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# San Diego I-15 ATDM/DMA Testbed Evaluation Results for Connected Vehicles Applications

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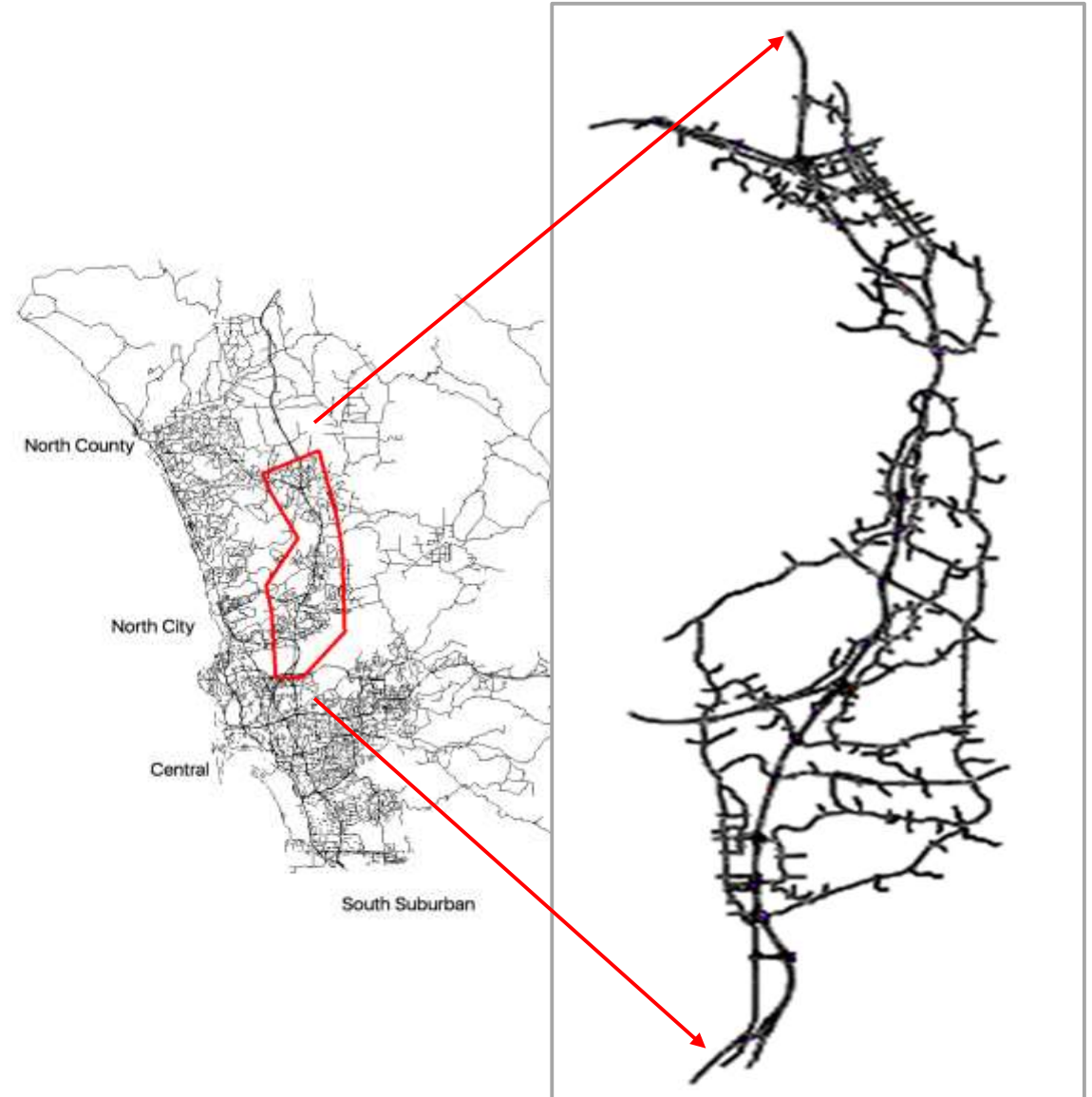
# Project description

- USDOT-funded Analysis, Modeling, and Simulation (AMS) Testbed Development and Evaluation to Support Dynamic Mobility Applications (DMA) and Active Transportation and Demand Management (ATDM) Programs
- Six simulation-based testbeds: San Mateo, Pasadena, Dallas, Phoenix, San Diego and Chicago
- Aimsun subcontractor of Becht Allen Hamilton for the San Diego testbed



# Testbed description

- 22-mile stretch of I-15
- 5 GP lanes per direction
- 4 HOT lanes in total, with changeable configuration
- 23 entrance ramps/merges SB, 25 NB
- Parallel arterials with actuated signals
- ICM demonstration site



# Methodology

- ICM microscopic traffic simulation model (Aimsun)
- Four real-world Operational Conditions
  - Cluster analysis of days with incident and response plan
  - AM from 5 AM to 10 AM, PM from 2 PM to 7 PM
  - Different incident severity and demand levels

	OC 1 (AM1)	OC 2 (AM2)	OC 3 (PM3)	OC 4 (PM4)
<b>Representative day</b>	05/27/15	02/09/15	06/30/15	07/07/14
<b>Operational Condition</b>	Southbound (AM) +Medium Demand + Medium Incident	Southbound (AM) +Medium Demand + High Incident	Northbound (PM) +Medium Demand + High Incident	Northbound (PM) +Medium Demand + Medium Incident
<b>VPH</b>	6201	6348	9034	8870
<b>Total Cluster Delay (min)</b>	49.88	108.03	99.72	63.25
<b>Number of Incidents/Period</b>	1.9	3.7	5.5	2.1

# Evaluation scenarios

- Six ATDM strategies
  - Dynamic Lane Use, Dynamic Speed Limits, Dynamic Merge Control, Predictive Traveler Information, Dynamic High-Occupancy Vehicle (HOV)/Managed Lanes, and Dynamic Routing
- One DMA bundle
  - Intelligent Network Flow Optimization (INFLO), which includes Dynamic Speed Harmonization (SPD-HARM) and Cooperative Adaptive Cruise Control (CACC)
- In isolation and in combination
- 25%, 50% and 90% CV penetration rates
- Full Evaluation Report FHWA-JPO-16-389 available online (<https://rosap.ntl.bts.gov/view/dot/34173>)

**Analysis, Modeling, and Simulation (AMS) Testbed Development and Evaluation to Support Dynamic Mobility Applications (DMA) and Active Transportation and Demand Management (ATDM) Programs**

Evaluation Report for the San Diego Testbed

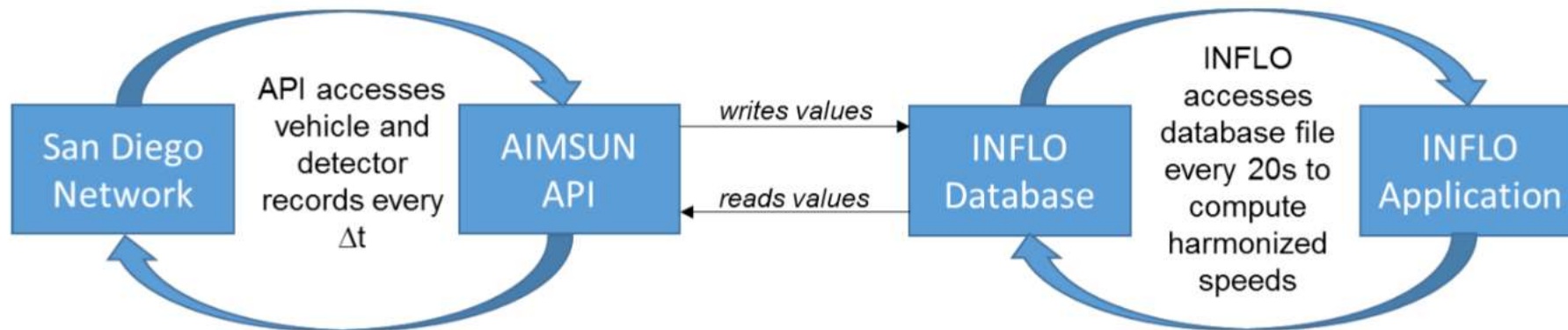
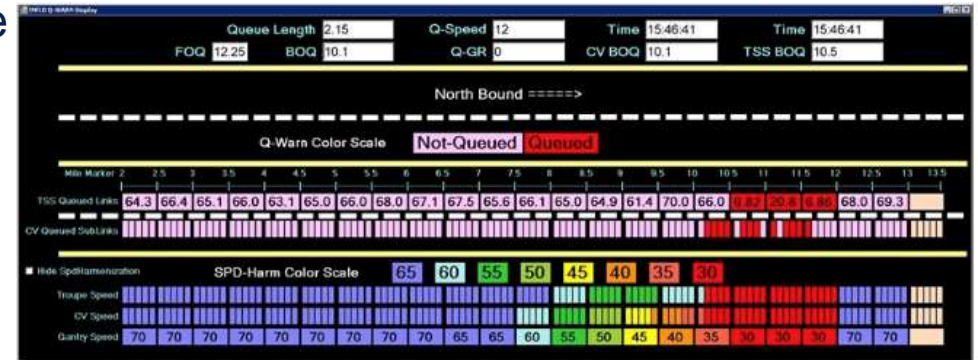
[www.its.dot.gov/index.htm](http://www.its.dot.gov/index.htm)  
Draft Report — July 2017  
FHWA-JPO-16-389



U.S. Department of Transportation

# How SPD-HARM was modeled

- Interface with the INFLO-SIM application in OSADP via database
- Every 20 s
  - Write 20 s speed, volume and occupancy of detector stations
  - Write position and instantaneous speed of CVs
  - Read speed for CVs in 0.1 mi segments
- Published in OSADP as AMS-Aimsun-INFLO

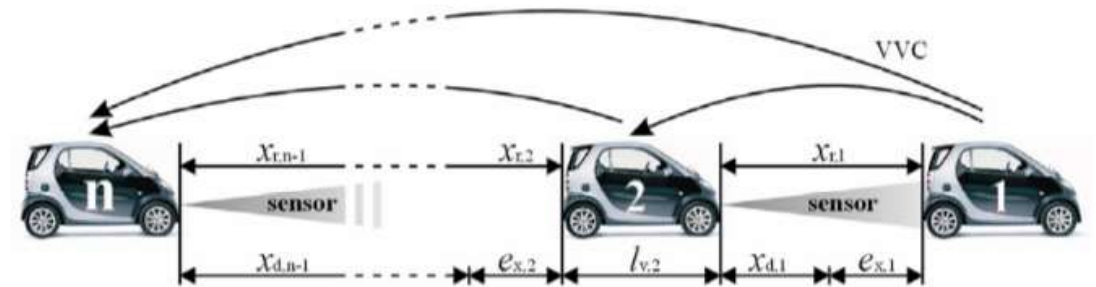


# How CACC was modeled

- Algorithm used by Leidos and TFHRC (CACC-Vissim in OSADP)

$$a_{d,n} = (k_2 e_{v,n-1} + k_1 e_{x,n-1}) + \left( \frac{k_2}{n-2} \sum_{i=1}^{n-2} e_{v,i} \right)$$

- $k_1 = 0.1$ ,  $k_2 = 0.58$ ,  $n = 6$ ,  $e_v = 0$  m/s,  $e_x = 5$  m
- No limit to the platoon size
- CACC allowed on specific GP lanes on I-15
  - The three leftmost for 25% and 50% CV penetration rate
  - All five lanes for 90% CV penetration rate
  - CVs have to use those lanes, but non-CVs can also
  - CVs disconnect CACC when approaching their exit
- Published in OSADP as AMS-CACC-Aimsun



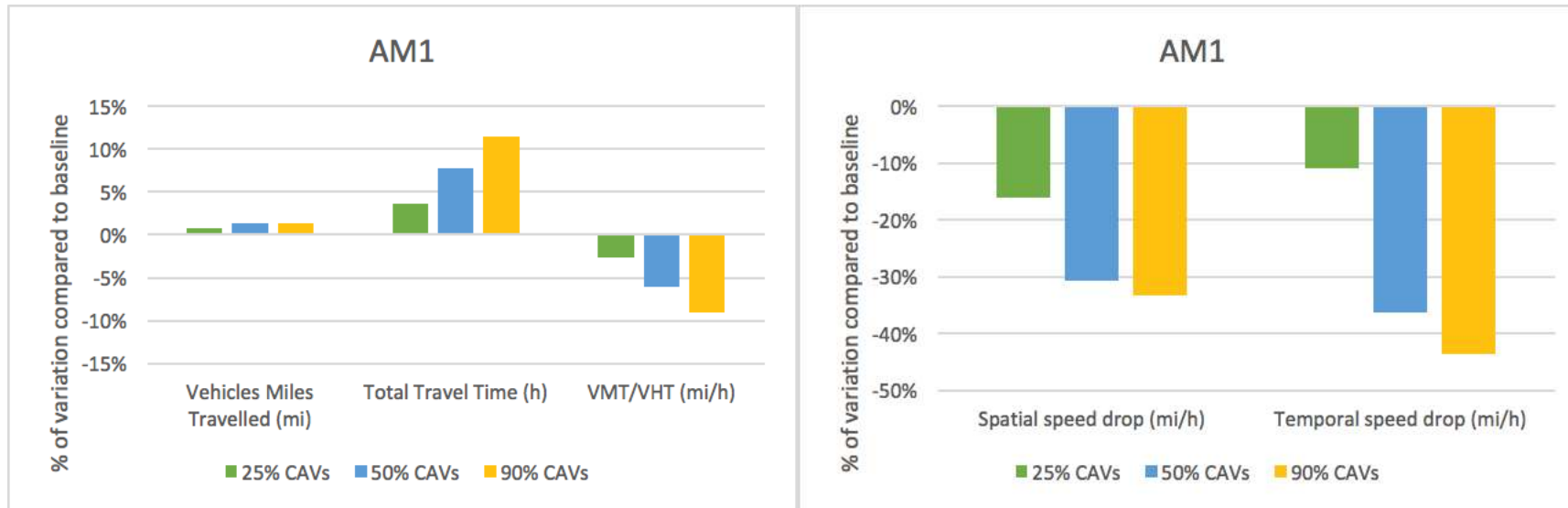


# Evaluation of SPD-HARM – AM1

	Del Norte Parkway	West Valley Parkway	Felicita Rd	Via Rancho Parkway	Pomeroado rd	Rancho Bernardo Rd	Camino del Norte	Ted Williams Parkway	Mira Mesa Blvd	Miramar Rd	Split I-15 / SR-163
BASE	Time	110716	110716	110716	110716	110716	110716	110716	110716	110716	110716
	6:15 AM	76	34	42	54	54	58	45	48	58	51
	6:30 AM	79	34	41	54	54	58	45	48	58	51
	6:45 AM	72	32	38	55	35	34	44	44	33	32
	7:00 AM	71	32	38	55	35	34	44	44	33	32
	7:15 AM	71	27	41	53	56	42	32	47	37	34
	7:30 AM	68	24	38	53	54	34	43	60	51	42
	7:45 AM	68	19	40	44	27	34	48	64	68	52
	8:00 AM	56	22	31	19	17	33	37	55	55	44
	8:15 AM	74	29	23	31	13	23	34	50	45	36
	8:30 AM	79	39	29	21	20	22	27	48	36	34
	8:45 AM	75	72	28	17	13	19	24	46	34	34
9:00 AM	75	74	27	18	16	19	24	44	33	33	
9:15 AM	76	74	28	15	20	24	34	52	34	32	
9:30 AM	75	74	32	24	23	25	43	42	38	25	
9:45 AM	75	73	32	47	41	34	30	48	39	34	
10:00 AM	75	74	32	56	55	54	58	62	60	68	
SPD-HARM 25%	Time	110716	110716	110716	110716	110716	110716	110716	110716	110716	110716
	6:15 AM	88	44	57	80	42	41	45	50	41	35
	6:30 AM	86	47	44	32	32	41	42	42	54	64
	6:45 AM	83	41	28	31	26	31	36	44	39	32
	7:00 AM	57	24	34	55	37	35	30	55	66	72
	7:15 AM	48	22	40	55	25	33	30	44	43	34
	7:30 AM	54	22	33	54	43	41	43	40	43	41
	7:45 AM	42	14	24	20	21	22	14	30	37	41
	8:00 AM	15	18	27	18	18	22	34	30	36	47
	8:15 AM	26	19	27	23	19	23	29	45	45	36
	8:30 AM	55	30	28	30	25	21	25	44	35	31
	8:45 AM	68	30	22	17	10	19	22	43	33	31
9:00 AM	71	62	19	17	18	18	23	43	31	31	
9:15 AM	73	66	42	16	17	18	22	43	36	43	
9:30 AM	74	71	62	29	17	19	21	43	45	37	
9:45 AM	74	73	70	66	30	32	25	43	41	35	
10:00 AM	75	73	77	68	60	67	57	55	55	66	
SPD-HARM 50%	Time	110716	110716	110716	110716	110716	110716	110716	110716	110716	110716
	6:15 AM	88	32	38	46	46	23	41	52	63	58
	6:30 AM	81	44	40	30	31	33	43	48	34	45
	6:45 AM	59	43	28	26	26	30	34	45	36	31
	7:00 AM	52	23	29	49	44	39	30	43	34	30
	7:15 AM	40	23	45	53	47	42	30	44	41	38
	7:30 AM	35	20	28	55	44	37	35	47	49	41
	7:45 AM	30	29	32	45	34	25	42	57	60	53
	8:00 AM	18	20	27	16	16	20	18	32	34	40
	8:15 AM	29	25	29	24	19	22	28	44	45	36
	8:30 AM	36	31	38	31	19	21	14	44	36	31
	8:45 AM	57	35	25	12	12	20	22	42	31	30
9:00 AM	66	37	21	17	18	19	22	42	30	30	
9:15 AM	70	66	41	16	17	18	22	41	31	30	
9:30 AM	70	69	54	23	17	18	21	41	35	32	
9:45 AM	74	71	58	37	33	30	22	42	36	34	
10:00 AM	74	73	75	64	62	59	55	64	62	69	
SPD-HARM 90%	Time	110716	110716	110716	110716	110716	110716	110716	110716	110716	110716
	6:15 AM	82	51	54	46	47	39	45	50	65	61
	6:30 AM	58	44	29	30	21	27	41	48	37	50
	6:45 AM	38	45	27	37	26	29	33	43	36	33
	7:00 AM	52	21	28	50	40	38	27	42	31	29
	7:15 AM	18	15	14	48	47	47	27	42	37	31
	7:30 AM	22	28	38	47	47	43	33	47	45	37
	7:45 AM	15	20	14	42	26	27	41	55	62	54
	8:00 AM	17	17	24	21	15	20	34	50	37	40
	8:15 AM	17	20	23	26	21	22	26	43	41	33
	8:30 AM	29	22	30	34	29	24	24	42	31	29
	8:45 AM	42	29	39	17	21	21	22	39	29	28
9:00 AM	56	34	44	29	20	19	22	31	29	25	
9:15 AM	60	54	44	29	20	19	22	31	29	25	
9:30 AM	62	57	44	29	21	19	22	31	29	25	
9:45 AM	72	68	53	47	38	36	32	42	42	39	
10:00 AM	75	72	69	57	55	51	29	42	37	34	

# Evaluation of SPD-HARM – AM1

Network Statistics	Base	SPD-HARM 25%	Difference	SPD-HARM 50%	Difference	SPD-HARM 90%	Difference
Vehicles Miles Travelled (mi)	2,320,947	2,340,587	0.8%	2,350,332	1.3%	2,351,385	1.3%
Total Travel Time (h)	61,946	64,185	3.6%	66,744	7.7%	68,997	11.4%
Passenger Hourly Travel Time (h)	78,635	81,499	3.6%	84,659	7.7%	87,306	11.0%
VMT/VHT (mi/h)	37.47	36.47	-2.7%	35.21	-6.0%	34.08	-9.0%
Spatial speed drop (mi/h)	15.0	12.6	-16.0%	10.4	-30.7%	10.0	-33.3%
Temporal speed drop (mi/h)	11.0	9.8	-10.9%	7.0	-36.4%	6.2	-43.6%

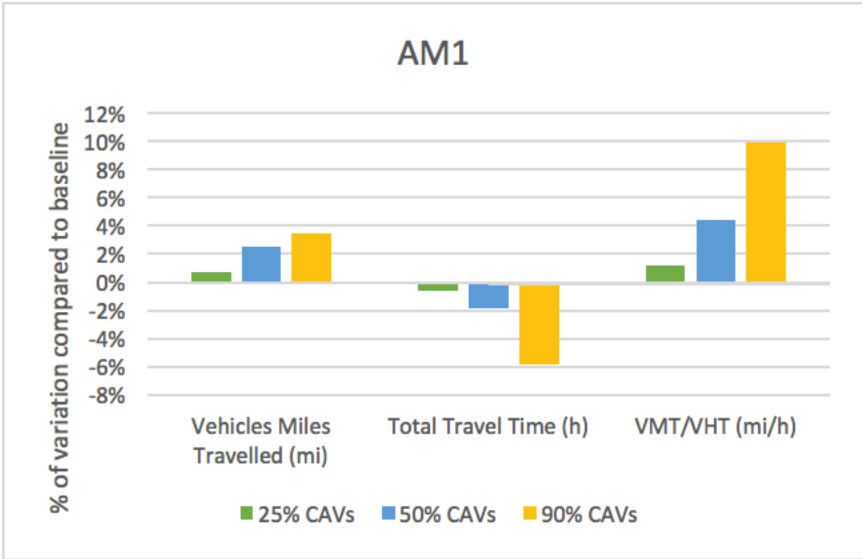






# Evaluation of CACC – AM1

Network Statistics	Base	CACC 25%	Difference	CACC 50%	Difference	CACC 90%	Difference
Vehicles Miles Travelled (mi)	2,320,947	2,336,549	0.7%	2,379,451	2.5%	2,402,310	3.5%
Total Travel Time (h)	61,946	61,602	-0.6%	60,803	-1.8%	58,358	-5.8%
Passenger Hourly Travel Time (h)	78,635	78,375	-0.3%	77,461	-1.5%	74,407	-5.4%
VMT/VHT (mi/h)	37.47	37.93	1.2%	39.13	4.4%	41.16	9.9%



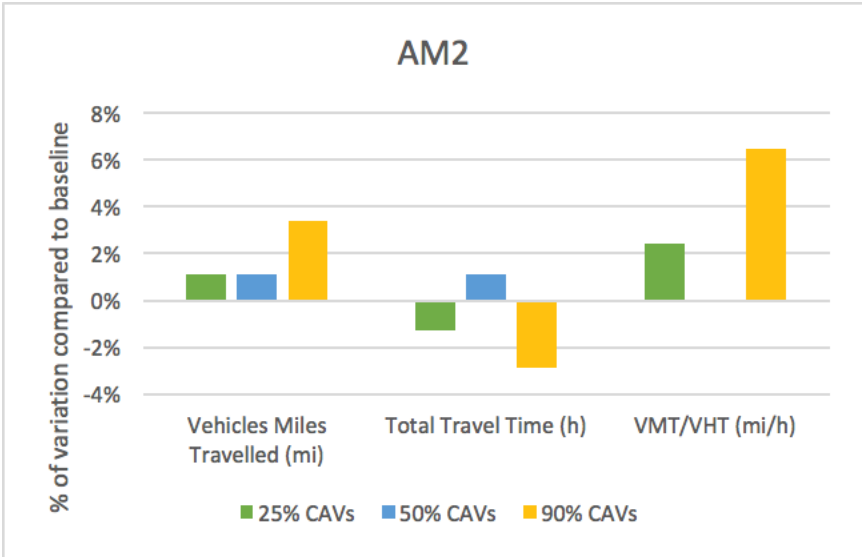


# Evaluation of CACC – AM2

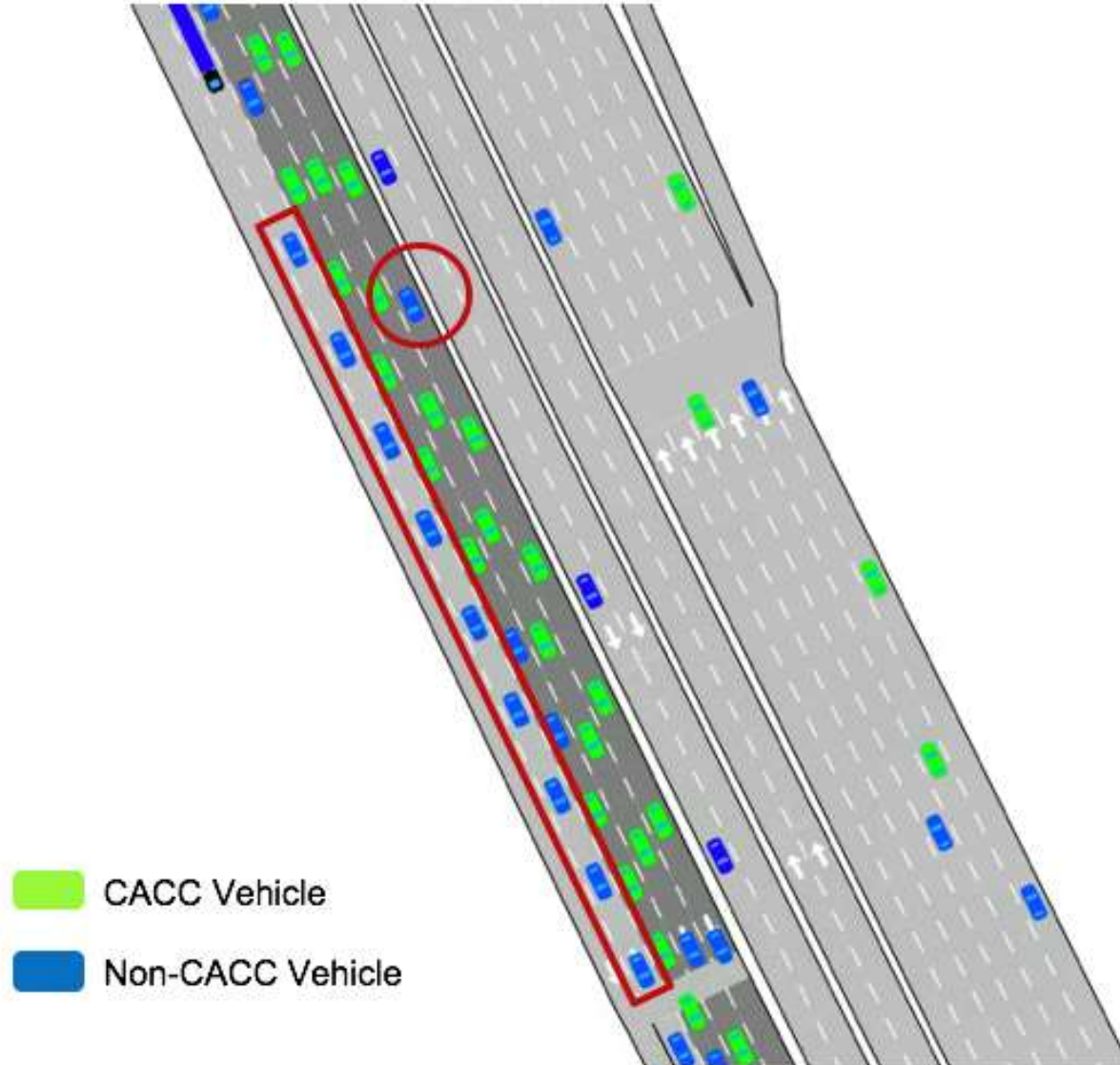
	El Norte Parkway	West Valley Parkway	Felicita Rd	Via Rancho Parkway	Pomerado Rd	Rancho Bernardo Rd	Camino del Norte	Ted Williams Parkway	Mira Mesa Blvd	Miramar Rd	Split I-15 / SR-163
Time	112706	112706	112706	112706	112706	112706	112706	112706	112706	112706	112706
<b>BASE</b>											
6:15 AM	74	74	66	66	55	45	35	27	17	48	35
6:30 AM	73	74	70	70	22	23	40	30	41	35	62
6:45 AM	72	67	17	44	22	17	48	57	35	33	55
7:00 AM	71	54	20	36	40	34	53	64	31	34	50
7:15 AM	63	24	17	46	40	34	36	67	45	37	62
7:30 AM	43	21	16	16	38	48	48	64	45	36	44
7:45 AM	41	24	17	28	58	64	51	68	54	38	45
8:00 AM	22	21	21	18	51	52	50	61	50	33	62
8:15 AM	15	19	17	21	51	35	48	51	37	33	58
8:30 AM	22	24	14	17	31	33	18	33	12	18	38
8:45 AM	69	46	17	17	50	33	40	39	32	32	57
9:00 AM	72	60	19	31	42	41	41	36	48	50	67
9:15 AM	76	72	12	62	60	38	50	38	54	64	63
9:30 AM	75	71	14	62	60	51	55	61	51	53	62
9:45 AM	75	74	14	60	63	63	62	60	68	60	71
10:00 AM	76	74	15	65	65	69	64	60	78	69	71
<b>CACC 25%, 3 lanes</b>											
6:15 AM	76	63	61	30	36	40	50	33	61	54	64
6:30 AM	73	62	34	34	21	17	54	40	37	48	64
6:45 AM	74	58	19	49	25	15	51	50	43	38	61
7:00 AM	71	58	19	61	46	43	61	41	41	41	61
7:15 AM	72	25	17	45	46	43	51	63	40	38	62
7:30 AM	72	17	19	17	21	23	48	63	30	37	63
7:45 AM	73	24	19	46	60	66	53	68	31	41	65
8:00 AM	20	20	19	17	49	49	50	61	45	41	69
8:15 AM	19	21	20	20	52	33	49	58	30	33	68
8:30 AM	20	27	35	23	48	48	47	29	33	35	65
8:45 AM	75	53	41	18	40	39	38	31	30	37	67
9:00 AM	75	72	68	10	37	44	45	40	33	37	67
9:15 AM	75	73	50	66	52	48	50	45	45	45	68
9:30 AM	75	71	44	65	63	51	50	64	59	62	69
9:45 AM	75	74	14	66	62	63	62	60	69	70	71
10:00 AM	76	74	15	69	66	69	64	69	76	71	72
<b>CACC 50%, 3 lanes</b>											
6:15 AM	74	68	52	30	38	41	57	61	64	60	62
6:30 AM	74	67	32	32	26	21	62	48	67	60	68
6:45 AM	74	59	23	45	42	40	59	67	61	53	67
7:00 AM	72	49	16	36	58	64	64	68	47	54	68
7:15 AM	61	64	42	62	47	48	55	67	38	52	66
7:30 AM	38	56	18	28	55	48	56	68	53	52	66
7:45 AM	72	33	23	47	58	68	64	71	55	54	68
8:00 AM	64	26	21	10	53	52	57	67	41	41	68
8:15 AM	62	24	19	17	49	56	57	37	43	43	69
8:30 AM	60	17	11	14	49	43	52	64	40	46	65
8:45 AM	76	71	47	62	54	48	50	54	50	62	68
9:00 AM	75	71	19	68	64	57	62	68	60	58	67
9:15 AM	75	71	60	68	64	57	62	68	61	68	68
9:30 AM	75	74	10	70	66	60	66	69	69	62	70
9:45 AM	75	74	11	71	67	62	66	69	69	62	71
10:00 AM	76	75	14	71	69	68	71	68	73	71	72
<b>CACC 90%, all lanes</b>											
6:15 AM	76	67	62	36	42	49	63	66	64	61	63
6:30 AM	75	71	37	44	36	42	69	71	68	68	71
6:45 AM	75	70	38	40	40	47	62	70	66	63	68
7:00 AM	75	61	31	30	68	64	63	71	62	53	70
7:15 AM	75	74	31	36	49	41	62	73	66	54	71
7:30 AM	74	70	33	38	63	57	62	71	63	52	73
7:45 AM	75	82	25	25	65	63	64	73	66	55	72
8:00 AM	74	73	45	45	63	50	71	61	52	71	71
8:15 AM	71	68	34	51	68	68	62	71	61	50	70
8:30 AM	75	88	35	33	69	63	71	64	57	70	73
8:45 AM	76	78	63	64	64	61	67	68	64	61	74
9:00 AM	76	75	73	62	70	57	68	71	68	63	74
9:15 AM	76	75	14	62	70	58	69	71	67	64	74
9:30 AM	76	75	14	61	70	68	71	68	71	68	74
9:45 AM	76	75	14	62	71	67	70	71	68	70	74
10:00 AM	76	75	15	63	72	68	71	71	68	63	74

# Evaluation of CACC – AM2

Network Statistics	Base	CACC 25%	Difference	CACC 50%	Difference	CACC 90%	Difference
Vehicles Miles Travelled (mi)	2,304,353	2,329,398	1.1%	2,329,302	1.1%	2,382,112	3.4%
Total Travel Time (h)	61,509	60,722	-1.3%	62,206	1.1%	59,719	-2.9%
Passenger Hourly Travel Time (h)	78,853	78,151	-0.9%	79,424	0.7%	76,560	-2.9%
VMT/VHT (mi/h)	37.46	38.36	2.4%	37.44	0.0%	39.89	6.5%



# Why 50% CACC is the worst case?



# Conclusions – SPD-HARM

- No significant benefits in terms of traffic performance, but a benefit in terms of safety (shockwave reduction)
- Shockwave reduction comes at the cost of a slight increase of travel time
- More effective with distributed congestion throughout the corridor
- With lower congestion, benefit only at high penetration rate



# Conclusions - CACC

- Most CACC algorithms available today only deal with car-following in a single lane and with an already formed platoon
  - Some parameters may produce an unstable car-following regime
- To produce tangible benefits in real-world conditions, CACC algorithms should deal also with other aspects of vehicle movement
  - Managing the transition (vehicle joining or leaving the platoon) is key to avoid instabilities
  - Managing the vehicle distribution across multiple lanes is key with multiple reserved lanes (higher penetration rates)
  - Managing the length of the platoon is key with mixed traffic, to prevent blocking non-connected vehicles
  - Managing the lane changing is key to allow connected vehicles take the exit they need to take and to prevent blocking non-connected vehicles

# Conclusions - CACC

- CACC appears to be more effective in congested situations; when congestion is low, at some penetration rates even a slight reduction of traffic performance can be observed, because CACC platoons may cause an obstacle for non-connected vehicle that want to change lane, which may have to reduce their speed and look for a gap between platoons
- Policy decisions, like the number of lanes that CACC platoons can utilize, and whether they are shared with non-connected vehicles, have a significant impact on the effectiveness of the technology
- The results should not be taken as an evaluation of the impact of CACC technology in general, but only of one specific implementation, based on the algorithm described above
  - The developers of this technology should make it capable to deal with real and complex situations
  - Studies presenting results of evaluations should be clear about the assumptions made



Thank you!

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