

Improve Traffic Data Collection with Inductive Loop Signature Technology

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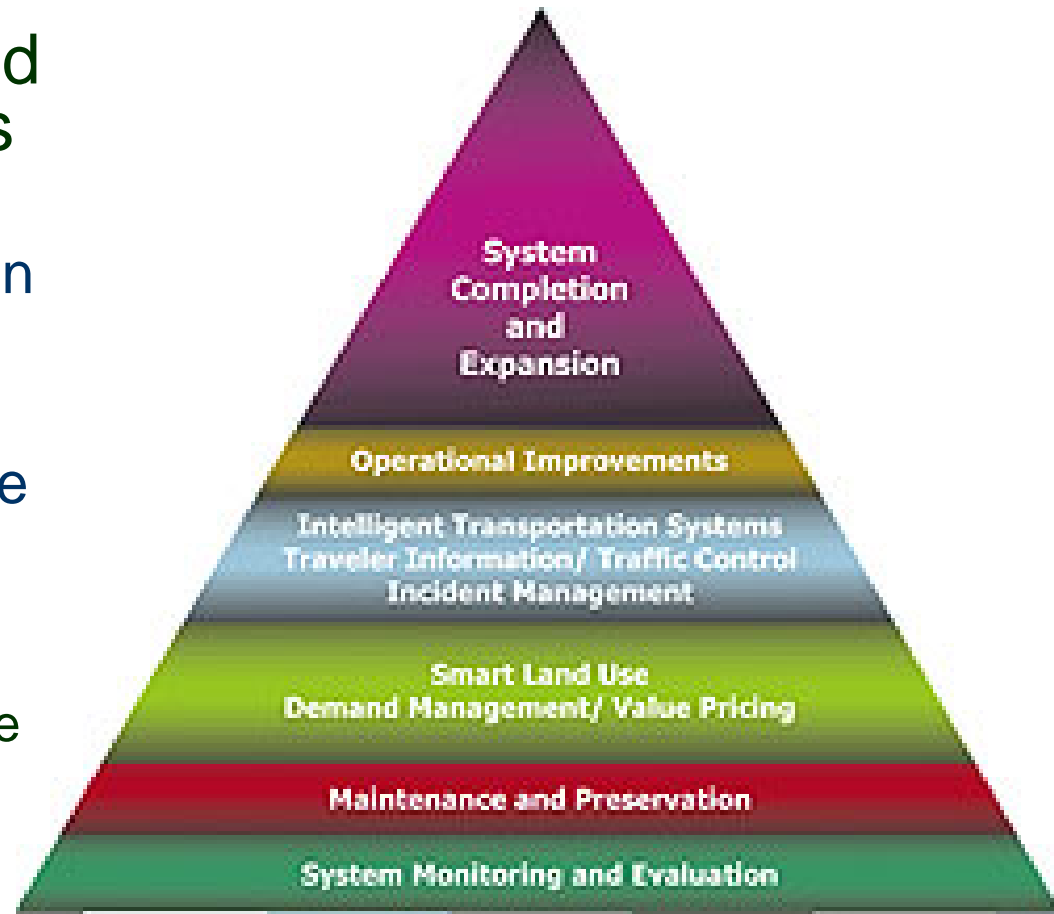
Presented @ NATMEC 2016, Miami 5/2/2016

Outline

- Background
- Technology
- Algorithms
- Applications
- Conclusion and Future Work

Traffic Management Pyramid

- System monitoring and evaluation is the basis
 - Traffic detection
 - Performance evaluation
- MAP-21 / FAST:
 - New surface transportation act in the US
 - Performance driven
 - Requires performance management to ensure the most efficient investment of Federal transportation funds



USA National Traffic Report

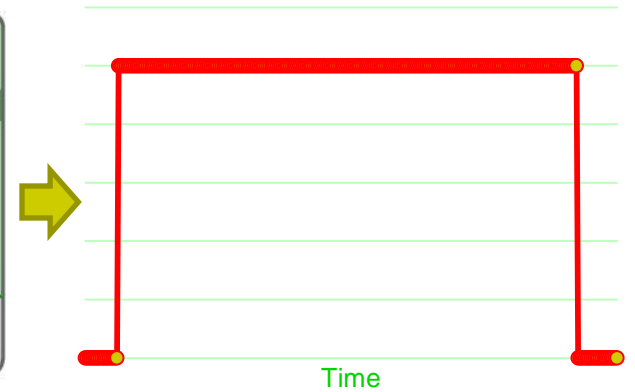
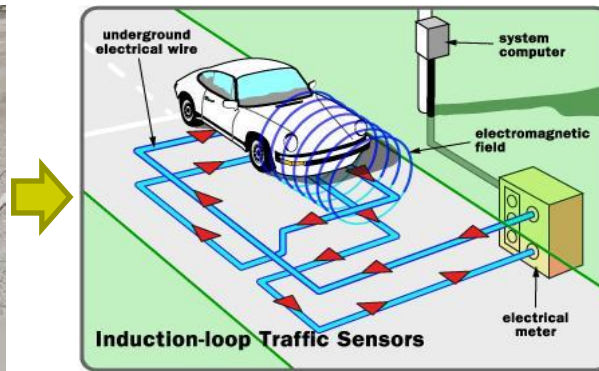


Traffic detection

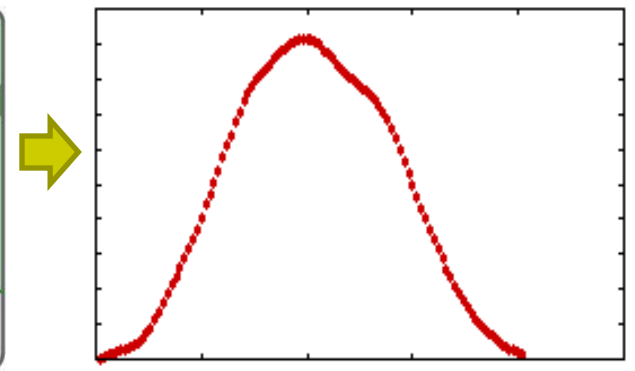
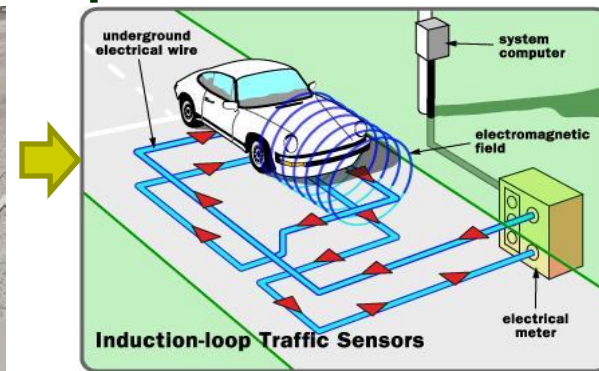
- Fixed sensors (volume, occupancy, speed)
 - Technology
 - Loop detector (dominant in the US)
 - Magnetometer, microwave radar, acoustic, video-image, laser
 - Data issues
 - Detection errors
 - Detection at a single location
 - Estimate the condition between two sensors
- Mobile sensors (speed, OD)
 - Technology
 - Probe vehicles
 - Cell phone (CDR, running map applications)
 - Data issues
 - No volume data
 - Speed data only is not enough for traffic flow analysis

Conventional vs Advanced Loop Detector

■ Conventional loop detector



■ Advanced loop detector

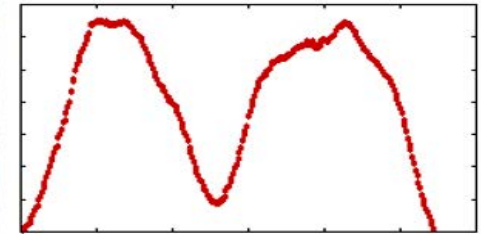
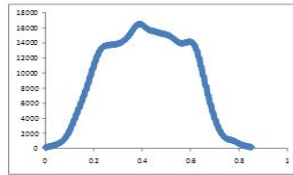


Signature Data Analysis

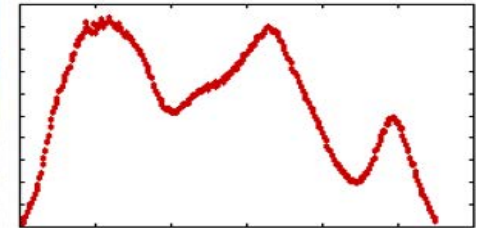
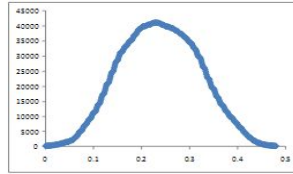
- Signature data depends on
 - Size, mental mass, number of axles, distance between the metal surfaces on the under carriage of the vehicle and the road surface
- Different vehicle types' signatures are different
- Same type of vehicles have similar signatures
- Same vehicle shows very similar signatures from different detectors

Inductive Loop Signatures for Different Type of Vehicles

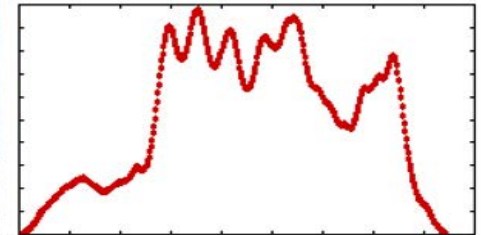
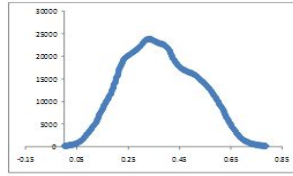
Bus



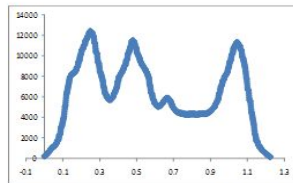
Sport car



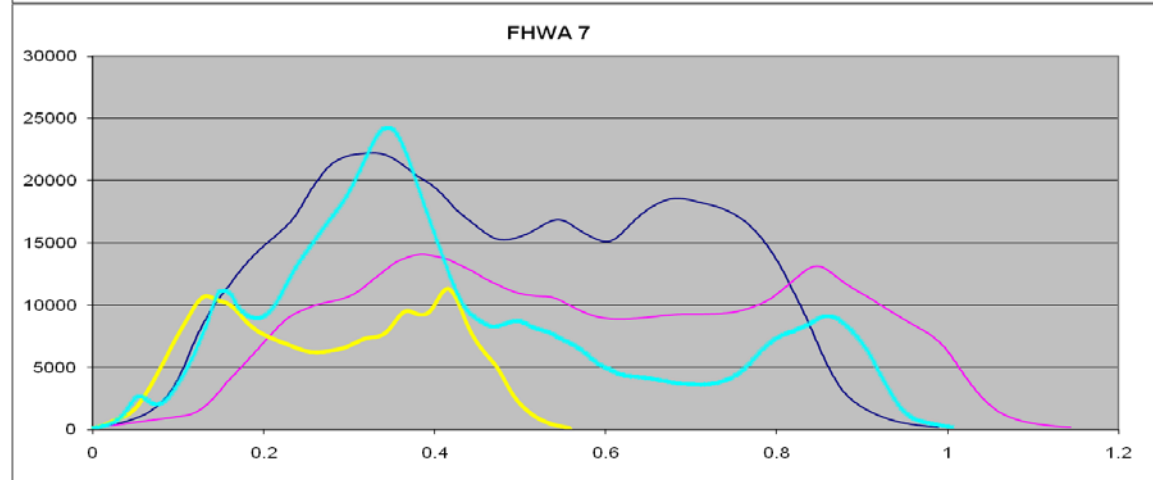
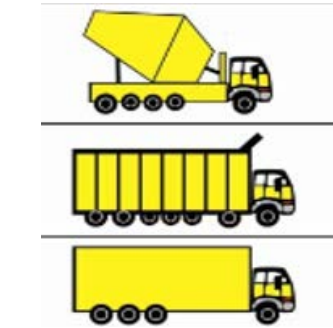
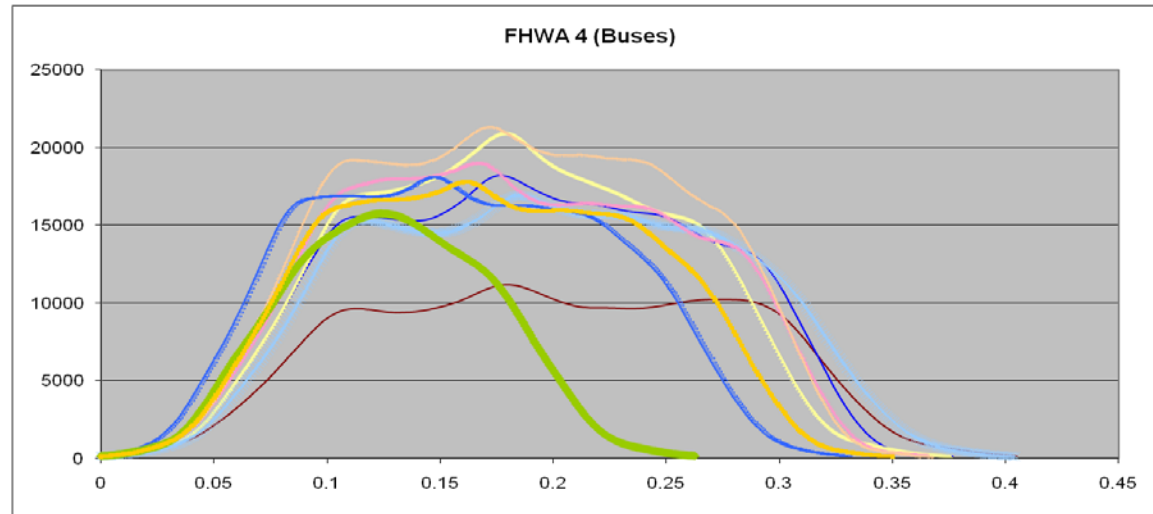
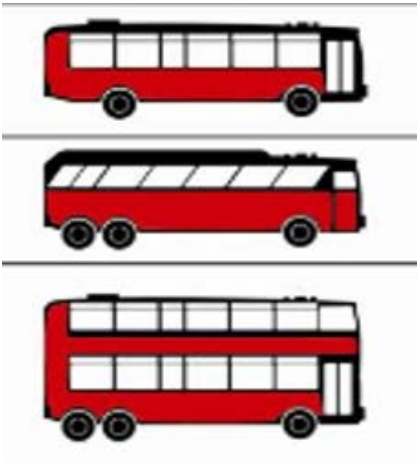
Pickup



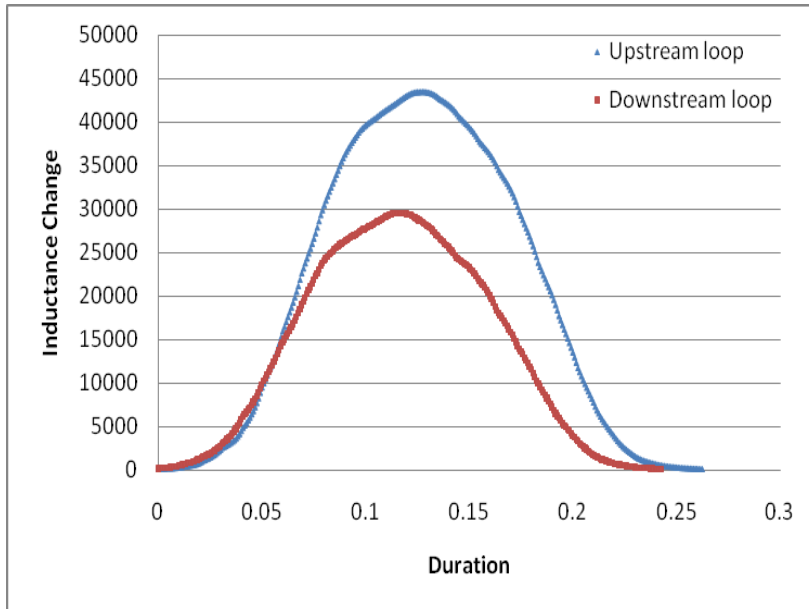
Truck



Typical Signatures for FHWA Class 4 & 7 Vehicles

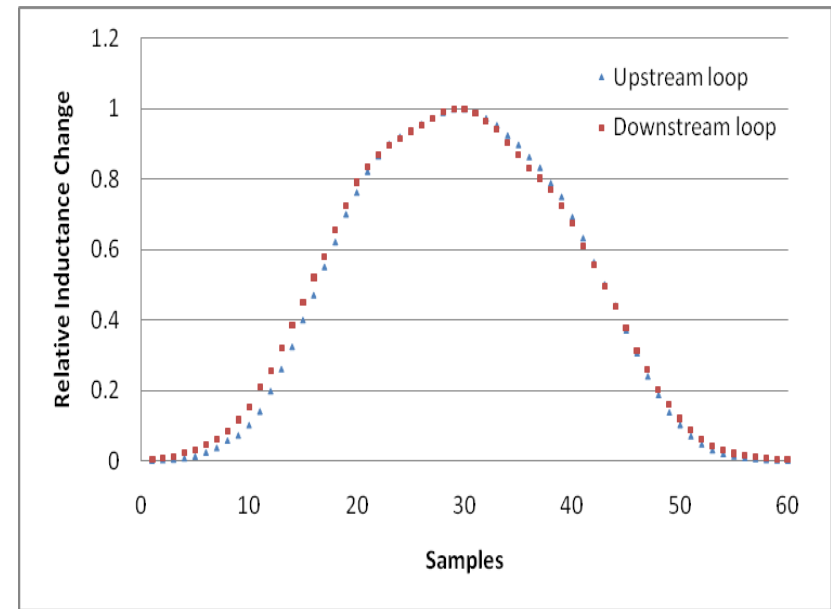


Same Vehicle's Signatures



(a) Raw signature

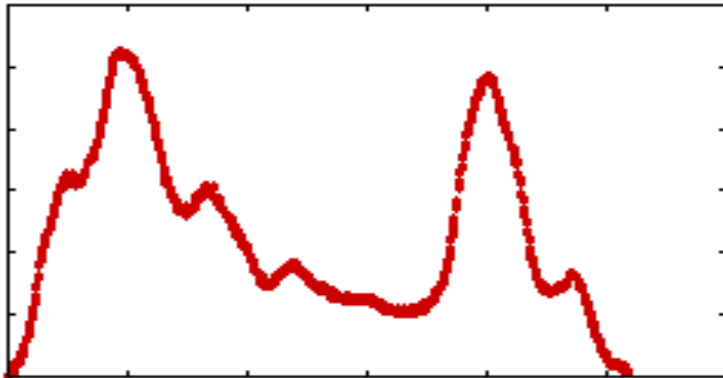
Upstream: 316 data points;
Downstream: 292 data points.



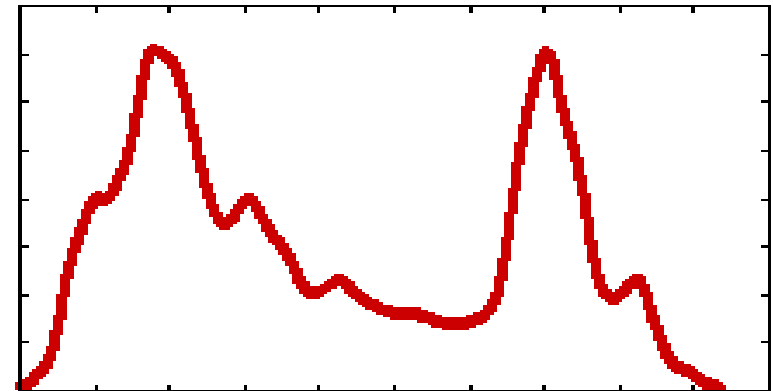
(b) X & Y-axis normalized signature

Upstream: 60 data points;
Downstream: 60 data points.

Same Vehicle at Different Detector Stations (19 miles apart)



Upstream: SR-57 SB at Lambert
(WIM station, square loop)



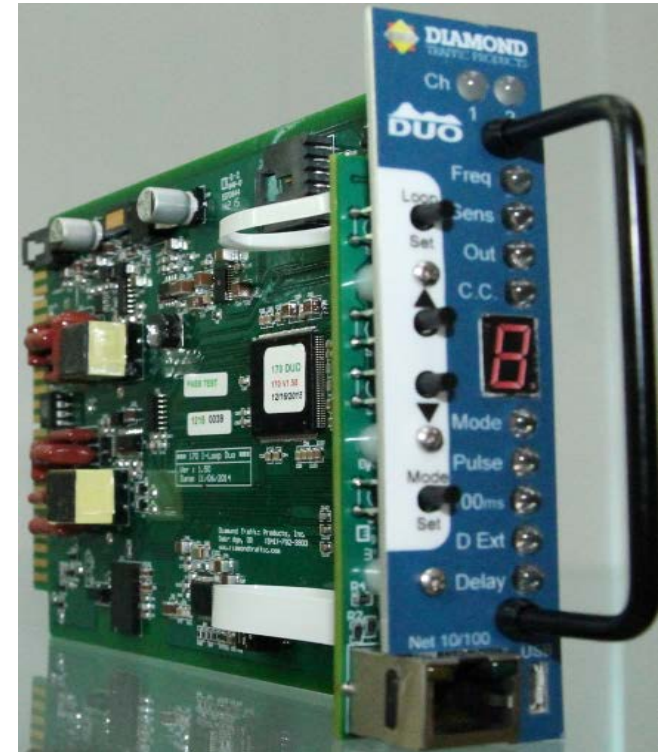
Downstream: I-5 SB at Yale
(counting station, round loop)

Past and Current Research / Development

- Inductive Loop Signature Technology
 - Caltrans investment on the research (late 1990s – 2009)
 - ITS America - Award for The Best ITS Research in 2000
 - Joe Palen, Dr. Steven Ritchie and Dr. Ben Coifman
- USDOT SBIR Projects (after 2010)
 - Transportation System Performance Measurement Using Existing Loop Infrastructure
 - Advanced signature detector card development
 - Core classification and vehicle re-identification algorithms development
 - Field demonstration along freeway and arterial
 - Tracking Heavy Vehicles based on Weigh-In-Motion and Vehicle Signature Technologies
 - Traffic Surveillance System using Heterogeneous Sensor Technologies for National Park Service
- Ongoing Projects sponsored by Caltrans
 - California ARB: Development of a New Methodology to Characterize Truck Body Types along California Freeways (Jul 2012 - Jun 2015)
 - Caltrans: California Truck Data Collection, Caltrans project (Aug 2015 – Jul 2016)

Advanced Signature Detector Card

- Collaboration with **Diamond Traffic Products**
- Replace conventional detector cards in ITS counting stations / signal controller cabinets
 - NEMA and 170 / 2070 compatible
 - European standard?
 - Sampling rate 100-5000 Hz
 - Show each vehicle's unique / un-seeable attributes
 - Clean signature
 - Digital / cutting-edge technology
- Fully tested in Caltrans detector testbed
 - Conditionally passed the Caltrans certification through Caltrans HQ



Other Solutions with Signature Capabilities

■ Diamond Traffic Products

□ Phoenix II

- Customized software and data communication protocol
- Applied in a SBIR phase I project

□ Potentially available in more product lines

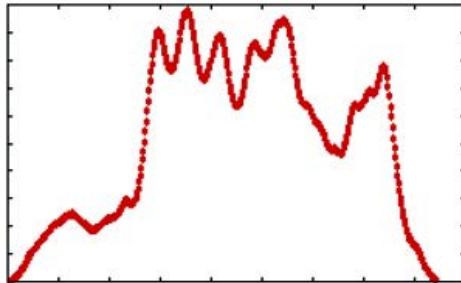
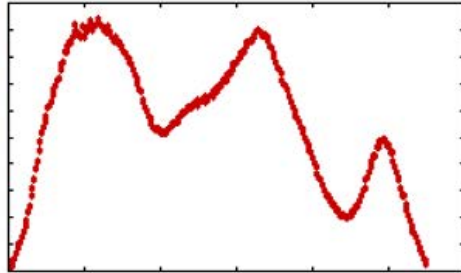
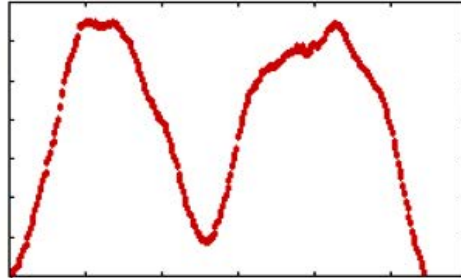
■ IRD

□ iSinc loop Module (LSM)

- Customized algorithm sampled at 100 Hz
- Diagnosis mode sampled at 250 Hz



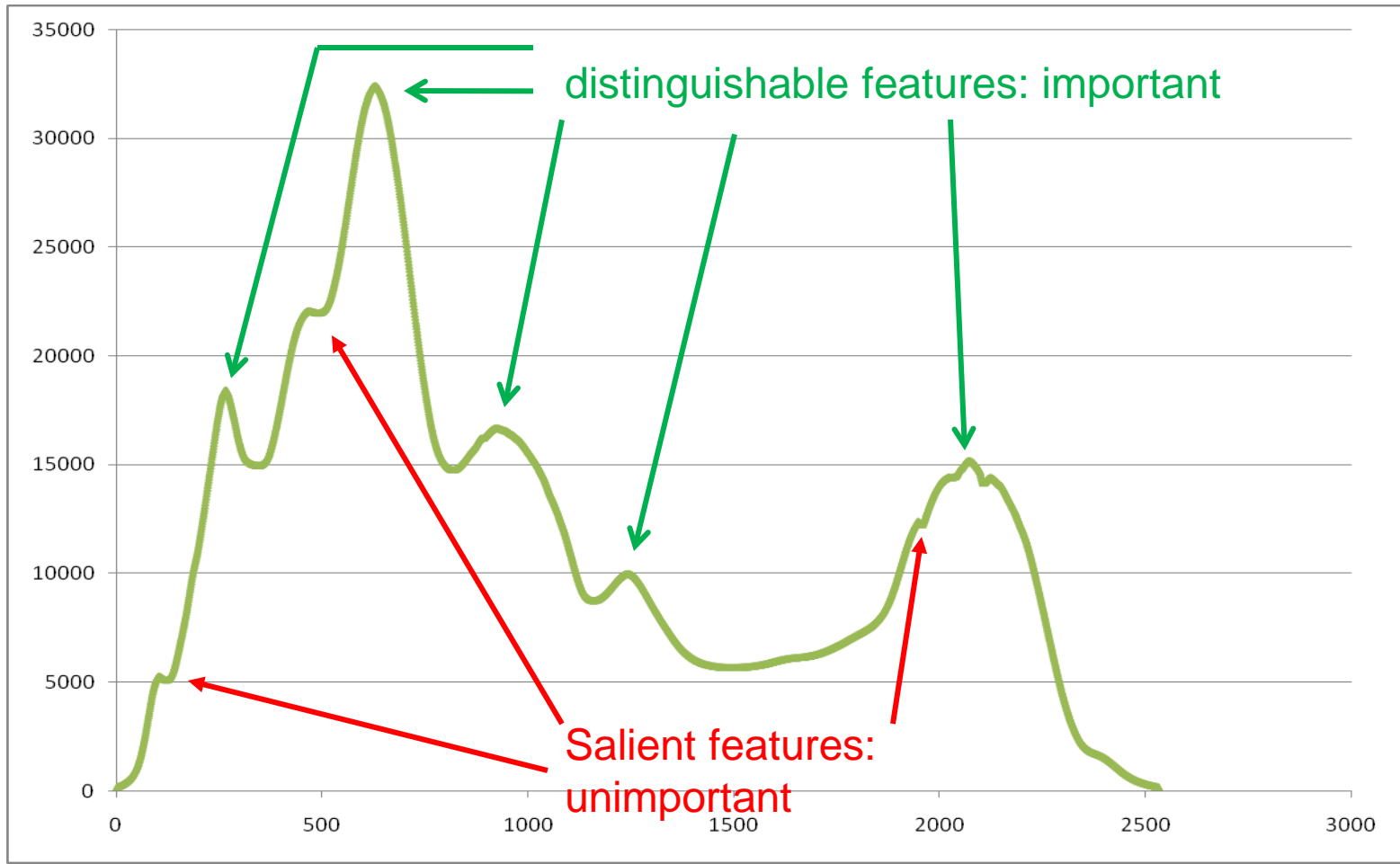
Vehicle Classification



- Algorithm
 - Wavelet
 - K-Nearest Neighborhood

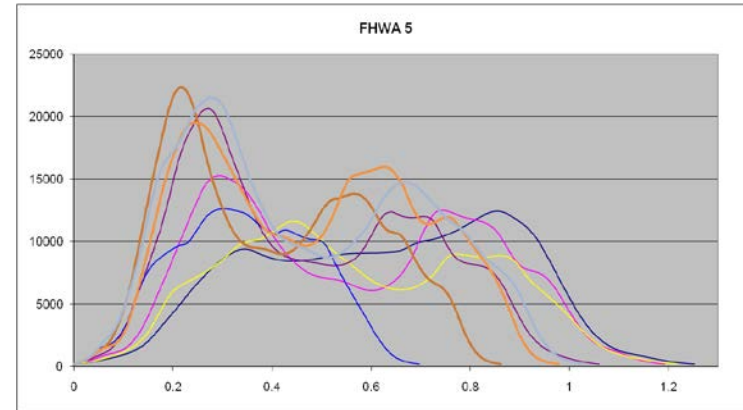
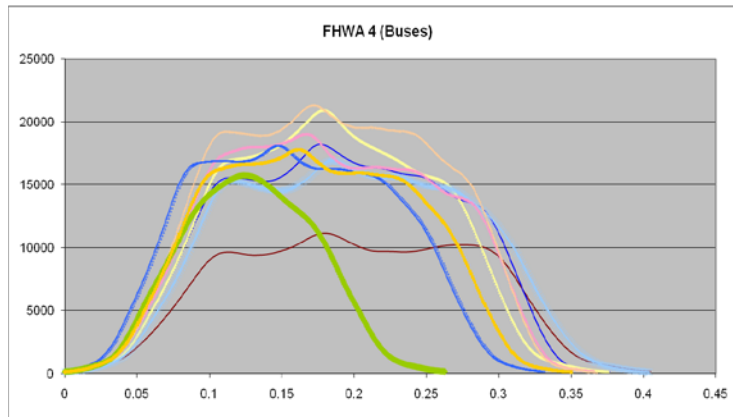
Different types show distinct signature data

Wavelet Transformation



Customizable Signature data Template Library

Station	FHWA Vehicle Class													Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	
453	9	17	17	19	9	7	1	9	10	-	6	-	-	104
501	-	-	-	-	10	8	2	9	10	3	8	2	2	54
Total	9	17	17	19	19	15	3	18	20	3	14	2	2	158



Classification Results*

Performance		Predicted Vehicle Class (with 90% Large Components)														Volume by Class	Classification Rate
13250	92.4%	1	2	3	4	5	6	7	8	9	10	11	12	13	99*		
FHWA Class	1	60	9	1	2										11	83	83.3%
	2	13	10800	249	43	44	7		9	2		1	1		25	11194	96.7%
	3		204	1243	80	48	3		4						3	1585	78.6%
	4		1	5	29	1										36	80.6%
	5		5	60	48	373	45	16	4	1						552	67.6%
	6		2	4	3	12	38	6	5	2						72	52.8%
	7						1	3								4	75.0%
	8				1	2	1	31	16	1	5					57	54.4%
	9			1	4		1	2	40	655	30	28	2	1		764	85.7%
	10									1	2					3	66.7%
	11						2			2		13	1		2	20	72.2%
	12												2			2	100.0%
	13											1		1		2	50.0%
Estimated Volume by Class		73	11021	1563	210	478	99	28	93	679	34	47	6	2	41	14374	
Estimated Vehicle Composition		0.5%	76.7%	10.9%	1.5%	3.3%	0.7%	0.2%	0.6%	4.7%	0.2%	0.3%	0.0%	0.0%	0.3%	100.0%	

* Including off-center and lane-changing vehicles. Actual performance will be higher.

Classification Results (HPMS Scheme)

Scheme		FHWA Class	Correctly Classified	Total Vehicles	Classification Rate
Class 1	Motorcycles	1	60	83	83.3%
Class 2	Passenger Cars	2	10800	11194	96.7%
Class 3	Light Truck	3	1243	1585	78.6%
Class 4	Buses	4	29	36	80.6%
Class 5	Single-Unit Truck	5 to 7	414	628	65.9%
Class 6	Combination Truck	8 to 13	704	848	83.0%
Overall			13250	14374	92.2%

Vehicle Reidentification Algorithm



Dataset

■ 05/12/2009 dataset

- I-405 Testbed in Irvine, California
- May 12, 2009 (Tue) from 6:30AM to 10:00AM
- 31,430 vehicles
 - Stratified-Random Sampling
 - Between 7:15AM and 9:15AM non-HOV lane

■ 05/29/2008 dataset

- San Onofre weight and inspection facility
- May 29, 2008 (Thu) from 8:10AM to 5:10PM
- 2,168 vehicles

Vehicle Reidentification Performance

■ TMR = 66.8%

Time period	ALL	6:36:00	7:00:30	7:35:30	8:01:00	8:10:30	8:20:30	8:35:30	9:00:30	9:35:30
		-	-	-	-	-	-	-	-	-
		6:40:30	7:04:00	7:39:00	8:04:00	8:14:00	8:23:00	8:39:30	9:03:30	9:38:30
SCMR	65.6%	74.5%	75.2%	51.8%	57.5%	70.1%	54.8%	55.3%	68.2%	78.7%

$$TMR = \frac{\text{total number of matched vehicles}}{\text{total number of vehicles}}$$

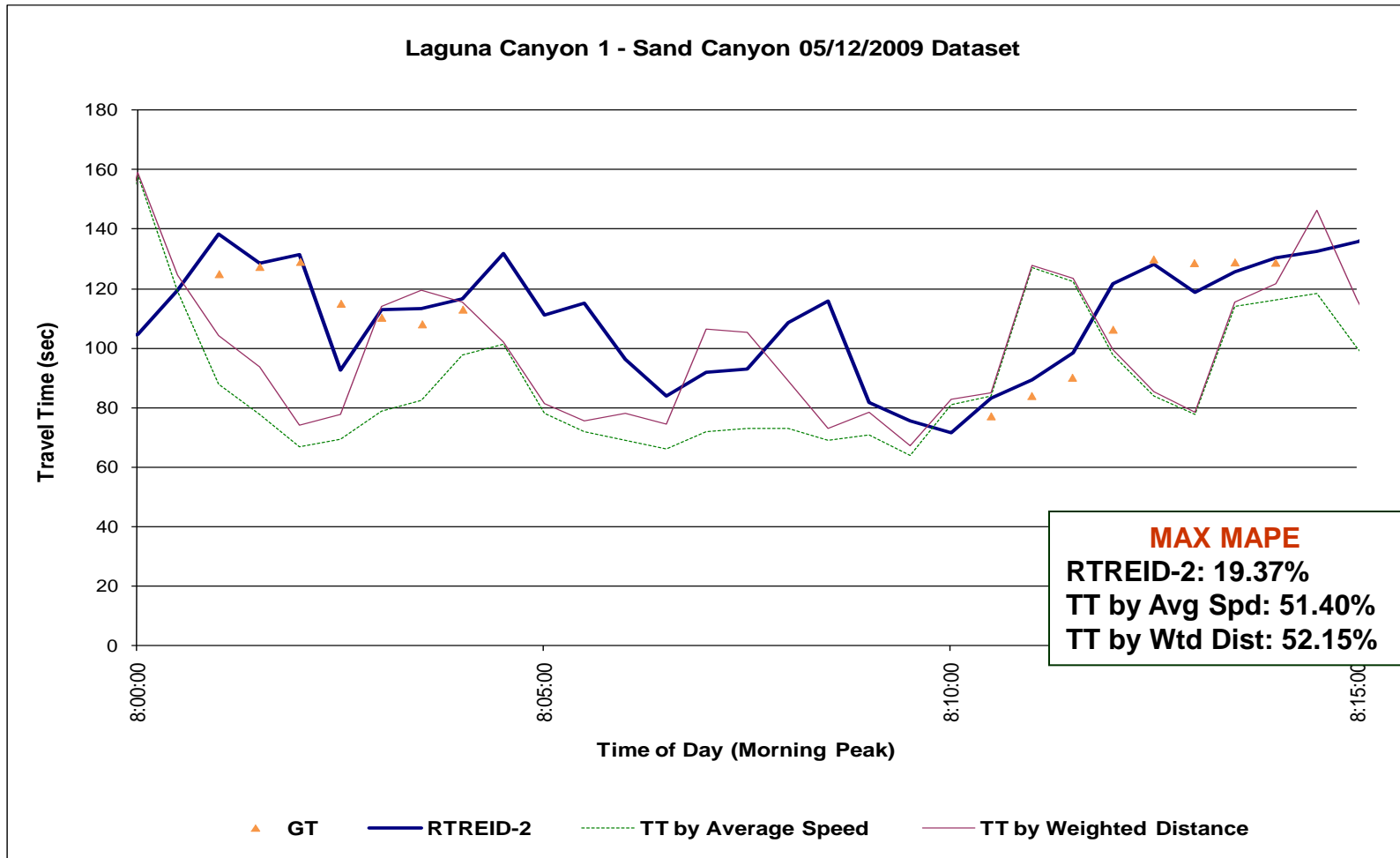
$$SCMR = \frac{\text{total number of correct matched vehicles}}{\text{total number of matched vehicles}}$$

Travel Time Performance

Time period	ALL	6:36:00 - 6:40:30	7:00:30 - 7:04:00	7:35:30 - 7:39:00	8:01:00 - 8:04:00	8:10:30 - 8:14:00	8:20:30 - 8:23:00	8:35:30 - 8:39:30	9:00:30 - 9:03:30	9:35:30 - 9:38:30
MAPE TT	4.3%	2.7%	3.6%	4.5%	6.0%	6.2%	3.1%	4.2%	4.8%	3.9%
Best Case	2.0%	1.6%	1.2%	2.7%	4.2%	3.5%	1.2%	1.0%	1.5%	2.0%
Worst Case	8.8%	5.5%	9.1%	9.9%	9.9%	19.5%	8.9%	4.7%	8.0%	8.6%

$$MAPE = \sum_{n=1}^N \left[\frac{|TTime_{obs,n} - TTime_{est,n}|}{TTime_{obs,n}} / N \right] \times 100\%$$

RTREID-2 TT vs Point Speed based TT (8:00-8:15)



Conventional vs Advanced

	Conventional	Advanced
Loops	Single or dual	Single
Data to be collected	Volume, occupancy, and speed (dual loop)	Volume and signature
Classification	Car or truck	HPMS, FHWA
Truck %	Rough estimate	Accurate estimate
Speed estimation	G-Factor and other methods	Improved real-time G-Factor based on vehicle classification
Vehicle tracking, OD	Platoon tracking (academic), no OD	Use signature data to track vehicles and can derive OD
Travel time estimation	Based on some assumptions	Based on vehicle tracking
VMT by class for Emission	Limited	Better estimate (connected with EMFAC model from CARB)

Applications / Products

- Conversion of counting stations to classification sites
 - Single loop
- Vehicle tracking
 - OD survey
 - Turning movement count
 - Better travel time
- High-definition traffic monitoring
 - Freeway & Arterial
 - More accurate count
 - Analyzing signature data to identify lane changing and noises
- Emission monitoring
 - VMT by class data
- Planning, Maintenance, Modeling
 - Volume by class
 - OD data

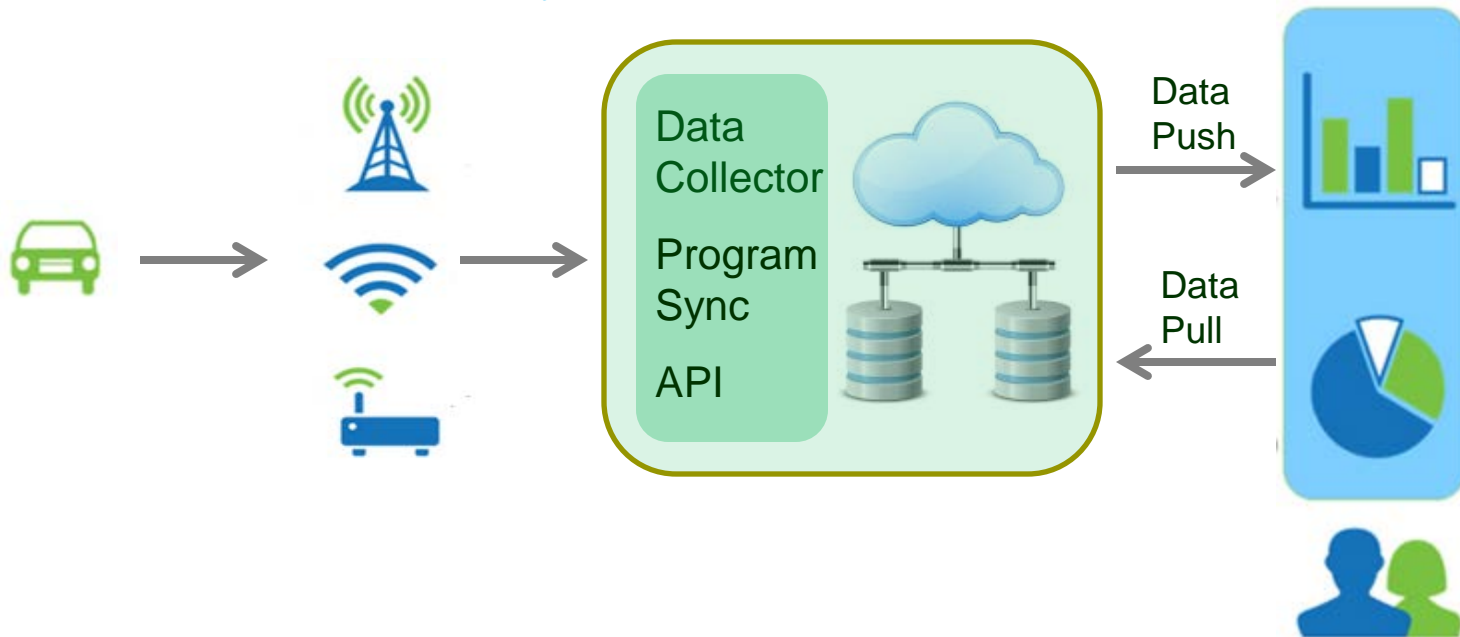
System Framework

Stations /
Devices

Any
Connectivity

Cloud / Server

Applications



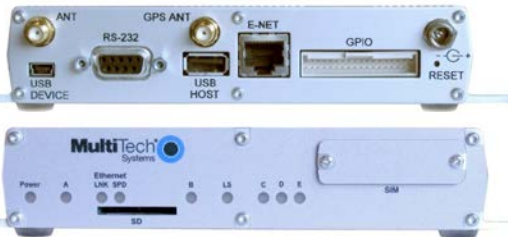
Master Computer Card/Device

- Data collection, computing and communication with central server
- Detector card format or small desktop
- 12 lane capability, expandable to more lanes with a USB Hub
- Wired and wireless communication and different carriers
- Developed based on *Multitech* OCG
 - 400MHz ARM 9 CPU / 256 MB NAND Flash / 64 MB SDRAM
 - Linux OS



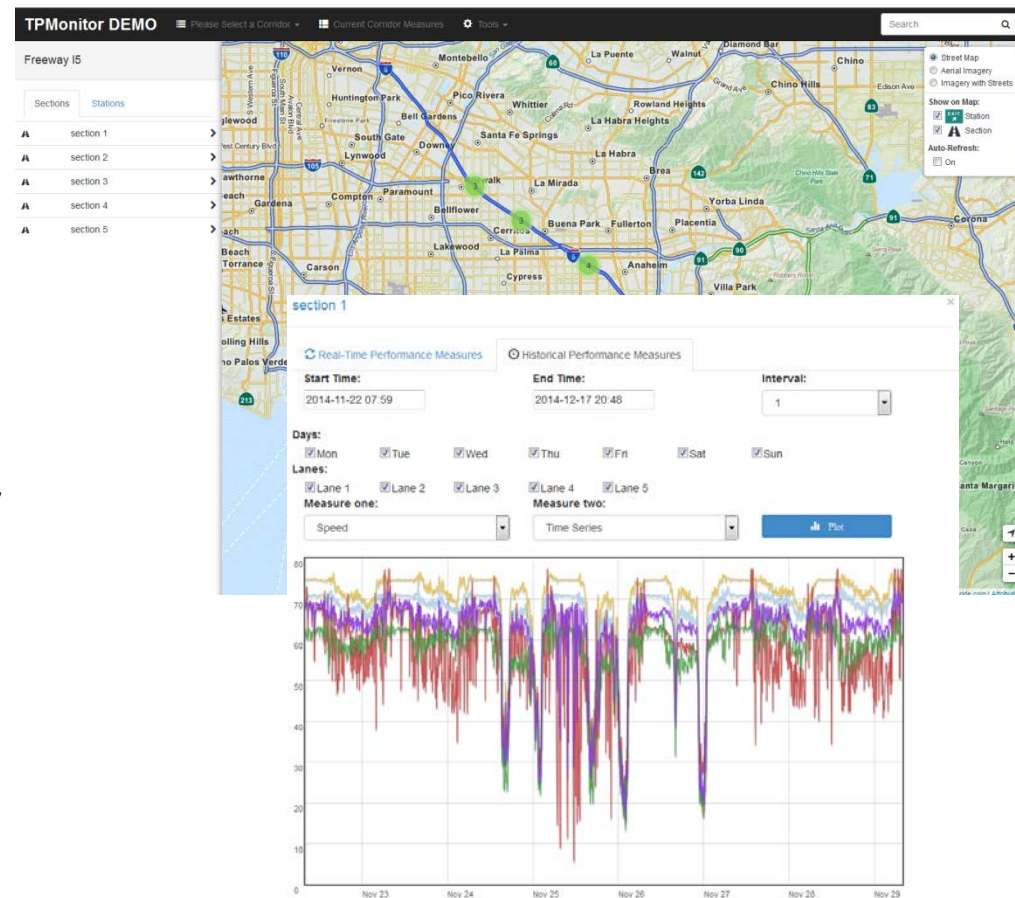
Desktop version
Dimension: 2.8" x 7.0" x 1.2"
(7.1 cm x 17.8 cm x 3.0 cm)

222 card format / dimension
Insert to the back panel directly



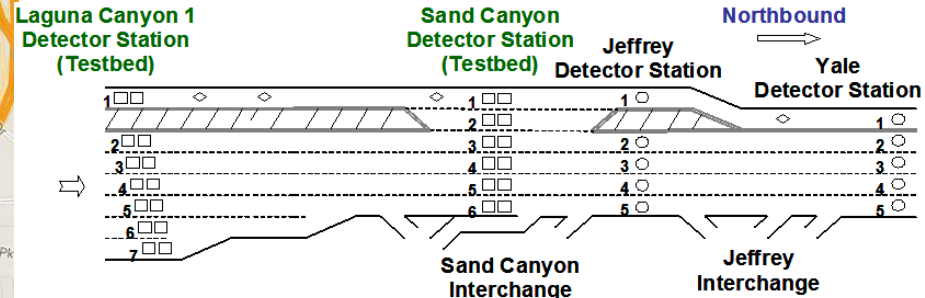
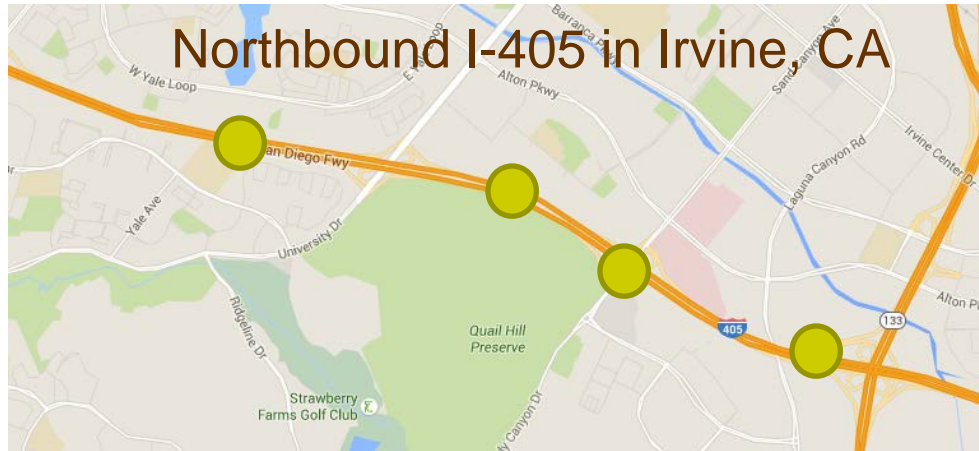
Central Server / Software

- Signature data receiver
- Central database
- Central core algorithms
 - Vehicle classification
 - Vehicles tracking
- Performance calculation modules
 - Point, section and corridor performance
 - Emission estimates
- Application modules
 - Traffic monitoring
 - Emission monitoring
- Website to visualize data

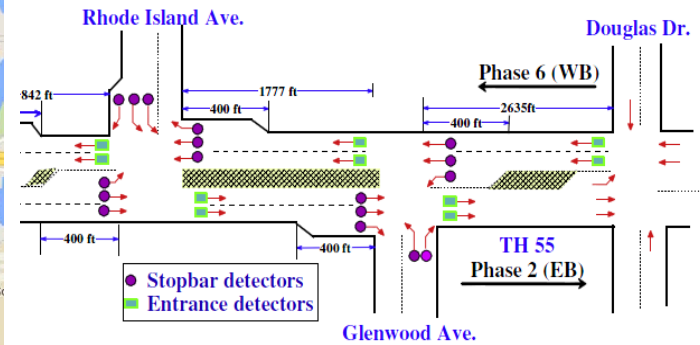
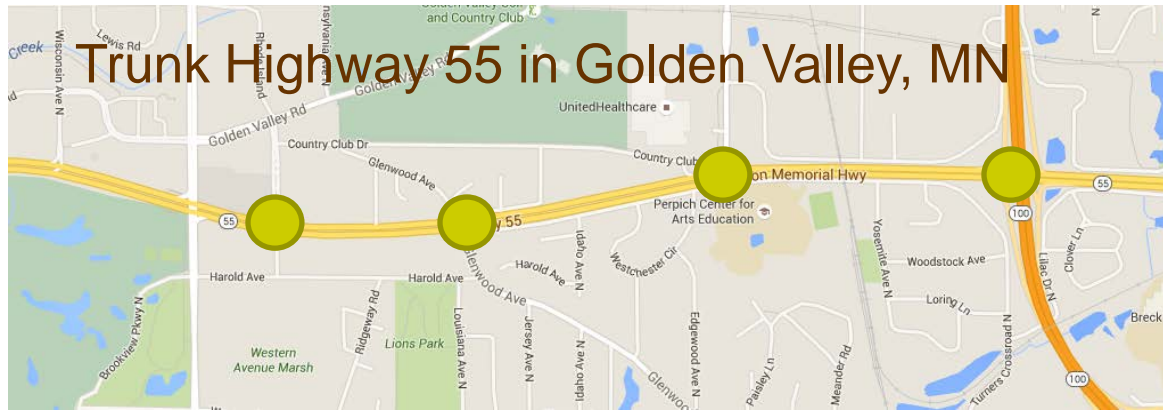


System Implementation and Demonstration

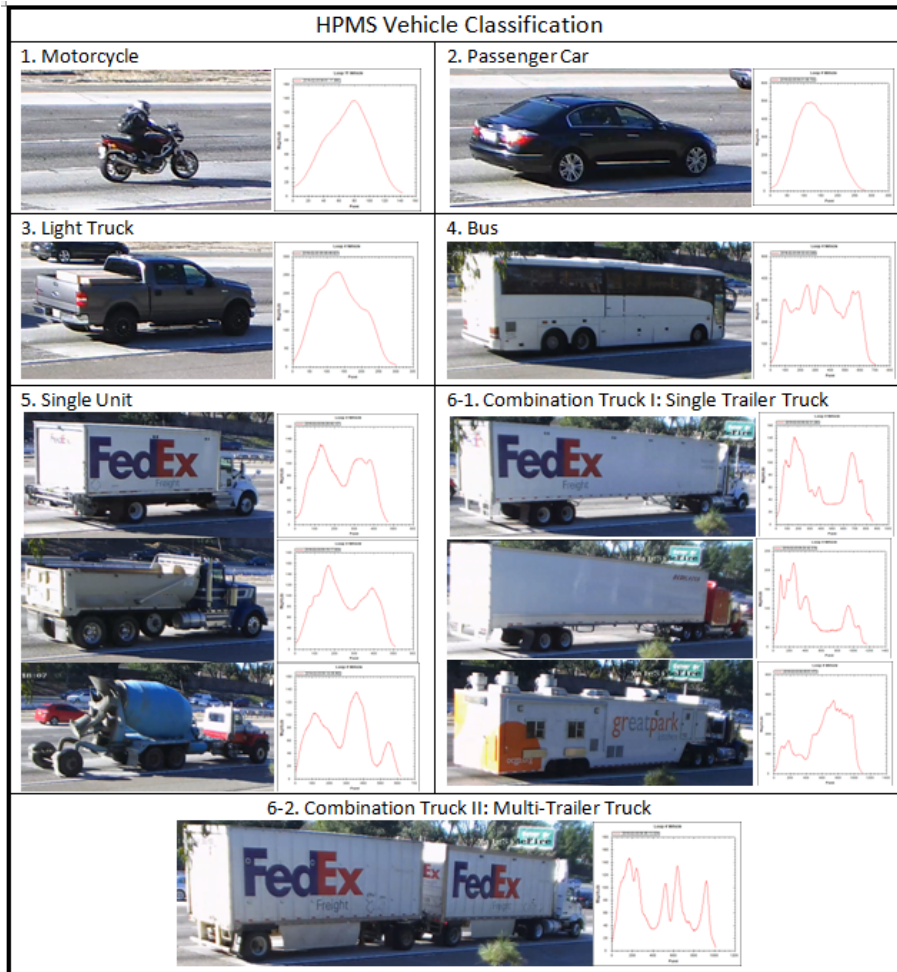
Northbound I-405 in Irvine, CA



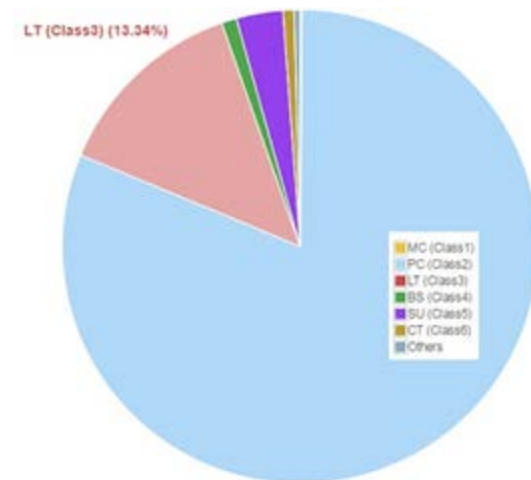
Trunk Highway 55 in Golden Valley, MN



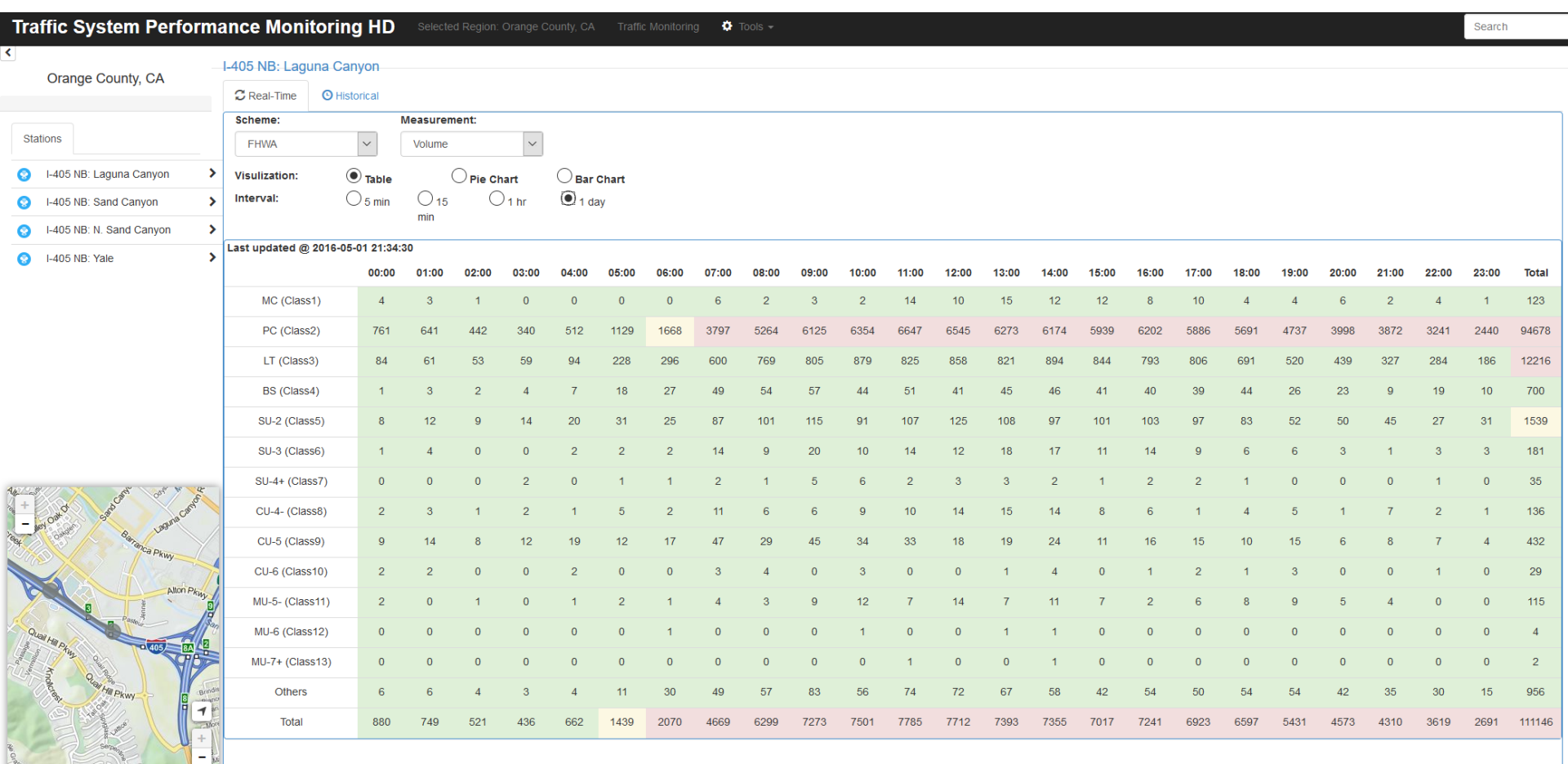
Vehicle Classification Product



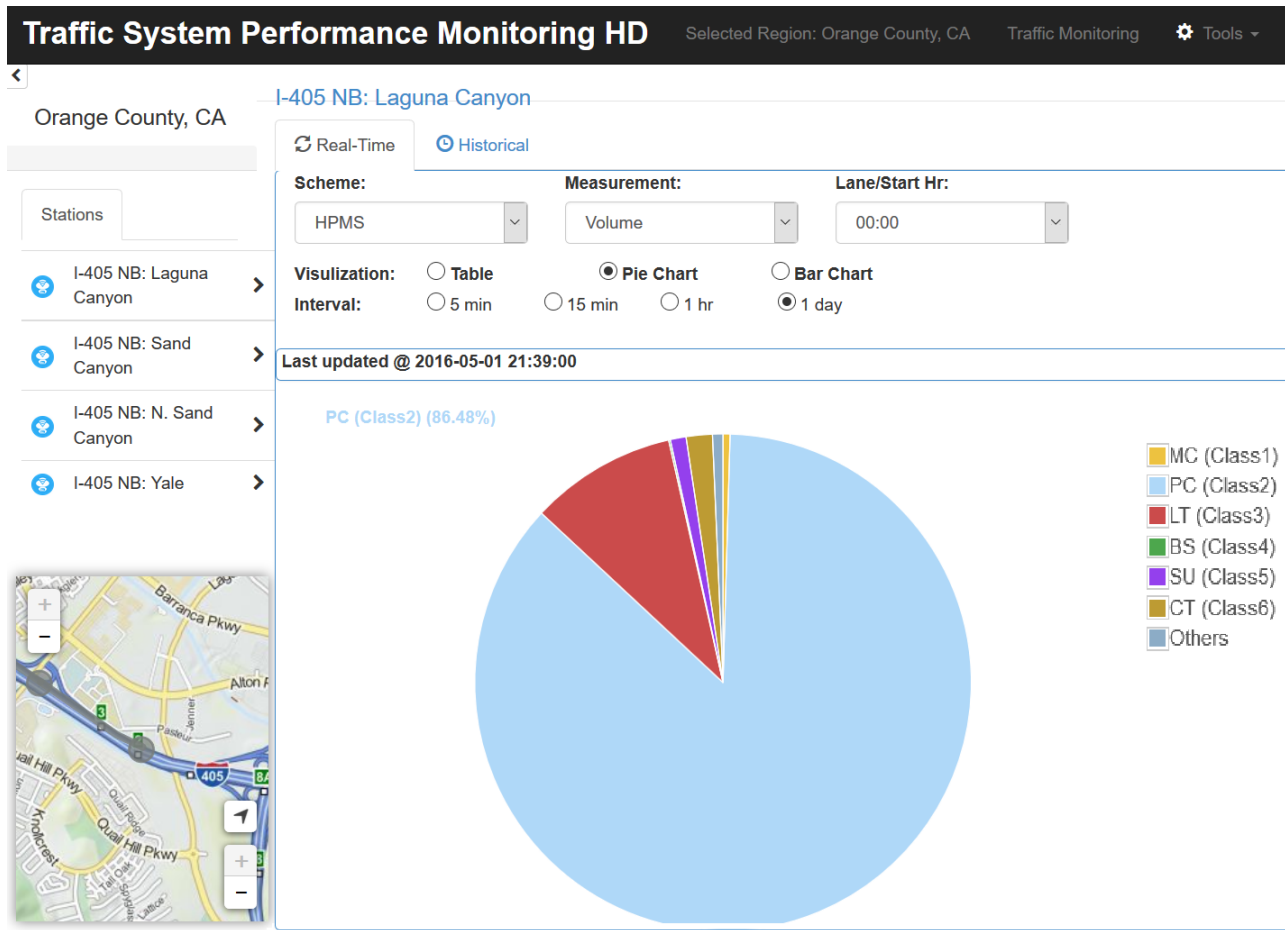
	HOV1	Lane1	Lane2	Lane3	Lane4	Lane5	Lane6	Total
MC (Class1)	1	0	0	0	0	8	2	11
PC (Class2)	1585	1537	1308	1351	873	868	805	8327
LT (Class3)	249	232	223	234	124	178	121	1361
BS (Class4)	5	20	16	30	19	7	7	104
SU (Class5)	33	54	89	96	16	24	18	330
CT (Class6)	1	1	40	33	3	2	1	81
Others	4	1	5	3	9	4	13	39
Total	1878	1845	1681	1747	1044	1091	967	10253



Website: 24-hr Volume by Class



Website: Class Volume % (by Lane or by Hour)



Detector Card Deployment

■ Freeway:

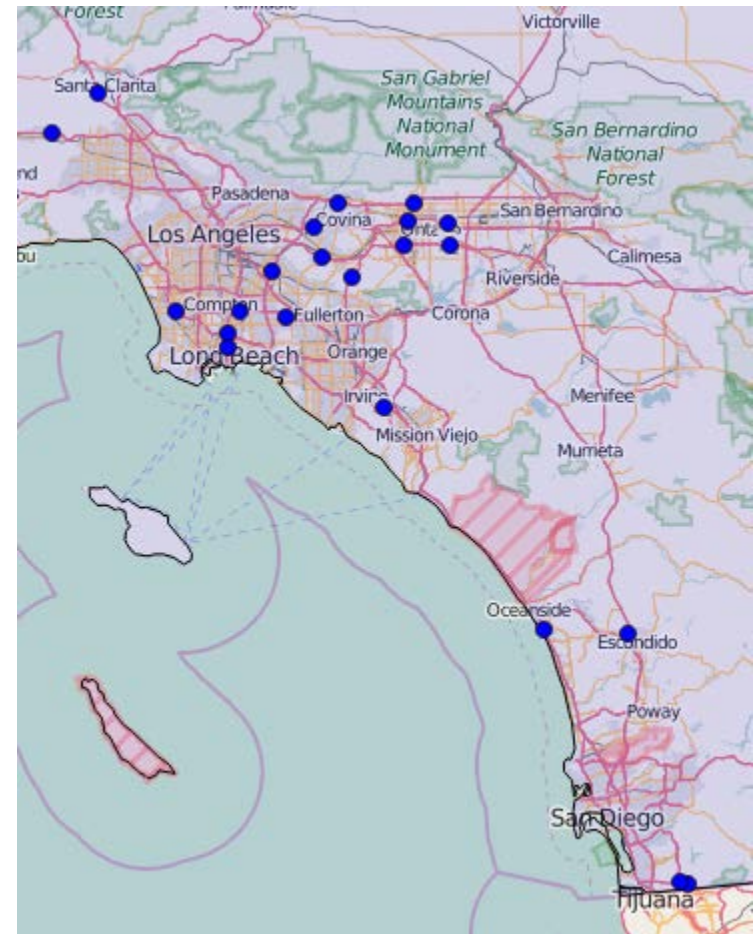
- California I-5, I-10, I-15, I-405, I-605, I-210, I-905, I-710, SR-60, SR-91, etc.

■ Arterial:

- Minnesota State Hwy 55

■ Deployed to about 30 locations

- 90 detector cards running in the field



UCI: Statewide Truck Study

Sponsored by Caltrans / CARB

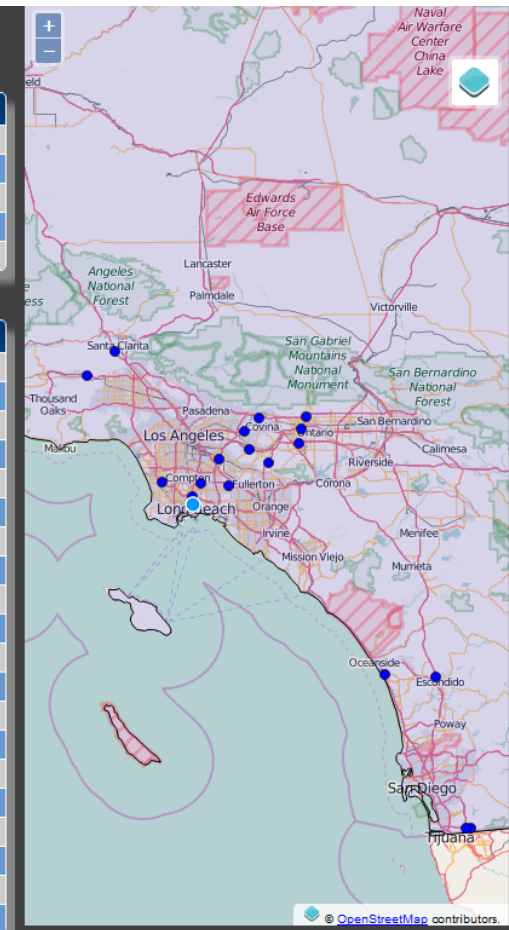
I-710 s/o Willow (ILD), ILD site
Summary Data for Friday, Apr 22 2016

Click on individual summary volume counts to obtain detailed hourly breakdown by body class

Vehicle Category	NB (Truck Lanes Only)	SB (Truck Lanes Only)
Passenger Vehicle	53684	54024
Single Unit Truck	7001	5940
Truck with Single Trailer	755	673
Tractor with Semi-Trailer	7139	7807
Tractor with Multiple Trailers	257	269

I-710 s/o Willow (ILD): NB (Truck Lanes Only), Tier 2 Class Semi: Breakdown by Hour of Day

Body Class	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total	
20ft Container	35	26	19	1	2	3	9	15	54	68	55	66	28	43	44	51	18	12	5	4	2	2	4	2	567	
40ft Container	187	162	95	26	15	35	42	68	162	196	177	214	87	86	133	99	58	12	16	20	8	11	13	5	1917	
40ft Container Reefer			2		1	3	2	1	5	4	5	2	4			1	2	1	4	1	2	1	1		42	
53ft Container	11	9	2	3	3	4	1	7	9	10	2	14	10	13	12	8	2	2	4	5	3	4		2	140	
Agriculture	3	3			1	1	2	3	3	7	7	5	3	3	3	3						1			51	
Auto	4	2		4	7	4	2	3	2	4	11	8	6	11	6	6	4	10	3	2	3	2	1		105	
Beverage		1		1				1	3	5	4	2	2	1	3	5	3	1	1	1			1	1	36	
Bulk Waste	1	1						2		1		1													6	
Container Chassis	4		1						2						1	1	2	1	1			1			14	
Drop Frame Van		2	1		1		1	2	4	4	2	6	8	3	8	7	2	5	4				2	2	1	65
Dump	48	37	37	10	9	9	16	23	59	68	73	67	39	31	56	33	25	13	8	10	6	7	2	4	690	
Enclosed Van (FHWA 8)	4	5	5	1	1	2	2	3	13	11	16	13	4	12	6	10	3	1	1	2	1				116	
Enclosed Van (FHWA 9)	5	6	4	5	3	6	7	19	25	41	32	40	30	33	33	23	13	18	15	7	9	8	8	9	399	
Enclosed Van Reefer (FHWA 8)	1								1			1	1	1	2	2							1		10	
Enclosed Van Reefer (FHWA 9)	5		3	2	3	2	5	7	18	16	25	23	13	12	14	4	9	2	2	5	2	1	1		174	
Logging	4	1	1	4	2	1	6	3	5	3	3	7	5	8	7	3			3	4	4	4	5		84	
Low Boy Platform	5	1	2	3		2	5	10	14	23	24	22	13	13	20	25	9	5	4	2	6	1	1		210	
Open Top Van	119	80	42	1	13	17	31	25	70	123	69	96	37	45	78	57	22	7	9	14	10	9	8	6	988	
Platform	22	27	20	5	10	11	21	20	44	74	49	54	42	40	46	44	23	16	13	11	9	5	9	4	619	
Tank	70	52	35	5	14	22	15	24	69	107	90	75	42	57	61	54	36	15	9	11	18	10	10	5	906	



Conclusion and Future Work

- Inductive loop signature technology shows great potential to significantly improve the traffic data collection
- Complete the SBIR Phase II project
- Solution to travel monitoring market
 - Upgrade existing products through swapping cards?
- Continue to develop and improve products
- Marketing and sales