Weigh-In-Motion Station Monitoring and Calibration using Inductive Loop Signature Technology

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Outline

- Background
- Truck tracking algorithms
- Calibration of drive tandem axle spacings
- Calibration of gross vehicle weight
- Conclusion and ongoing / future Study

Background

- Heavy vehicles
  - Represent a small portion of vehicles on the roads
  - Have significant influences on pavement, safety, environment, fuel consumption, and the performance of traffic system
- Weigh-In-Motion (WIM)
  - Collect truck data on the freeways
  - Existing WIM stations has sophisticated sensors, periodic and proper calibration is critical to their performance
  - Issues
    - WIM stations usually are not calibrated in a timely fashion
    - Calibration is normally performed using five-axle single-trailer trucks (FHWA Class 9) due to limited resources

Proposed Solution

- Develop a WIM monitoring and remote calibration system based on an inductive loop signature-WIM based approach
  - Track heavy vehicles at WIM stations and generated "**Matched Vehicle Pairs (MVPs)**"
    - WIM data
    - Inductive Loop Signatures (ILS)
  - Perform WIM station monitoring and calibration using MVPs

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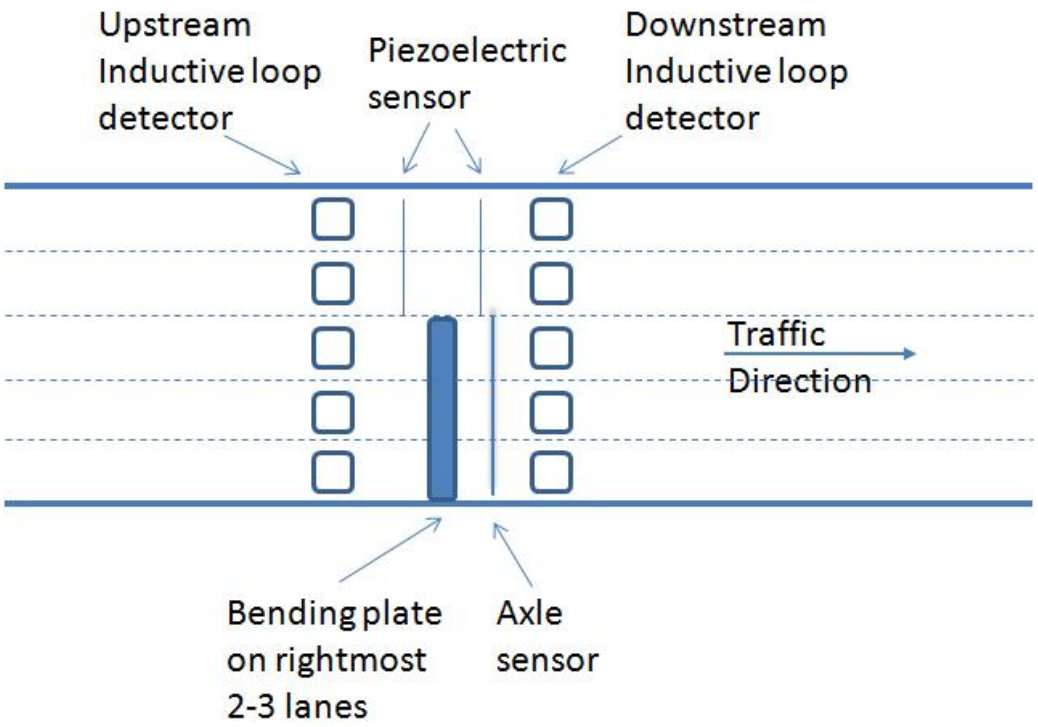
WIM Data

- Weight
- Axle-spacing
- Vehicle length
- Volume
- Class



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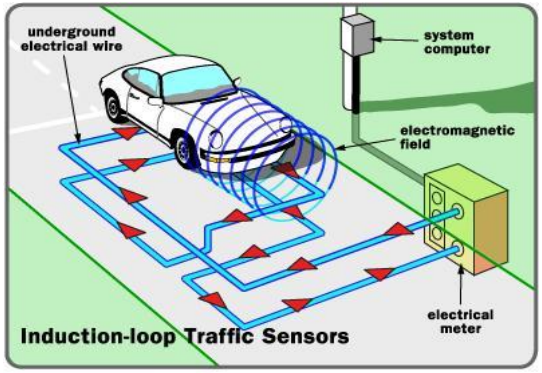
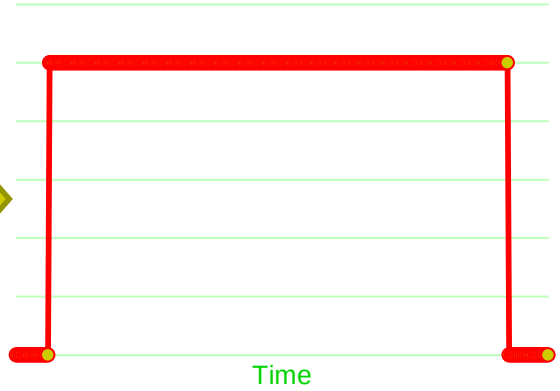
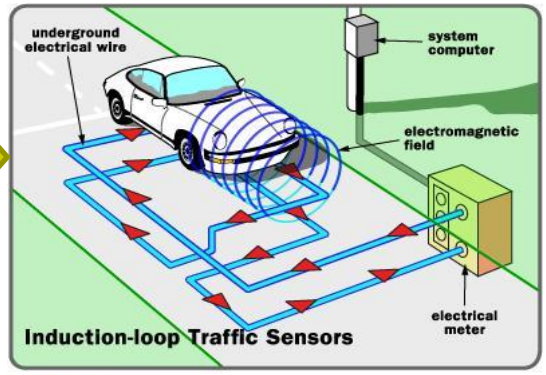
Conventional vs Advanced Loop Detector

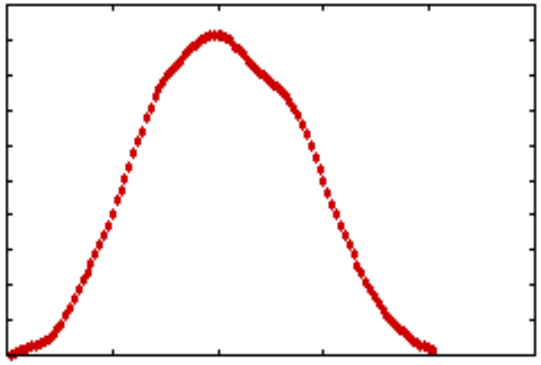
- Conventional loop detector





- Advanced loop detector





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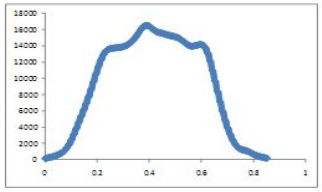
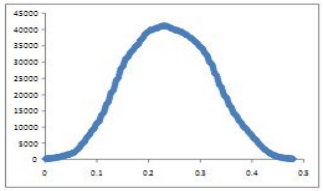
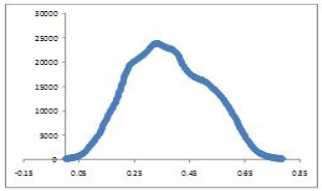
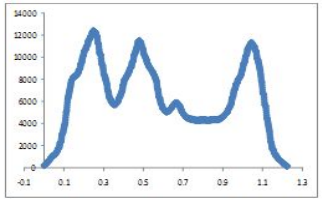
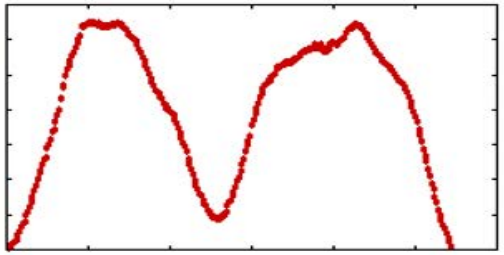
Sample Vehicle Signatures

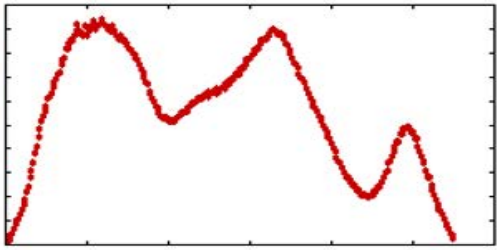


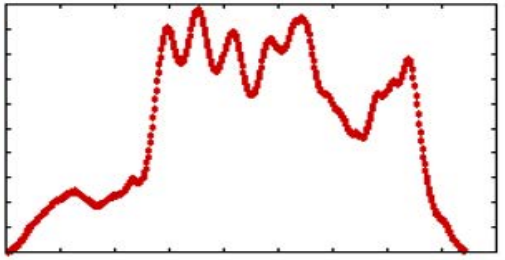












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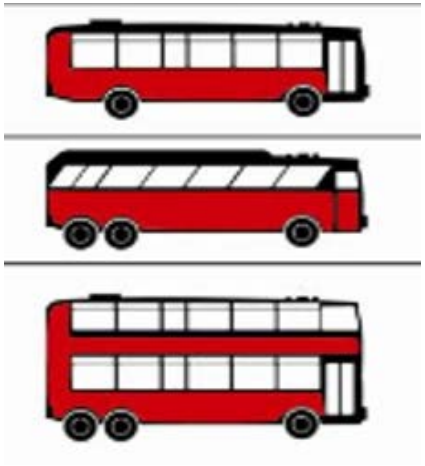
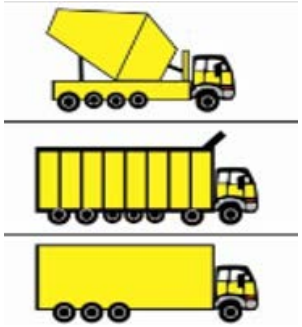
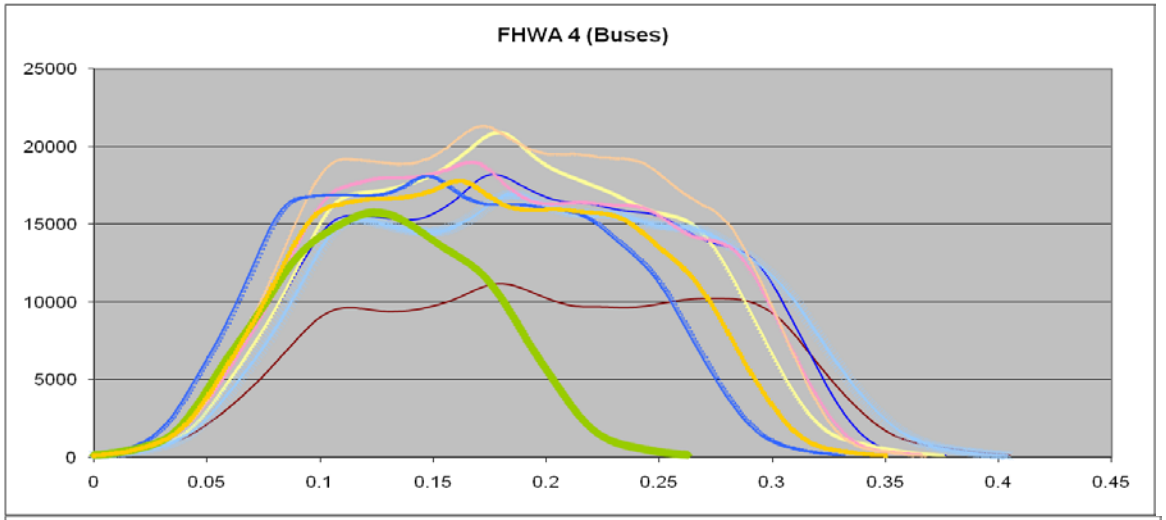
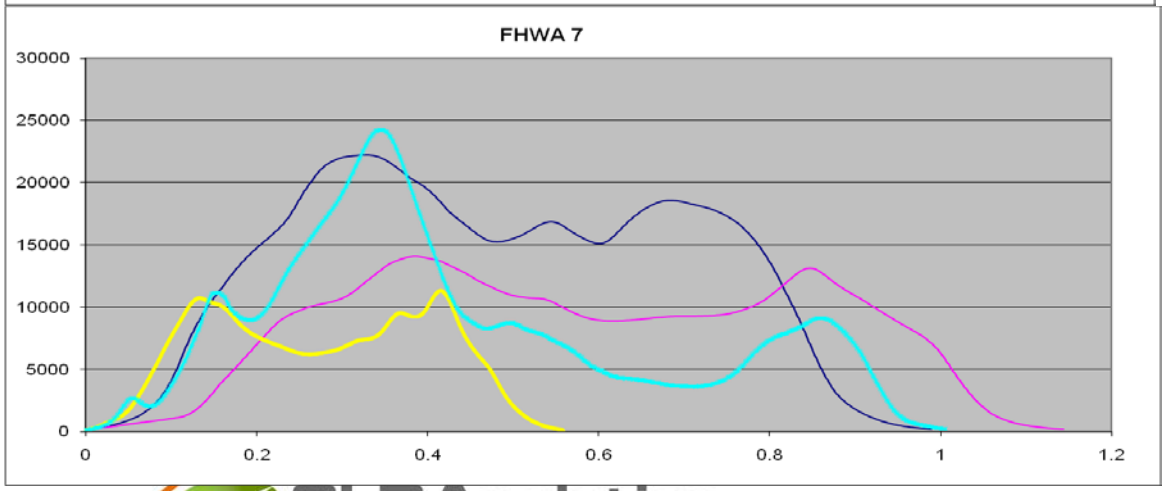
Typical Signatures for FHWA Class 4 & 7 Vehicles









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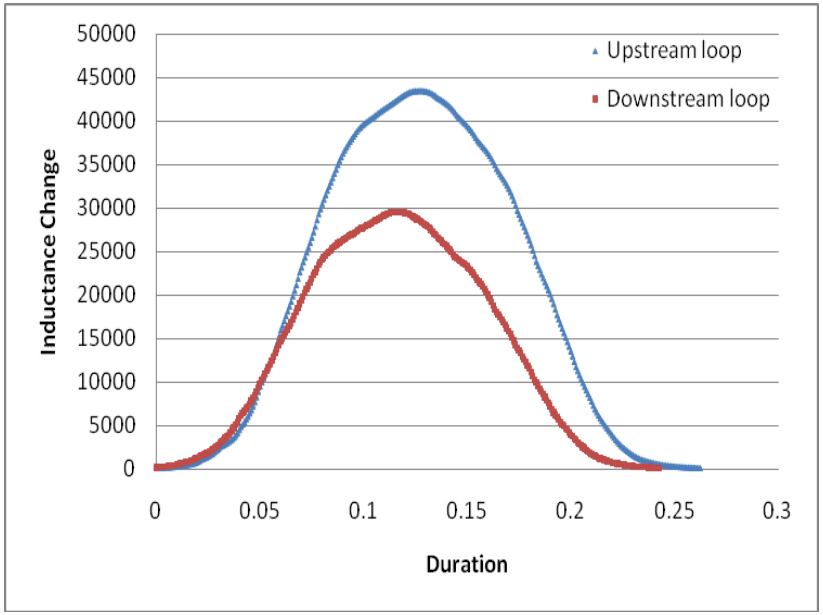
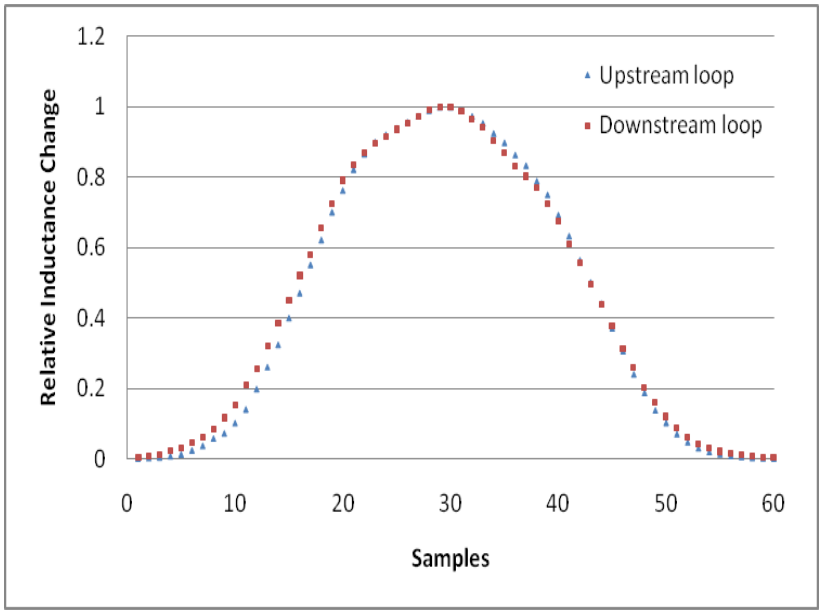
Same Vehicle's Signatures



(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.

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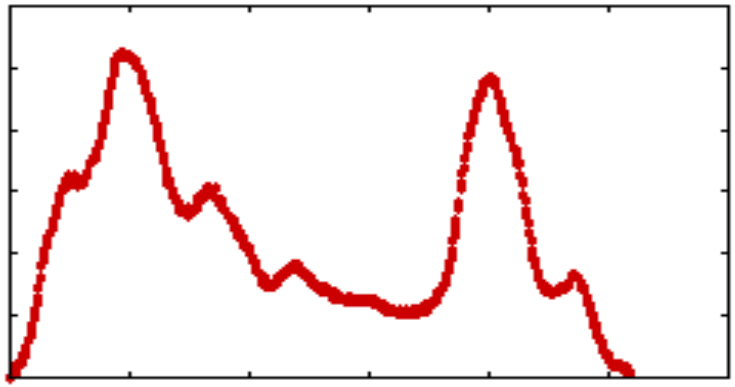
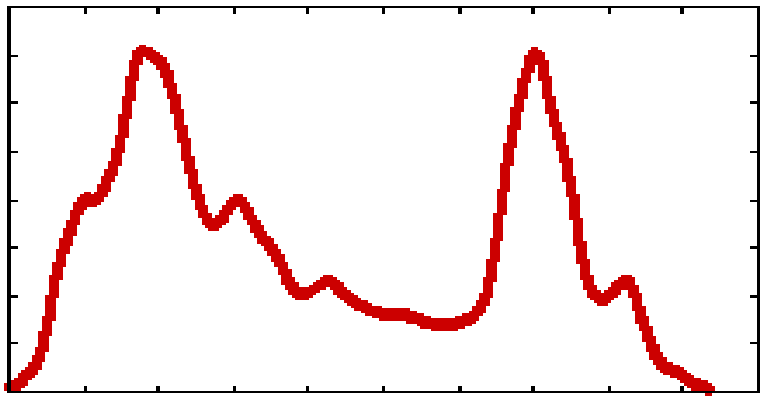
Same Vehicle at Different Detector Stations (19 miles apart)



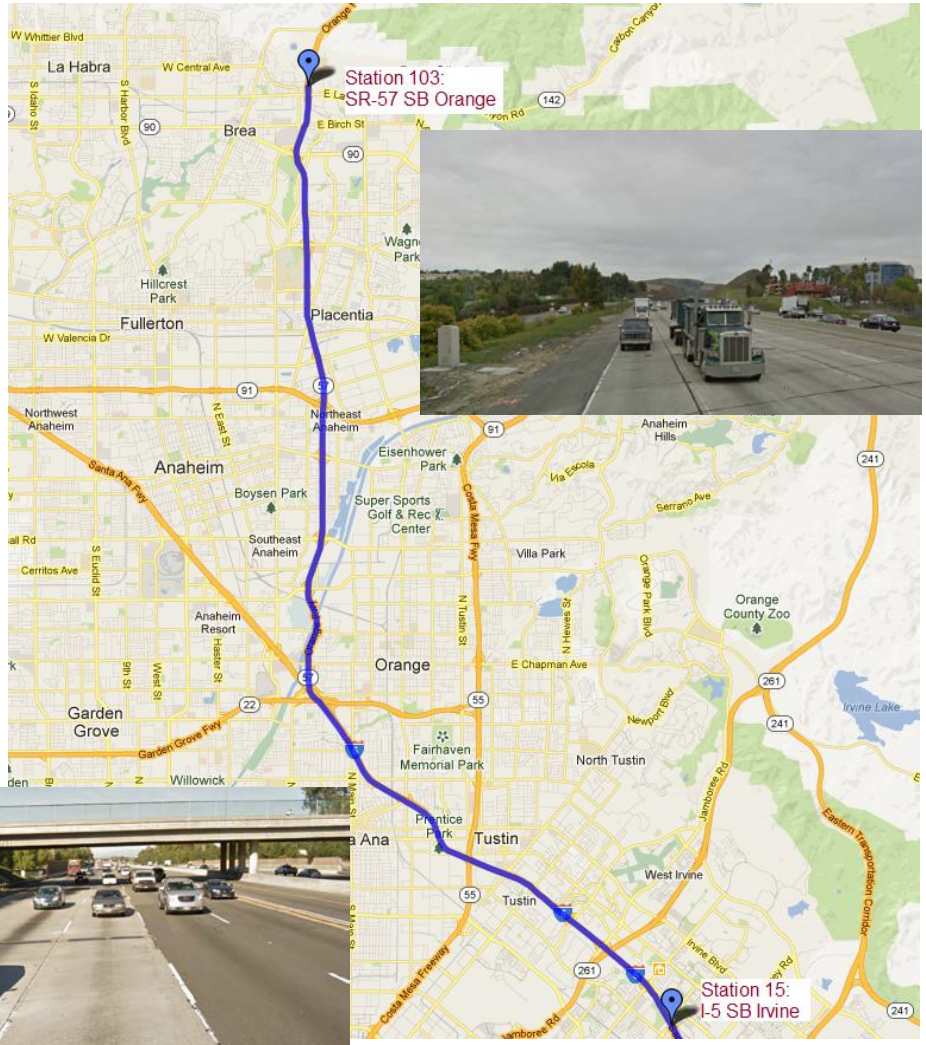
Upstream: SR-57 SB at Lambert
(WIM station, square loop)



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

Site Selection

- SR-57 SB
  Orange to I-5 SB
  Irvine stations
  - About 19 miles apart
  - 21 interchanges in between
  - variation of traffic conditions



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Data Collection Setup

SR-57 SB Orange Station
iSinc Controller running at diagnosis mode

I-5 SB Irvine Station
1060 series controller with a customized solution from UCI

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Camera Setup for License Plate and Vehicle Classification

SR-57 SB Orange Station

I-5 SB Irvine Station

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Dataset Description

- SR-57 SB Orange Station: the rightmost two lanes
- I-5 SB Irvine Station: the rightmost three lanes
- Dataset for model development: 03/21/13
- Dataset for testing: 03/22/13 and 03/25/13
- Time period

Station	3/21/2013	3/22/2013	3/25/2013
SR-57 SB Orange Station	8:00-15:00	8:00-15:00	8:40-12:40
I-5 SB Irvine Station	8:20-15:20	8:20-15:20	9:00-13:00

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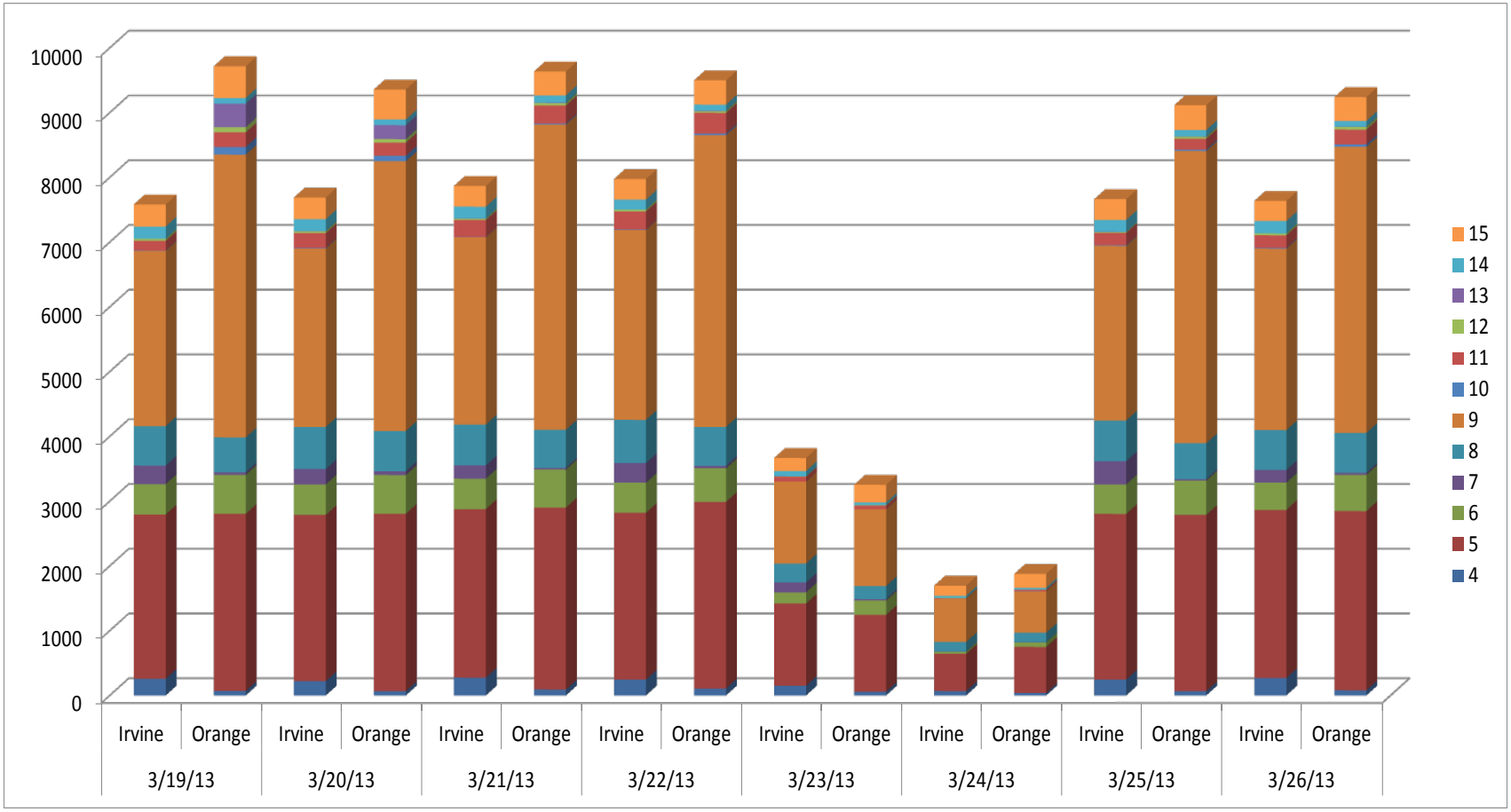
Station Flow by FHWA Class



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Ground-truthed Common Vehicle Rate

FHWA Vehicle Class	3/21/13		3/22/13		3/25/13	
	# of GT Vehicles	Ground-truthing Rate	# of GT Vehicles	Ground-truthing Rate	# of GT Vehicles	Ground-truthing Rate
4	77	2.6%	64	0.0%	17	11.8%
5	1425	4.5%	1411	4.7%	890	5.3%
6	196	10.7%	188	10.1%	153	8.5%
7	157	0.0%	292	0.3%	221	1.8%
8	119	8.4%	127	10.2%	73	11.0%
9	1166	13.0%	1148	13.6%	693	12.3%
10	4	0.0%	5	20.0%	3	0.0%
11	47	0.0%	22	4.5%	7	14.3%
12	2	0.0%	1	0.0%	1	100.0%
13	2	0.0%	1	100.0%	1	100.0%
14	95	6.3%	100	12.0%	76	10.5%
15	7	0.0%	2	50.0%	5	0.0%
Total	3297	-	3361	-	2140	-

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03/21/13 Dataset

SR57 SB Orange to I-5 SB Irvine 03/21/13 Dataset													
	FHWA Vehicle Class 4-15												
Hour	4	5	6	7	8	9	10	11	12	13	14	15	Total
8	0	2	0	0	0	8	0	0	0	0	0	0	10
9	1	13	2	0	2	24	0	0	0	0	0	0	42
10	0	18	6	0	2	33	0	0	0	0	2	0	61
11	0	10	3	0	1	28	0	0	0	0	2	0	44
12	0	7	3	0	1	24	0	0	0	0	0	0	35
13	0	8	4	0	3	20	0	0	0	0	0	0	35
14	1	6	3	0	1	10	0	0	0	0	2	0	23
15	0	0	0	0	0	5	0	0	0	0	0	0	5
Total	2	64	21	0	10	152	0	0	0	0	6	0	255

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03/22/13 Dataset

SR57 SB Orange to I-5 SB Irvine 03/22/13 Dataset													
	FHWA Vehicle Class 4-15												
Hour	4	5	6	7	8	9	10	11	12	13	14	15	Total
8	0	4	0	0	0	12	0	0	0	0	0	1	17
9	0	13	1	0	5	25	0	0	0	0	0	0	44
10	0	7	3	0	1	20	1	1	0	1	3	0	37
11	0	14	1	0	2	26	0	0	0	0	0	0	43
12	0	12	7	0	3	30	0	0	0	0	1	0	53
13	0	9	3	1	0	19	0	0	0	0	5	0	37
14	0	8	3	0	2	15	0	0	0	0	3	0	31
15	0	0	1	0	0	9	0	0	0	0	0	0	10
Total	0	67	19	1	13	156	1	1	0	1	12	1	272

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03/25/13 Dataset

SR57 SB Orange to I-5 SB Irvine 03/25/13 Dataset													
	FHWA Vehicle Class 4-15												
Hour	4	5	6	7	8	9	10	11	12	13	14	15	Total
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	2	10	1	1	2	27	0	0	1	0	1	0	45
10	0	6	4	1	2	13	0	1	0	1	4	0	32
11	0	13	7	2	2	28	0	0	0	0	1	0	53
12	0	18	1	0	2	17	0	0	0	0	2	0	40
13	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2	47	13	4	8	85	0	1	1	1	8	0	170

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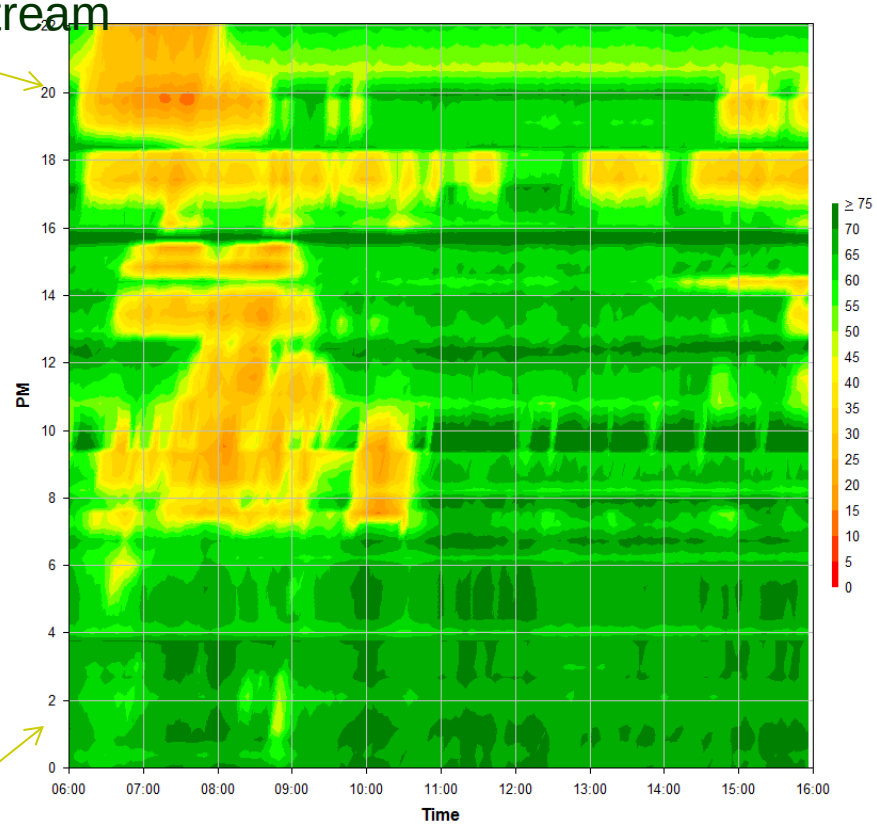
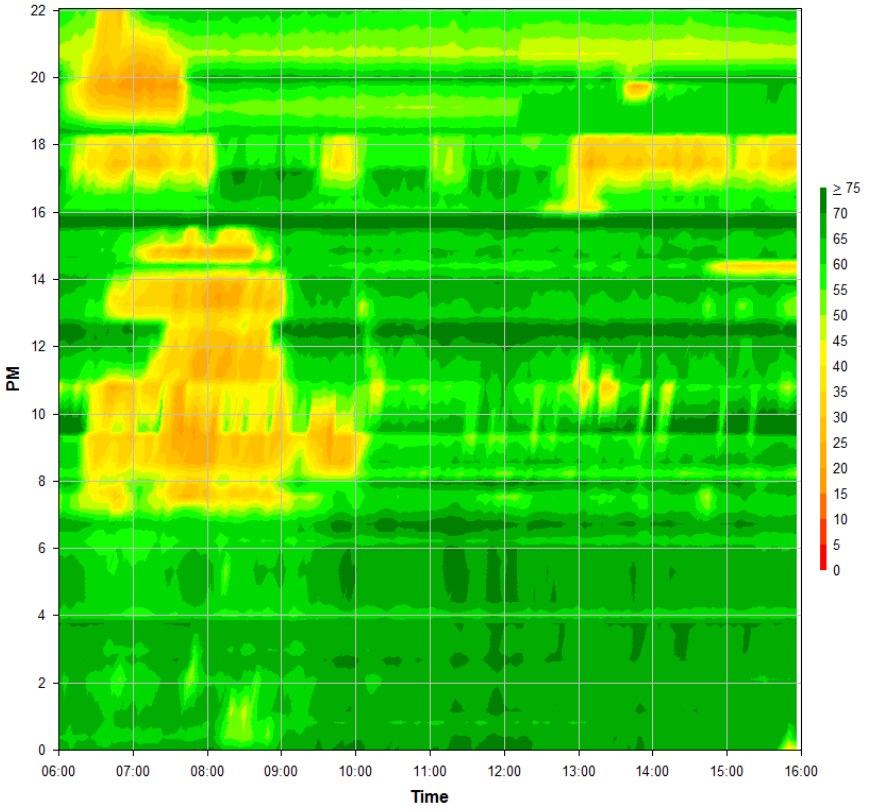
Speed Contour Map

Upstream



Downstream

03/21/13



03/22/31

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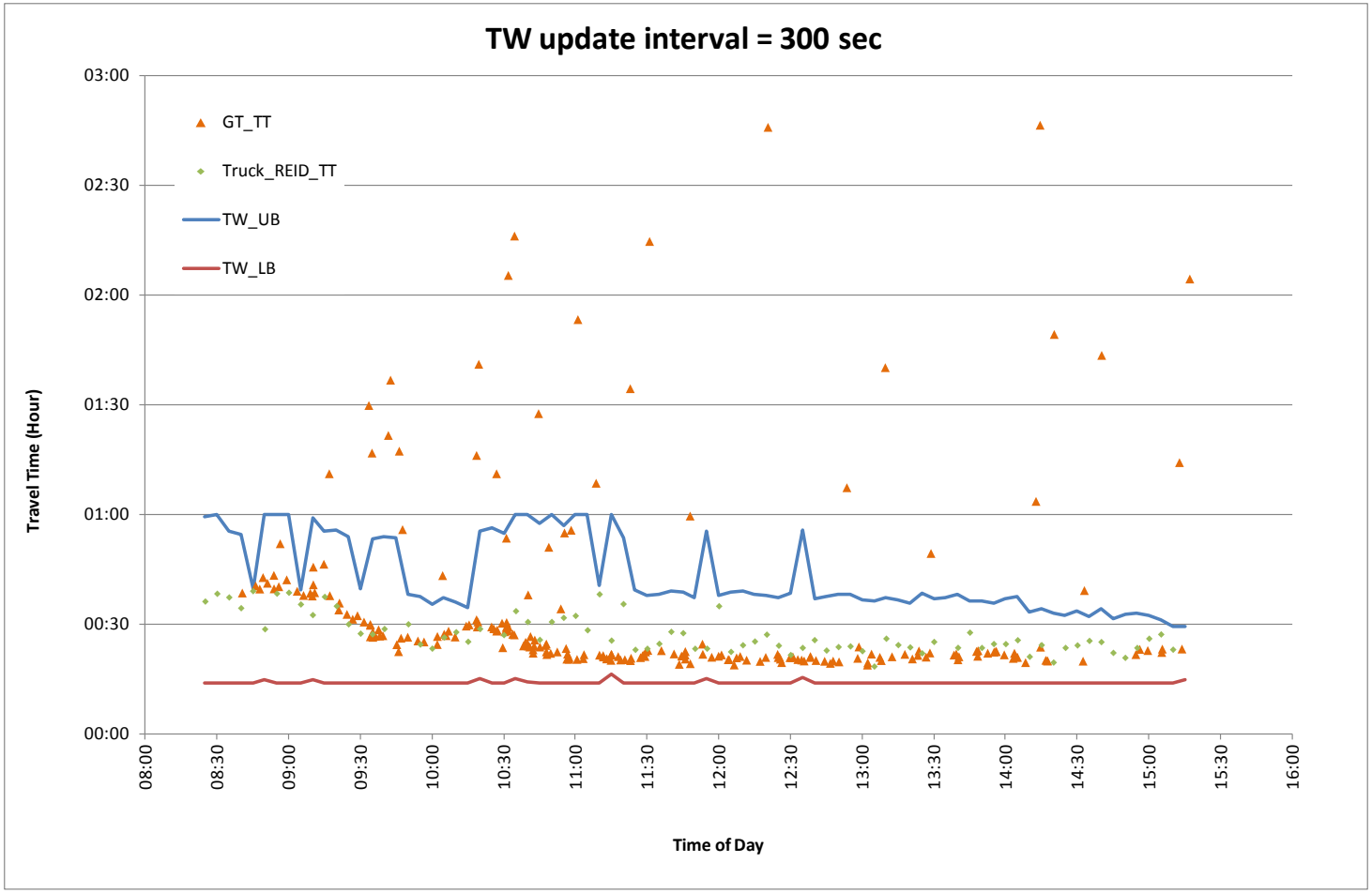
Dynamic Time Window in RTREID-2MT



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Data Summary

- Common trucks: those crossing both stations
- Those with travel time higher than 1 hours were treated as outliers and removed

	3/21/2013	3/22/2013	3/25/2013
Total # of vehicles at upstream station (SR-57 SB Orange Station)	12,622	12,675	6,831
Total # of vehicles at downstream station (I-5 SB Irvine Station)	25,577	27,775	13,831
# of trucks at downstream station	3,070	3,221	1,987
# of common trucks	213	217	144
Truck % at downstream station	12.0%	11.6%	14.4%
Common truck %	0.8%	0.8%	1.0%

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Vehicle Reidentification using Different Types of Data

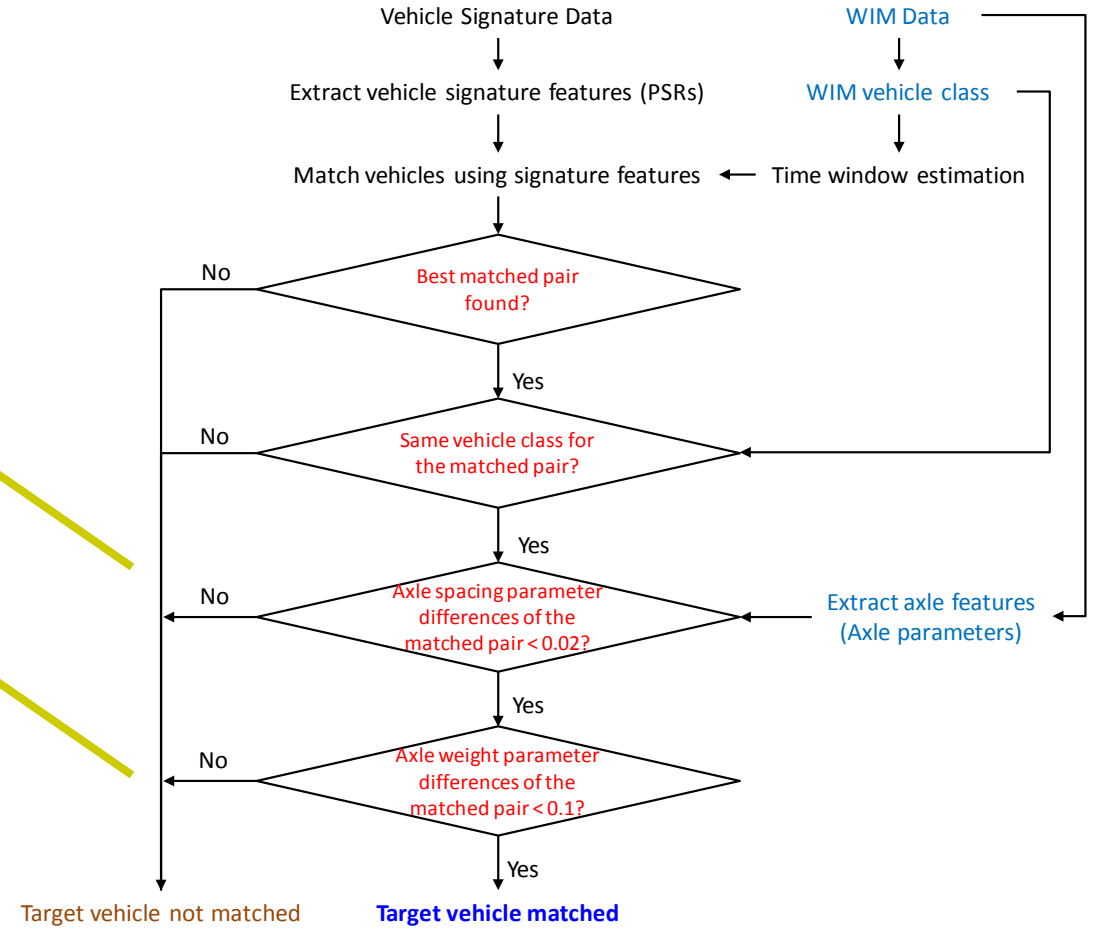
Vehicle Signature Data w/o or w/ WIM Data

Scenario 2
using vehicle signature data only

Scenario 3
using vehicle signature and WIM axle spacing(s) data

Scenario 4
using vehicle signature and WIM axle spacing(s) and axle weight data

Vehicle Signature based Vehicle Reidentification Approach



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Performance Index

- System Correct Match Rate (SCMR)
  - percentage of accuracy when the system indicates there is a match

$$SCMR = \frac{CMVeh}{MVeh_{Total}}$$

- System Error Rate (SER)
  - indicate the overall system reliability via finding out the errors occurred in the system
    - a vehicle is a common truck but it is not matched
    - a vehicle is a common truck but it is mismatched
    - a vehicle is observed only at the downstream station but it is matched by the system

$$SER = \frac{MMVeh}{Veh_{Total}}$$

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Truck Reidentification Performance

03/21/13 Dataset

Performance Index	Scenario 2	Scenario 3	Scenario 4
SCMR	16.2%	53.0%	61.5%
SER	32.2%	6.3%	5.1%

03/22/13 and 03/25/13 Datasets

Performance Index	Scenario 2	Scenario 3	Scenario 4
SCMR	17.6%	54.1%	61.7%
SER	29.2%	6.2%	5.2%

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Reidentification Results by Class

FHWA Vehicle Class	3/21/2013							3/22/2013							3/25/2013						
	Trucks Observed at Irvine Station			Common Truck				Trucks Observed at Irvine Station			Common Truck				Trucks Observed at Irvine Station			Common Truck			
	match_type			m_idx				match_type			m_idx				match_type			m_idx			
	1	3	Total	-1	0	1	Total	1	3	Total	-1	0	1	Total	1	3	Total	-1	0	1	Total
4	1	69	70	1	0	1	2	0	62	62	0	0	0	0	0	13	13	2	0	0	2
5	63	1261	1324	33	2	14	49	55	1284	1339	35	1	16	52	41	784	825	27	3	11	41
6	20	159	179	5	0	15	20	16	167	183	5	0	9	14	7	132	139	4	0	5	9
7	2	148	150	0	0	0	0	7	272	279	0	0	1	1	1	209	210	0	0	0	0
8	7	103	110	2	0	5	7	11	109	120	3	0	9	12	5	66	71	2	0	5	7
9	139	946	1085	20	0	110	130	138	971	1109	22	0	106	128	78	564	642	20	0	58	78
10	0	4	4	0	0	0	0	0	5	5	0	0	0	0	0	2	2	0	0	0	0
11	5	40	45	0	0	0	0	3	17	20	0	0	1	1	1	6	7	0	0	1	1
12	0	2	2	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	1	1
13	0	2	2	0	0	0	0	1	0	1	0	0	1	1	1	0	1	0	0	1	1
14	6	86	92	0	0	5	5	8	92	100	2	0	5	7	6	65	71	0	0	4	4
15	1	6	7	0	0	0	0	1	1	2	0	0	1	1	0	5	5	0	0	0	0
Total	244	2826	3070	61	2	150	213	240	2981	3221	67	1	149	217	141	1846	1987	55	3	86	144

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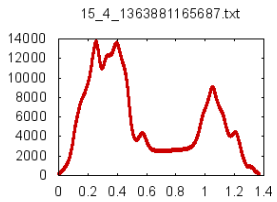
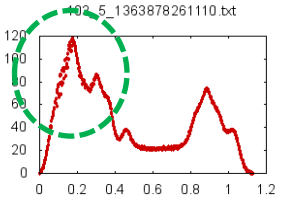
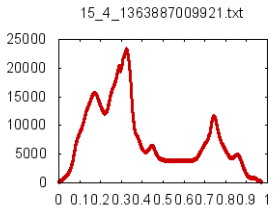
Error Category Examples

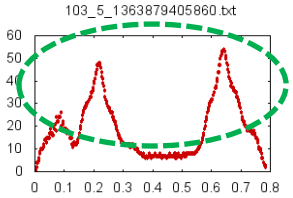


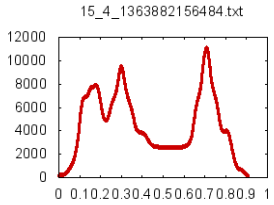
Off-center



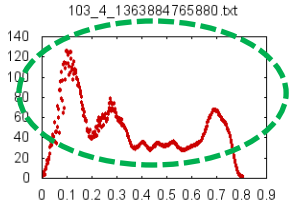


Lane Changing





Trucks Nearby



IRD 1060 (downstream)

IRD iSinc (upstream)

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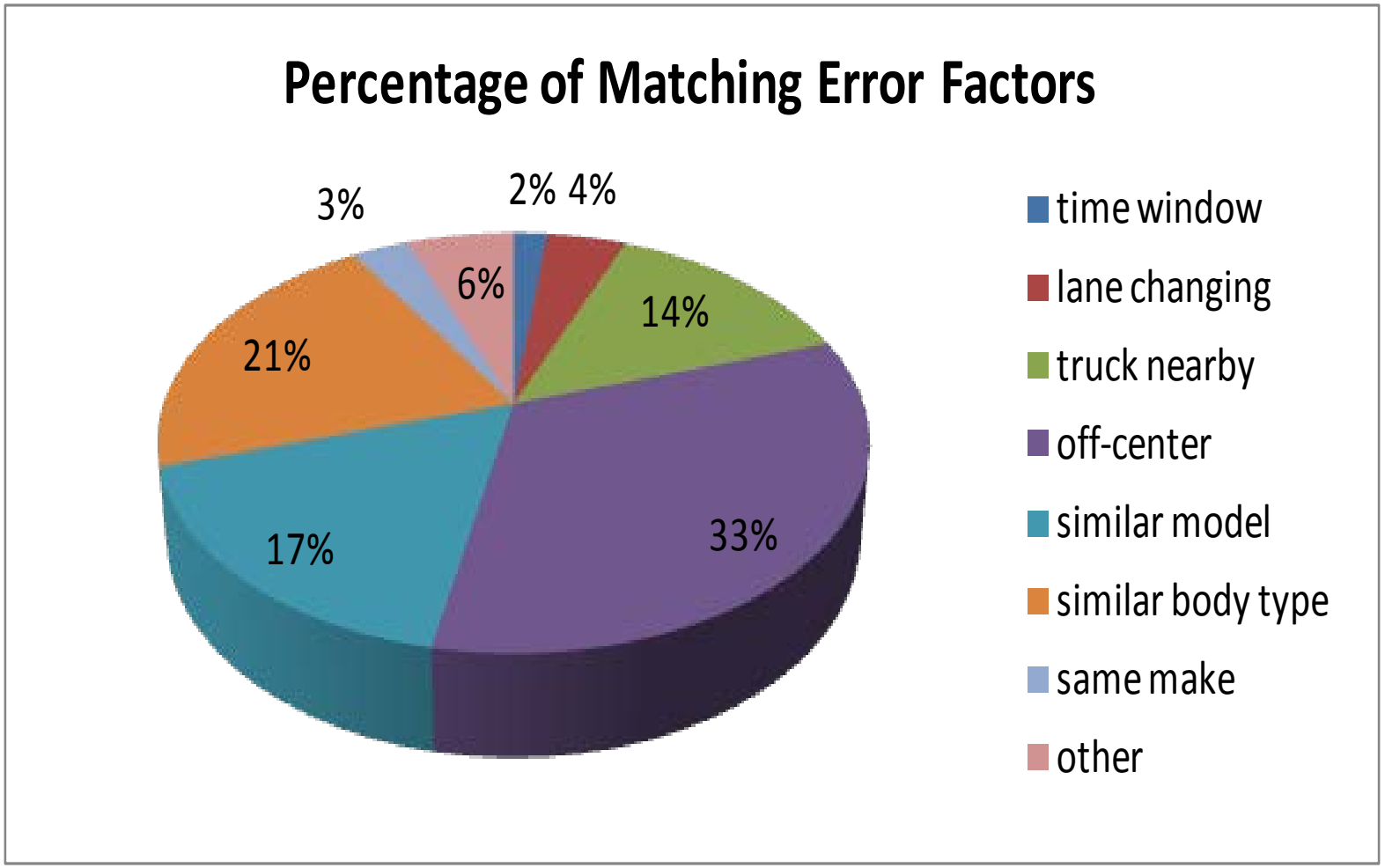
Matching Error Analysis



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Increase Correct Matching Rate

- Bayesian reidentification algorithm
  - Inputs:
    - WIM Data (Axle spacings, Axle weights)
    - Match vehicle pairs from the previous step
  - Output: Matching probability
- If (Matching probability > 90%)
  - Vehicle matched!

Previous SCMR

61.7% →

	Class 4-15	Class 6-15	Class 9
MVPs	225	198	153
SCMR	76%	86%	89%

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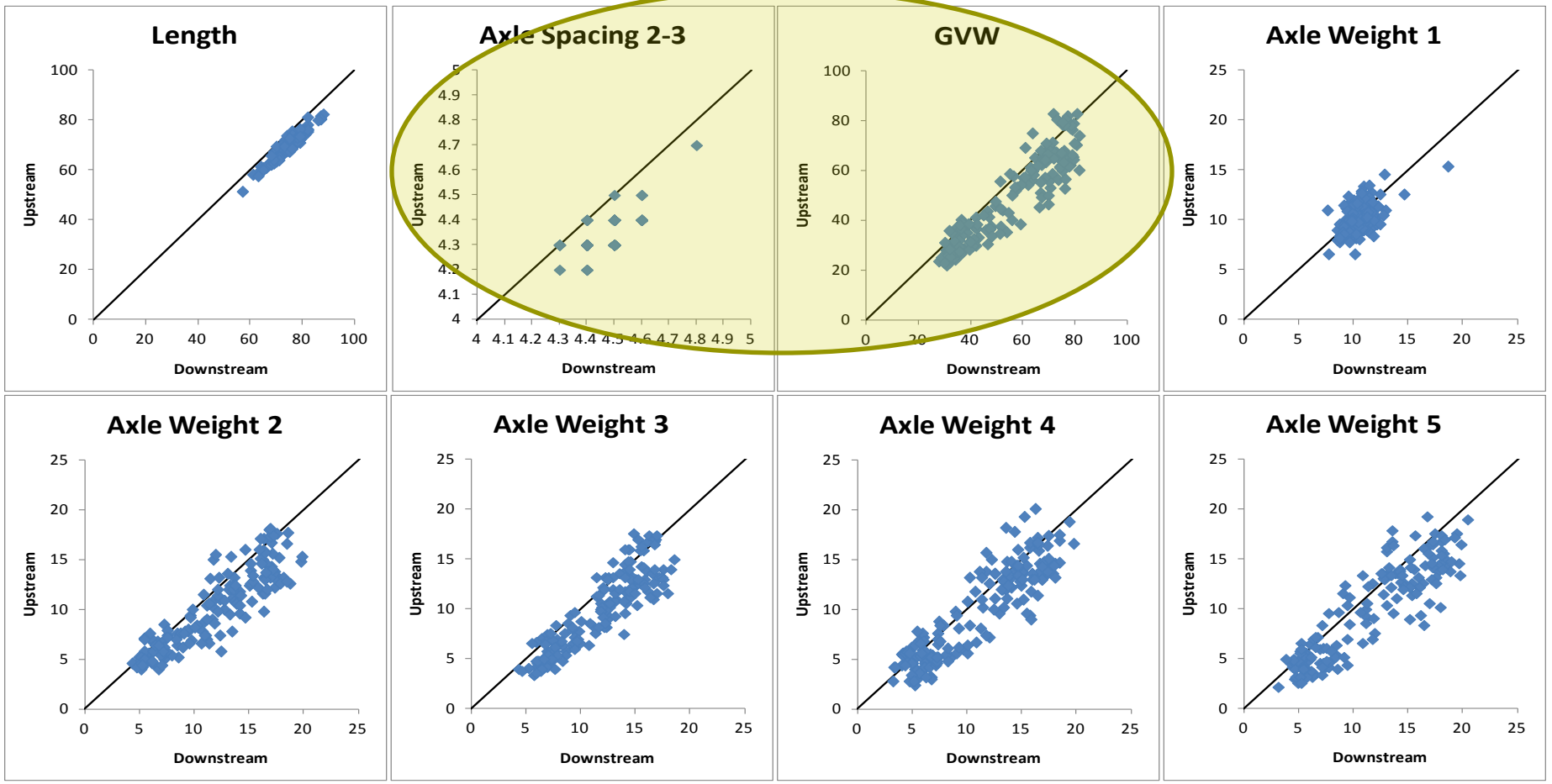
Comparison of WIM Data based on MVPs



Upstream: SR-57 Orange Station

Downstream: I-5 SB Irvine Station

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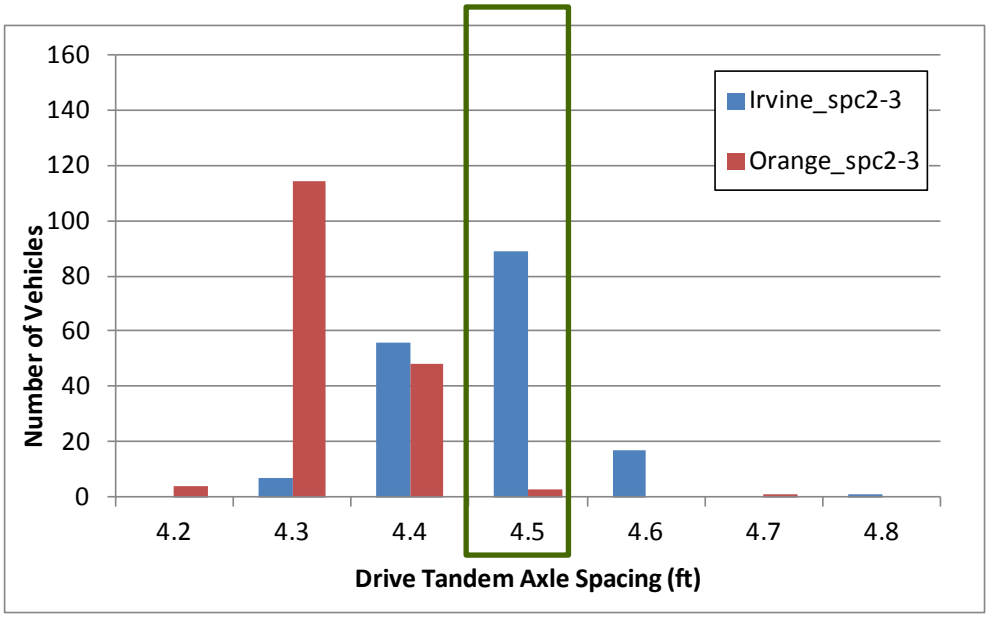
Calibration Monitoring Procedures

- The objective of the calibration monitoring procedures (WIM Data Analyst's Manual):
  - Maintain system calibration throughout the life of the system
  - Verify the desired effects of calibration factor adjustments on WIM weight, axle spacing, and vehicle length outputs
  - Identify weigh sensors that are intermittently and/or subtly malfunctioning
  - Adjust calibration factors for a weigh sensor exhibiting calibration drift pending onsite recalibration using test trucks
  - Temporarily assign calibration factors for a weigh sensor replacement pending onsite recalibration using test trucks
  - Schedule onsite calibrations/validation for sites with most need when funding and/or resources for running test trucks is limited

FHWA Class 9 Drive Tandem Axle Spacing Histograms

- Average drive tandem axle spacing (i.e., axle spacing 2-3) for FHWA Class 9 vehicles is about 4.3 feet for most locations in the U.S.

- I-5 SB station:
  - Drive tandem axle spacings were too high based on MVPs.



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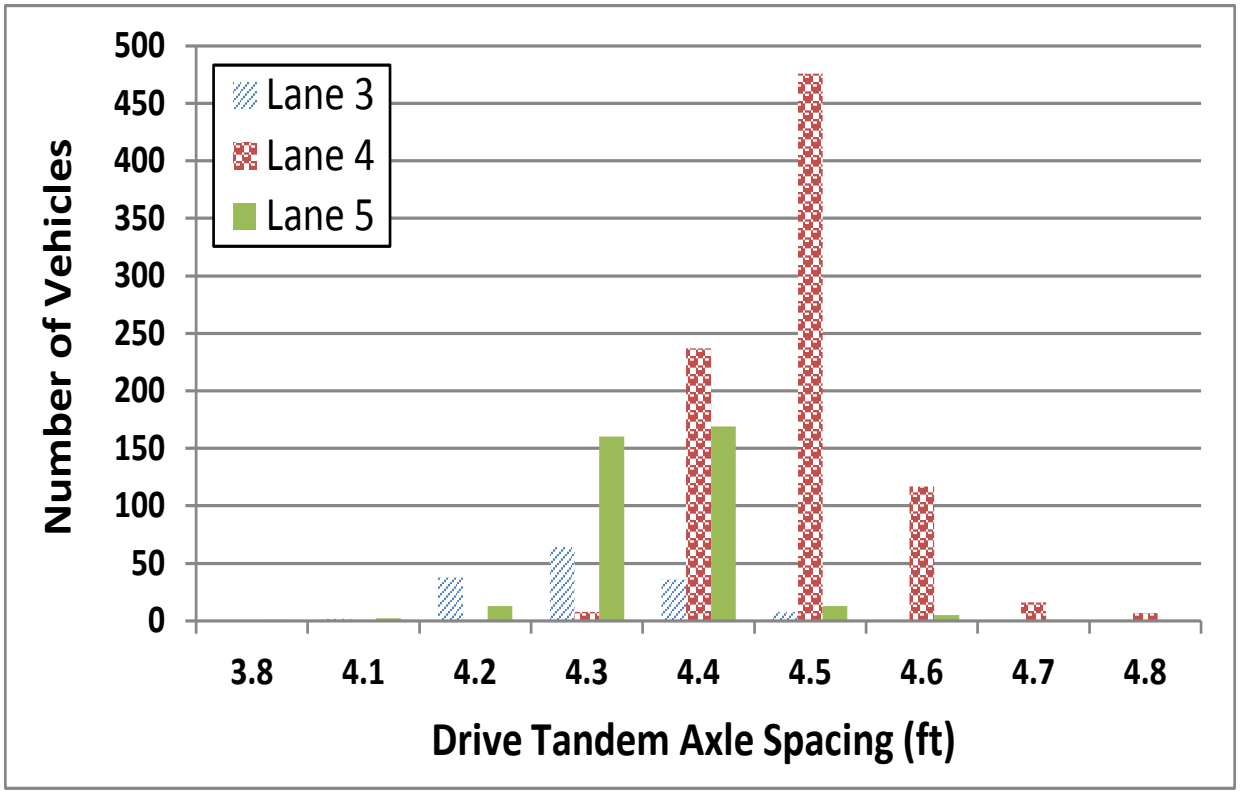
FHWA Class 9 Drive Tandem Axle Spacing Histograms by Lane at I-5 SB Irvine Station



FHWA Class 9 Drive Tandem Axle Spacing Histograms at I-5 SB Irvine Station by Lane (for all Class 9 vehicles at the site)

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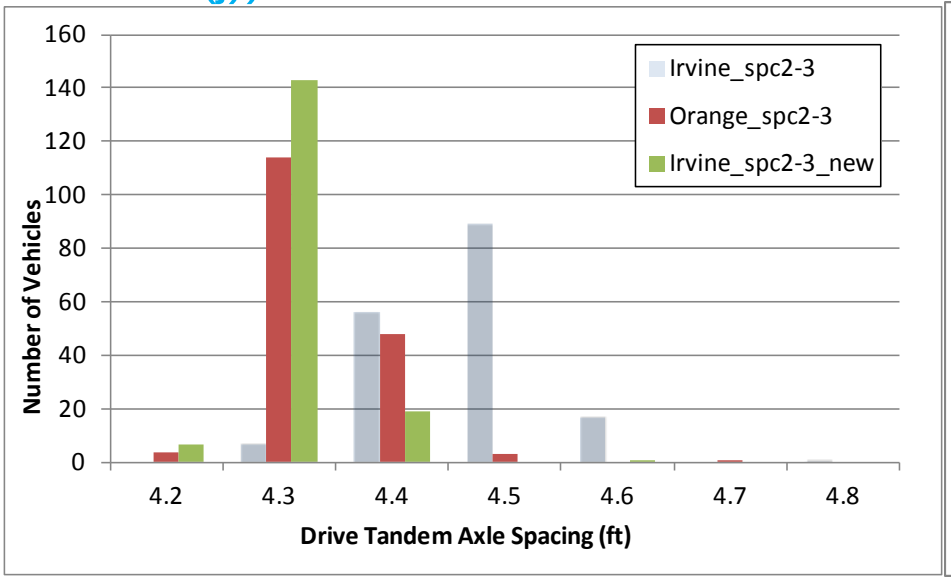
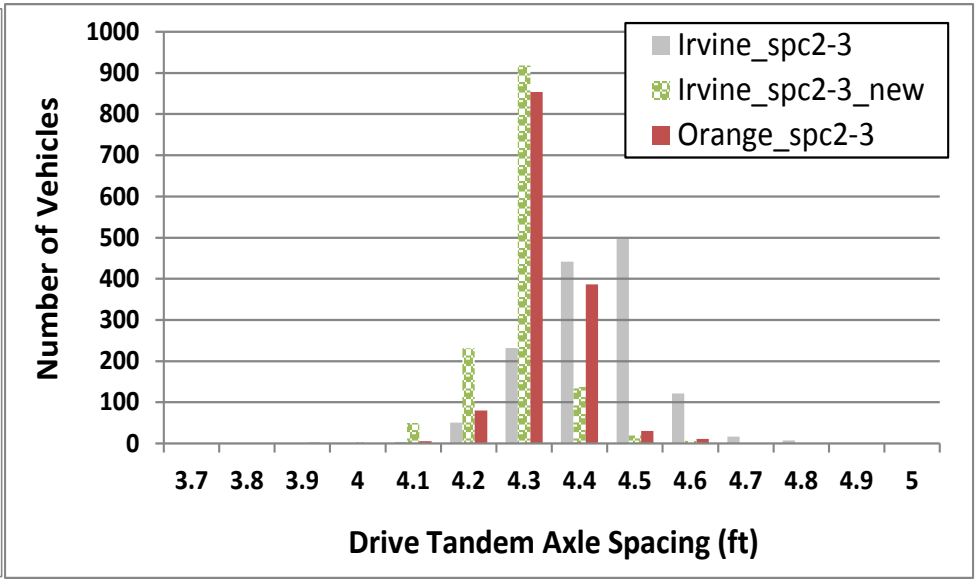
Approximate Calibration: Drive Tandem Axle Spacing

The lane-based average offset based on MVPs can be derived from the matched vehicle pairs and then applied to the I-5 SB WIM station:

Offset (lane i, Irvine) = Spacing(Orange, lane i, MVP(j)) - Spacing(Irvine, MVP(j))





Applied to MVPs

Applied to All Class 9 vehicles

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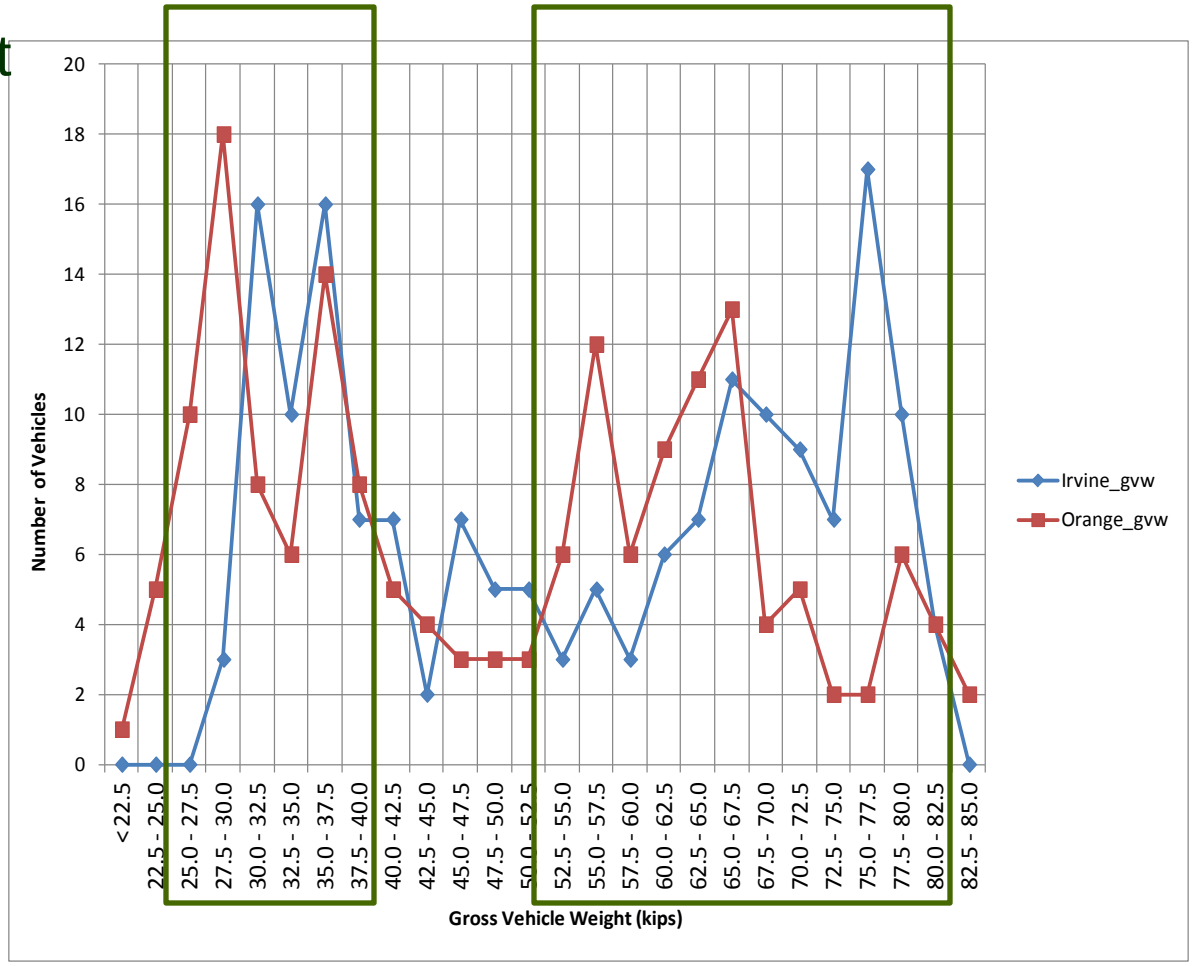
FHWA Class 9 GVW Distribution

- FHWA Class 9 weight
  - Empty truck GVW distribution typically peaks at "30~35" kips
  - Loaded truck distribution typically peaks at "70~80" kips.
- WIM sensors at SR-57 SB Orange station
  - Weights are too low from both the empty and loaded truck distribution peaks.



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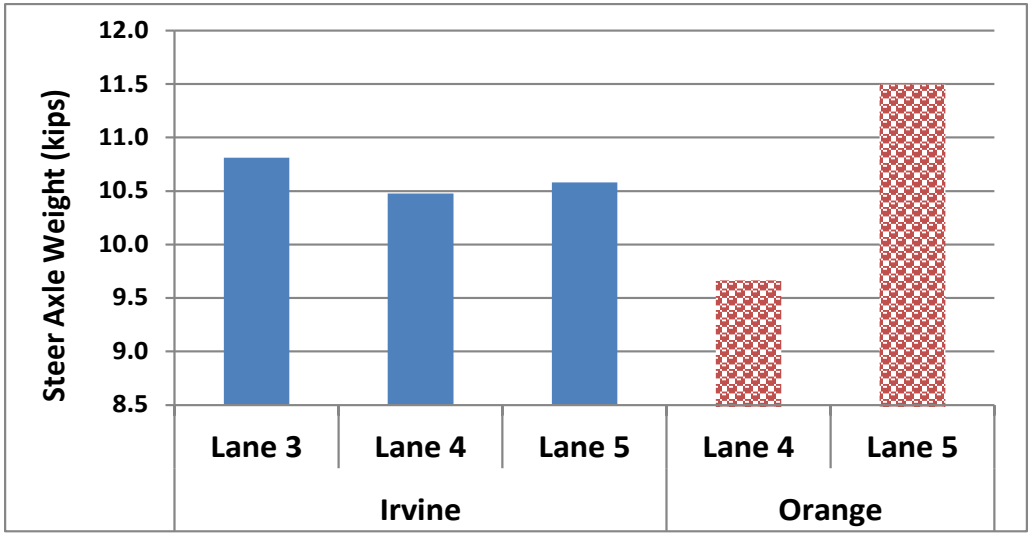
Approximate Calibration: GVW Distribution

- SR-57 SB Orange station data was further investigated on a per-lane basis using the 03/21/13 WIM data.
  - Lane 4 reported lower weights
  - Lane 5 reported higher steer axle weights



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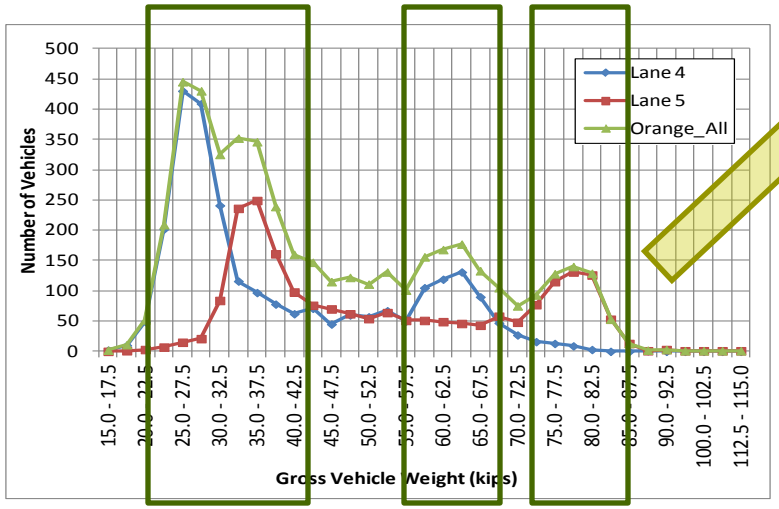
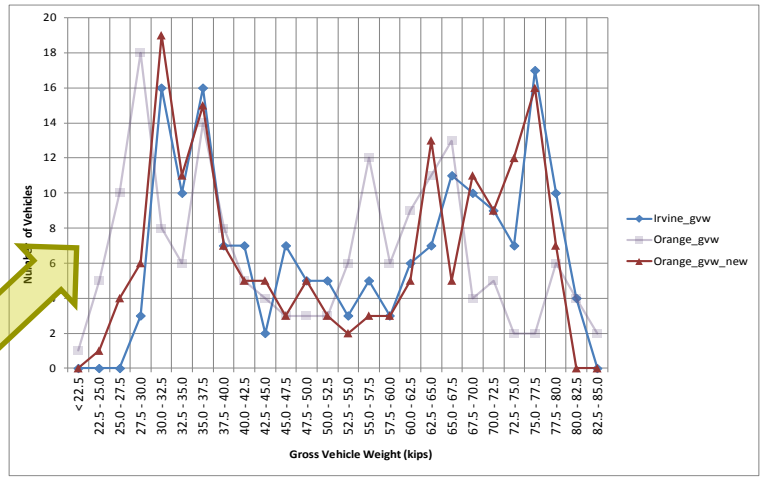
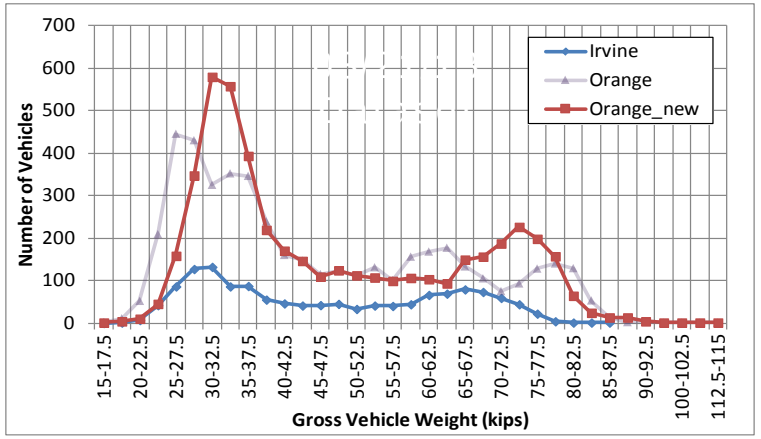
Approximate Calibration: GVW Distribution

The lane-based average offset can be directly derived from MVPs.



Before Calibration





After Calibration

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Conclusion

- The proposed approach has potential to fundamentally change the way WIM stations are operated and monitored in practices:
  - Provide a low-cost solution to keep track of truck movement
  - Provide truck movement data for WIM calibration
  - Identify out-of-calibration stations
  - Monitor the performance of the WIM station continuously
  - Perform temporary approximate calibration
- Future research will focus on
  - Developing a comprehensives remote WIM performance evaluation and calibration monitoring system
  - Field demonstration

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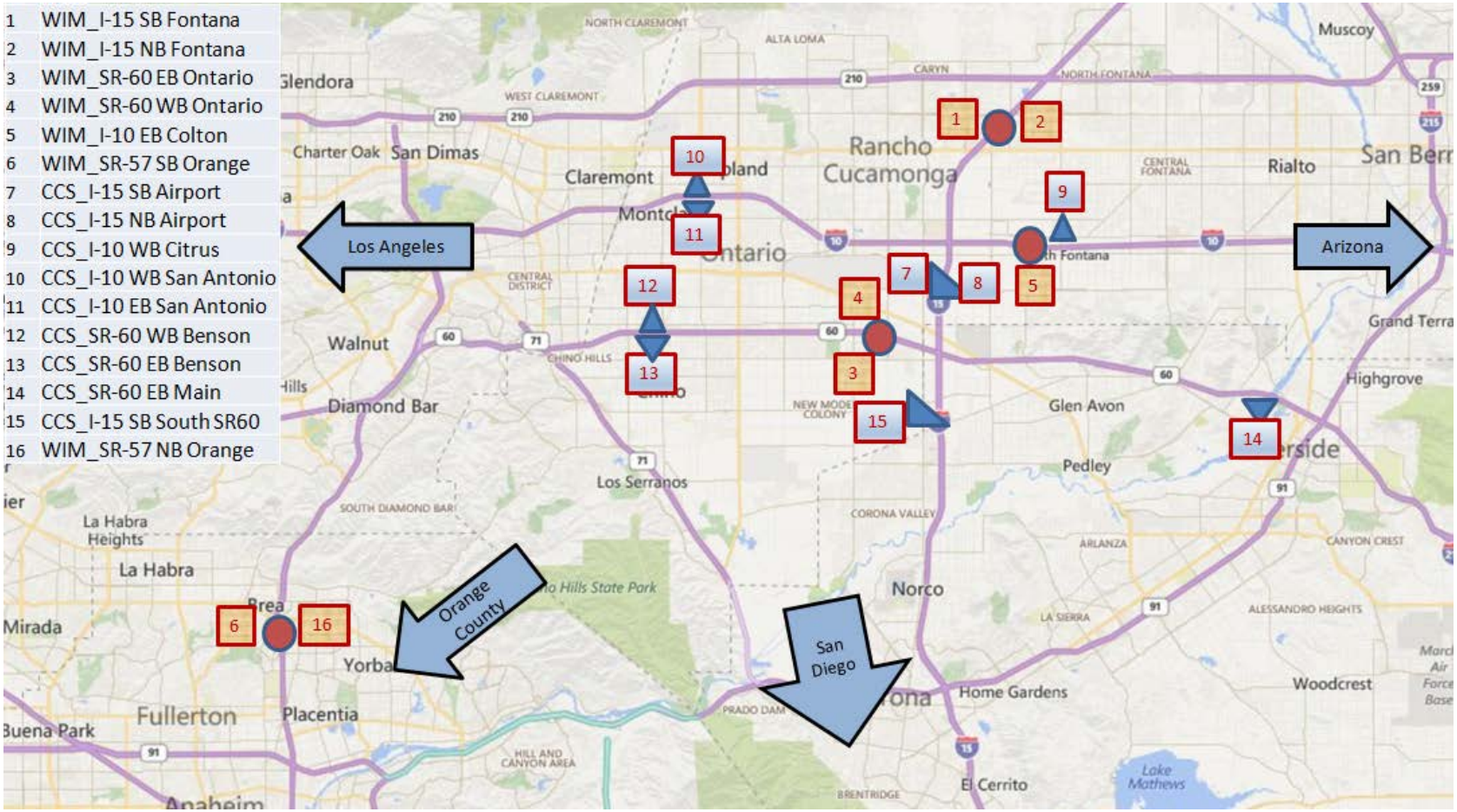
Ongoing Study: SBIR Phase 2

1	WIM_I-15 SB Fontana
2	WIM_I-15 NB Fontana
3	WIM_SR-60 EB Ontario
4	WIM_SR-60 WB Ontario
5	WIM_I-10 EB Colton
6	WIM_SR-57 SB Orange
7	CCS_I-15 SB Airport
8	CCS_I-15 NB Airport
9	CCS_I-10 WB Citrus
10	CCS_I-10 WB San Antonio
11	CCS_I-10 EB San Antonio
12	CCS_SR-60 WB Benson
13	CCS_SR-60 EB Benson
14	CCS_SR-60 EB Main
15	CCS_I-15 SB South SR60
16	WIM_SR-57 NB Orange



Applications and customers

- Traffic monitoring
- WIM stations calibration
- Heavy Vehicle OD data
- Freight: Better heavy vehicle classification and heavy vehicles tracking
- Pavement design based on heavy vehicles' load distribution in the highway system
- Environmental, better emission monitoring at vehicle detection stations and WIM stations
- Heavy Vehicle Safety
- Policy

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