶ [Incidents on the Freeway: Detection and Management](#), K. F. Petty, Department of Electrical Engineering and Computer Science, University of California, Berkeley, California. Fall 1997. [pdf, 2.9M]