WIM System Field Calibration and Validation Summary Report

Washington SPS-2
SHRP ID – 530200

Validation Date: May 2, 2012
Submitted: June 12, 2012

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1 Executive Summary

A WIM validation was performed on May 1 and 2, 2012 at the Washington SPS-2 site located on route US-395, milepost 93.0, 3.1 miles south of Interstate 90.

This site was installed on March 1, 1998. The in-road sensors are installed in the northbound, righthand driving lane. The site is equipped with half-lane quartz WIM sensors and an IRD 1060 Series WIM controller. The LTPP lane is identified as lane 1 in the WIM controller. From a comparison between the report of the most recent validation of this equipment on March 30, 2011 and this validation visit, it appears that no changes have occurred during this time to the basic operating condition of the equipment.

The equipment is in working order. Electronic and electrical checks of the WIM components determined that the the equipment is operating within the manufacturer's tolerances. None of the in-road sensors show signs of damage or excessive wear and appear to be fully secured in the pavement. Further equipment discussion is provided in Section 3.

During the on-site pavement evaluation, There were several pavement distresses noted that may affect the accuracies of the WIM system. A visual observation of the trucks as they approach, traverse, and leave the sensor area indicated several locations where truck bouncing occurred. The truck dynamics noted that are within the 400-foot approach section of the WIM scales may have affected the accuracy of the WIM system. The trucks appear to track down the center of the lane. Further pavement condition discussion is provided in Section 4.

Based on the criteria contained in the LTPP Field Operations Guide for SPS WIM Sites, Version 1.0 (05/09), this site is currently providing research quality loading data. However, weight measurement errors observed at this site are higher when compared with average errors observed at other SPS WIM sites. Based on pre-validation results, this site was not providing research quality data prior to May 2, 2012 calibration. The summary results of the validation are provided in Table 1-1 below.

Table 1-1 – Post-Validation Results – 2-May-12

Parameter	95% Confidence Limit of Error	Site Values	Pass/Fail
Steering Axles	±20 percent	-3.8 ± 11.9%	Pass
Tandem Axles	±15 percent	1.7 ± 12.1%	Pass
Tridem Axles	±15 percent	6.3 ± 8.2%	Pass
Axle Groups	±15 percent	2.8 ± 11.1%	Pass
GVW	±10 percent	2.1 ± 7.7%	Pass
Vehicle Length	±3.0 percent (1.9 ft)	0.0 ± 0.8 ft	Pass
Axle Length	± 0.5 ft [150mm]	0.0 ± 0.1 ft	Pass

Truck speeds were manually collected for each test run by a radar gun and compared with the speed reported by the WIM equipment. For this site, the error in speed measurement was -0.2 ± 2.5 mph, which is greater than the ±1.0 mph tolerance established by the LTPP Field Operations Guide for SPS WIM Sites. However, since the site is measuring axle spacing length with a mean error of 0.0 feet, and the speed and axle spacing measurements are based on the distance between the axle detector sensors, it can be concluded that the distance factor is set correctly and that the speeds being reported by the WIM equipment are within acceptable ranges.

This site is providing research quality vehicle classification data for heavy trucks (Class 6 – 13). The heavy truck misclassification rate of 1.2% is within the 2.0% acceptability criterion for LTPP SPS WIM sites. The overall misclassification rate of 12.8% from the 109 vehicle sample (Class 4 – 13) was due to the 13 cross-classifications of Class 3, 4, 5, and 8 vehicles.

There were two test trucks used for the post-validation. They were configured and loaded as follows:

- The Primary truck was a Class 9 vehicle with air suspension on the tractor and trailer tandems, and standard (4 feet) tandem spacings. It was loaded with concrete blocks.

- The Secondary truck was a Class 10 vehicle with air suspension on the tractor tandem, air suspension on the tractor tandem, and a tridem on the trailer. The Secondary truck was loaded with palletized bags of silicone.

Prior to the validation, the test trucks were weighed and measured, cold tire pressures were taken, and photographs of the trucks, loads and suspensions were obtained (see Section 7). Axle length (AL) was measured from the center hub of the first axle to the center hub of the last axle. Axle spacings were measured from the center hub of the each axle to the center hub of the subsequent axle. Overall length (OL) was measured from the edge of the front bumper to the edge of the rear bumper. The test trucks were re-weighed at the conclusion of the validation. The average post-validation test truck weights and measurements are provided in Table 1-2.

Table 1-2 – Post-Validation Test Truck Measurements

Test Truck	Weights (kips)							Spacings (feet)						
	GVW	Ax1	Ax2	Ax3	Ax4	Ax5	Ax6	1-2	2-3	3-4	4-5	5-6	AL	OL
1	75.6	11.9	15.7	15.6	16.2	16.4		18.3	4.3	29.3	4.0		55.9	62.3
2	65.4	11.5	12.7	12.6	11.0	9.3	8.3	18.2	4.2	25.3	4.8	5.2	57.7	63.8

The posted speed limit at the site is 60 mph. During the testing, the speed of the test trucks ranged from to 47 to 59 mph, a variance of 12 mph.

During test truck runs, pavement temperature was collected using a hand-held infrared temperature device. The post-validation pavement surface temperatures varied from 44.4 to 82.5 degrees Fahrenheit, a range of 38.1 degrees Fahrenheit. The weather conditions provided the desired 30 degree range in temperatures.

A review of the LTPP Standard Release Database 25 shows that there are 4 years of level “E” WIM data for this site. This site requires 1 more year of data to meet the minimum of five years of research quality data.

2 WIM System Data Availability and Pre-Visit Data Analysis

To assess the quality of the current traffic data, a pre-visit analysis was conducted by comparing a two-week data sample from April 14, 2012 (Data) to the most recent Comparison Data Set (CDS) from April 14, 2011. The assessments performed prior to the site visits are used to develop reasonable expectations for the validation. The results of further investigations performed as a result of the analyses are provided in Section 5 of this report.

2.1 LTPP WIM Data Availability

A review of the LTPP Standard Release Database 26 shows that there are 4 years of level “E” WIM data for this site. Table 2-1 provides a breakdown of the available data for years 2006 to 2011.

Table 2-1 – LTPP Data Availability

Year	Total Number of Days in Year of Level E Data	Number of Months
2006	31	1
2007	365	12
2008	343	12
2009	363	12
2010	346	12
2011	204	8

As shown in the table, this site requires 1 additional year of data to meet the minimum of five years of research quality data (requiring 210 days of data per year). Reporting of data in the next data release may provide for a complete year of data for 2011.

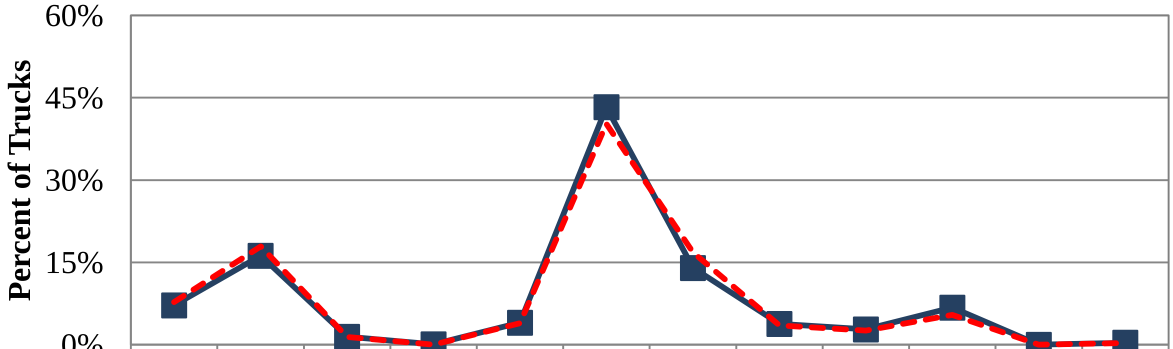
Table 2-2 provides a monthly breakdown of the available data for years 2006 through 2011.

Table 2-2 – LTPP Data Availability by Month

Year	Month												No. of Months
	1	2	3	4	5	6	7	8	9	10	11	12	
2006												31	1
2007	31	28	31	30	31	30	31	31	30	31	30	31	12
2008	31	29	31	30	31	24	24	31	30	21	30	31	12
2009	31	28	30	29	31	30	31	31	30	31	30	31	12
2010	31	28	16	30	31	30	31	31	30	30	29	29	12
2011	31	23	19	14	31	30	31	25					8

2.2 Classification Data Analysis

The traffic data was analyzed to determine the expected truck distributions. This analysis provides a basis for the classification distribution study that was conducted on site. Figure 2-1 provides a comparison of the truck type distributions for the two datasets.



	4	5	6	7	8	9	10	11	12	13	14	15
Data	7.2%	16.2%	1.5%	0.1%	4.0%	43.3%	14.0%	3.8%	2.8%	6.8%	0.0%	0.4%
CDS	7.8%	17.9%	1.4%	0.0%	3.9%	40.3%	16.8%	3.5%	2.6%	5.4%	0.0%	0.3%

Figure 2-1 – Comparison of Truck Distribution

Table 2-3 provides statistics for the truck distributions at the site for the two periods represented by the two datasets. The table shows that according to the most recent data, the most frequent truck types crossing the WIM scale are Class 9 (43.3%) and Class 5 (16.2%). Table 2-3 also provides data for vehicle Classes 14 and 15. Class 14 vehicles are vehicles that are reported by the WIM equipment as having irregular measurements and cannot be classified properly, such as negative speeds from vehicles passing in the opposite direction of a two-lane road. Class 15 vehicles are unclassified vehicles. The table indicates that 0% percent of the vehicles at this site were unclassified.

Table 2-3 – Truck Distribution from W-Card

Vehicle Classification	CDS		Data		Change
	Date				
	4/14/2011		4/14/2012		
4	625	7.8%	1945	7.1%	-0.7%
5	1434	17.9%	4498	16.4%	-1.5%
6	115	1.4%	454	1.7%	0.2%
7	4	0.0%	26	0.1%	0.0%
8	313	3.9%	1129	4.1%	0.2%
9	3226	40.3%	11849	43.1%	2.8%
10	1346	16.8%	3761	13.7%	-3.1%
11	281	3.5%	1019	3.7%	0.2%
12	208	2.6%	781	2.8%	0.2%
13	436	5.4%	1932	7.0%	1.6%
14	0	0.0%	0	0.0%	0.0%
15	23	0.3%	116	0.4%	0.1%

From the table it can be seen that the number of Class 9 vehicles has increased by 2.8 percent from April 2011 and April 2012. Changes in the percentage of heavier trucks may be attributed to natural and seasonal variations in truck distributions and an increase in goods movement during current economic cycle. During the same time period, the number of Class 5 trucks decreased by 1.5 percent. These differences may be attributed to changes in the use of the roadway for local deliveries, cross-classifications of type 3 and 5 vehicles, as well as natural variations in truck volumes.

2.3 Speed Data Analysis

The traffic data received from the Phase II Contractor was analyzed to determine the expected truck speed distributions. This will provide a basis for determining the speed of the test trucks during validation testing. The CDS distribution of speeds is shown in Figure 2-2.

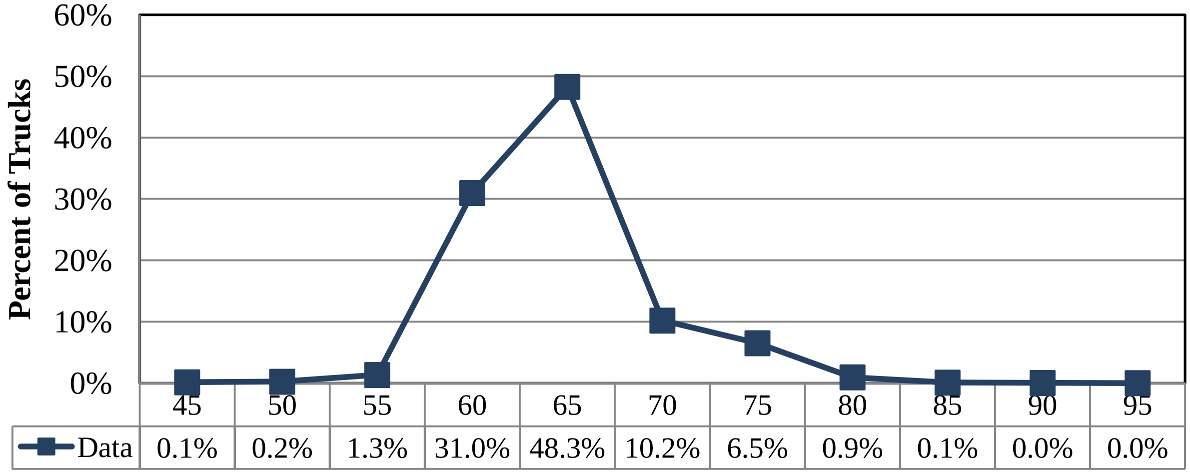


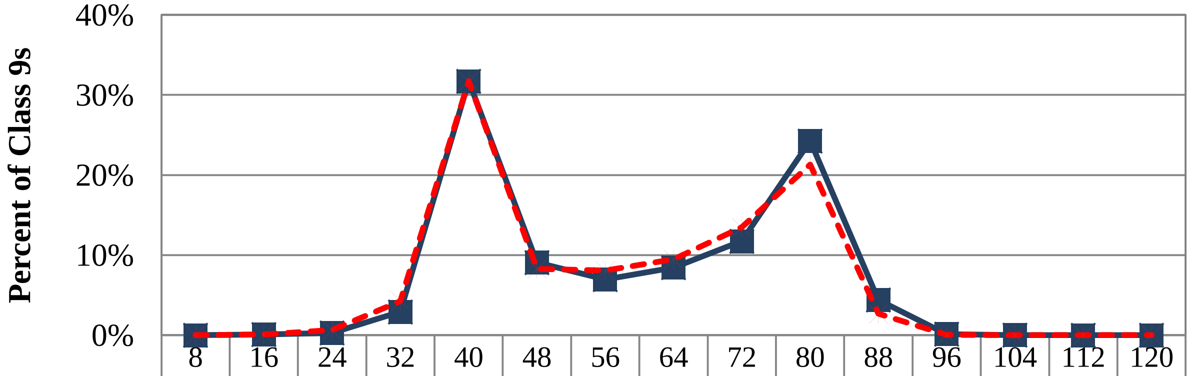
Figure 2-2 – Truck Speed Distribution – 1-Apr-12

As shown in Figure 2-2, the majority of the trucks at this site are traveling between 60 and 70 mph. The posted speed limit at this site is 60 mph and the 85th percentile speed for trucks at this site is 67 mph. Based on the pre-visit analysis, the expected range of test truck speeds was 50 to 60 mph.

2.4 GVW Data Analysis

The traffic CDS data received from the Regional Support Contractor was analyzed to determine the expected Class 9 GVW distributions. Figure 2-3 shows a comparison between GVW plots generated using a two-week W-card sample from April 2012 and the Comparison Data Set from April 2011.

As shown in Figure 2-3, there is an upward shift for the loaded peak between the April 2011 Comparison Data Set (CDS) and the April 2012 two-week sample W-card dataset (Data). The results indicate that there may have been a small change in the types of commodity being transported by trucks traveling over the WIM system, a possible positive bias (overestimation of loads), or pavement condition or sensor deterioration.



	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120
Data	0.0%	0.1%	0.3%	2.9%	31.7	9.1%	7.0%	8.4%	11.7	24.3	4.4%	0.1%	0.0%	0.0%	0.0%
CDS	0.0%	0.1%	0.6%	4.2%	31.7	8.3%	8.1%	9.5%	13.5	21.3	2.7%	0.0%	0.0%	0.0%	0.0%

Figure 2-3 – Comparison of Class 9 GVW Distribution

Table 2-4 is provided to show the statistical comparison for Class 9 GVW between the Comparison Data Set and the current dataset.

Table 2-4 – Class 9 GVW Distribution from W-Card

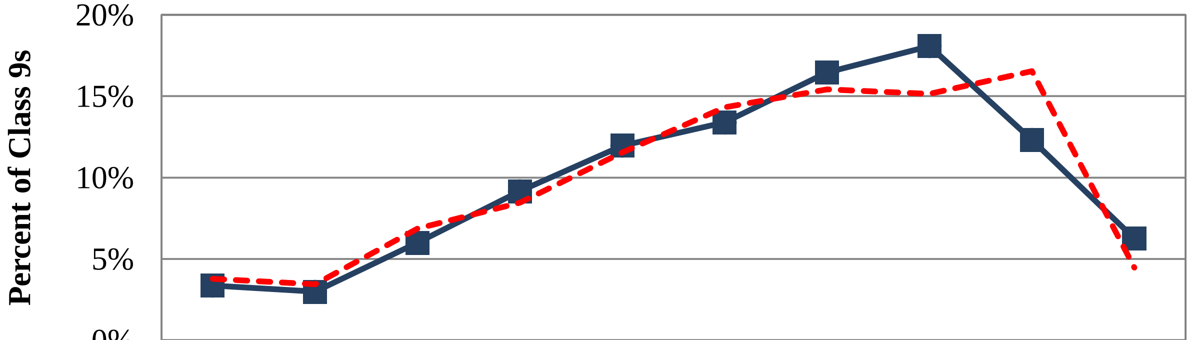
GVW weight bins (kips)	CDS		Data		Change
	Date				
	4/14/2011		4/14/2012		
8	0	0.0%	0	0.0%	0.0%
16	4	0.1%	12	0.1%	0.0%
24	26	0.6%	48	0.3%	-0.3%
32	174	4.2%	409	2.7%	-1.5%
40	1299	31.7%	4729	31.7%	-0.1%
48	339	8.3%	1326	8.9%	0.6%
56	330	8.1%	1083	7.2%	-0.8%
64	388	9.5%	1279	8.6%	-0.9%
72	552	13.5%	1790	12.0%	-1.5%
80	873	21.3%	3558	23.8%	2.5%
88	109	2.7%	685	4.6%	1.9%
96	2	0.0%	17	0.1%	0.1%
104	0	0.0%	5	0.0%	0.0%
112	0	0.0%	0	0.0%	0.0%
120	0	0.0%	0	0.0%	0.0%
Average =	58.4 kips		58.7 kips		0.3 kips

As shown in the table, the number of unloaded class 9 trucks in the 32 to 40 kips range decreased by 0.1 percent while the number of loaded class 9 trucks in the 72 to 80 kips range increased by 2.5 percent. During this time period, the number of overweight trucks increased by 2.0 percent. Based on the average Class 9 GVW values from the per vehicle records, the GVW average for this site increased by 0.5 percent, from 58.4 to 58.7 kips.

2.5 Class 9 Front Axle Weight Data Analysis

The CDS data received from the Regional Support Contractor was analyzed to determine the expected average front axle weight. This will provide a basis for the evaluation of the quality of the data by comparing the average front axle weight from the current data sample set with the expected average front axle weight average from the Data Comparison Set.

Figure 2-4 shows a comparison between Class 9 front axle weight plots generated by using the two week W-card sample from April 2012 and the Comparison Data Set from April 2011. The percentages of light axles (9.5 to 10.5 kips) decreased by approximately 0.2% and the percentages of heavy axles (11.5 to 12.5 kips) increased by approximately 3.9%.



	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5
Data	3.4%	3.0%	6.0%	9.2%	12.0%	13.4%	16.5%	18.1%	12.3%	6.3%
CDS	3.8%	3.5%	6.9%	8.5%	11.5%	14.3%	15.4%	15.1%	16.5%	4.5%

Figure 2-4 – Distribution of Class 9 Front Axle Weights

It can be seen in the figure that the greatest percentage of trucks have front axle weights measuring between 12.0 and 13.0 kips. The percentage of trucks in this range has decreased by 1.3% between the April 2011 Comparison Data Set (CDS) and the April 2012 dataset (Data), indicating a possible negative (underestimation) of front axle weights.

Table 2-5 provides the Class 9 front axle weight distribution data for the April 2011 Comparison Data Set (CDS) and the April 2012 dataset (Data).

Table 2-5 – Class 9 Front Axle Weight Distribution from W-Card

F/A weight bins (kips)	CDS		Data		Change
	Date				
	4/1/2011		4/1/2012		
9.0	127	3.8%	114	3.4%	-0.4%
9.5	116	3.5%	101	3.0%	-0.5%
10.0	231	6.9%	203	6.0%	-0.9%
10.5	284	8.5%	310	9.2%	0.7%
11.0	388	11.5%	405	12.0%	0.4%
11.5	481	14.3%	453	13.4%	-0.9%
12.0	518	15.4%	557	16.5%	1.0%
12.5	509	15.1%	612	18.1%	2.9%
13.0	556	16.5%	417	12.3%	-4.2%
13.5	150	4.5%	212	6.3%	1.8%
Average =	11.3 kips		11.4 kips		0.1 kips

The table shows that the average front axle weight for Class 9 trucks has increased by 0.1 kips, or 0.9 percent. According to the values from the per vehicle records, the average front axle weight for Class 9 trucks is 11.4 kips.

2.6 Class 9 Tractor Tandem Spacing Data Analysis

The CDS data received from the Regional Support Contractor was analyzed to determine the expected average tractor tandem spacing. This will provide a basis for the evaluation of the accuracy of the equipment distance and speed measurements by comparing the observed average tractor tandem spacing from the sample data (Data) with the expected average tractor tandem spacing from the comparison data set (CDS).

The class 9 tractor tandem spacing plot in Figure 2-5 is provided to indicate possible shifts in WIM system distance and speed measurement accuracies.

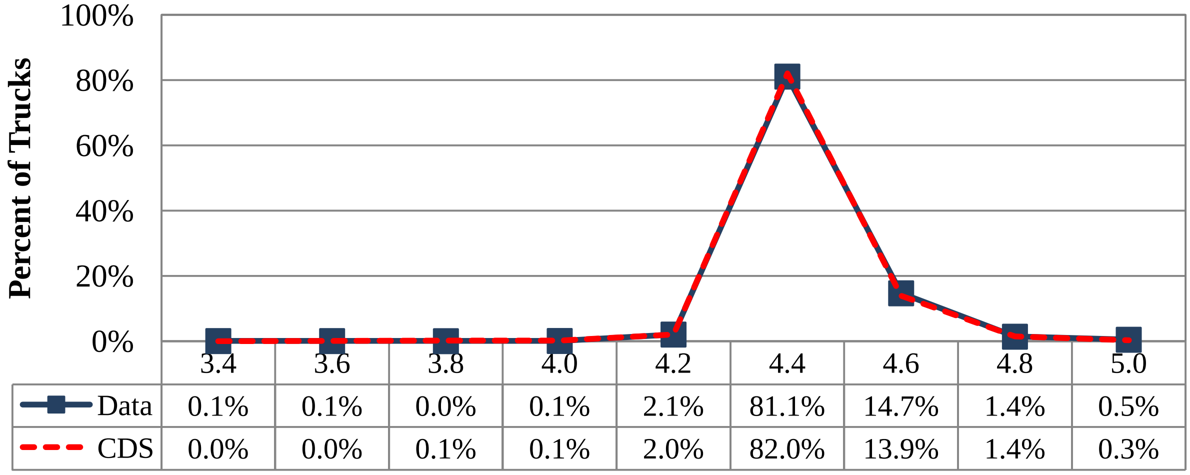


Figure 2-5 – Comparison of Class 9 Tractor Tandem Spacing

As seen in the figure, the Class 9 tractor tandem spacings for the April 2011 Comparison Data Set and the April 2012 Data are nearly identical.

Table 2-6 shows the Class 9 axle spacings between the second and third axles.   .

Table 2-6 – Class 9 Axle 2 to 3 Spacing from W-Card

Tandem 1 spacing bins (feet)	CDS		Data		Change
	Date				
	4/14/2011		4/14/2012		
3.0	0	0.0%	0	0.0%	0.0%
3.2	0	0.0%	0	0.0%	0.0%
3.4	2	0.1%	0	0.0%	-0.1%
3.6	2	0.1%	1	0.0%	0.0%
3.8	1	0.0%	5	0.1%	0.1%
4.0	3	0.1%	5	0.1%	0.1%
4.2	66	2.1%	71	2.0%	0.0%
4.4	2604	81.1%	2856	82.0%	0.9%
4.6	472	14.7%	483	13.9%	-0.8%
4.8	45	1.4%	50	1.4%	0.0%
5.0	15	0.5%	10	0.3%	-0.2%
Average =	4.3 feet		4.3 feet		0.0 feet

From the table it can be seen that the drive tandem spacing of Class 9 trucks at this site is between 4.2 and 4.6 feet. Based on the average Class 9 drive tandem spacing values from the per vehicle records, the average tractor tandem spacing is 4.3, which is identical to to the expected average of 4.3 from the CDS per vehicle records. Further axle spacing analyses are performed during the validation and post-validation analysis.

2.7 Data Analysis Summary

Historical data analysis involved the comparison of the most recent Comparison Data Set (April 2011) based on the last calibration with the most recent two-week WIM data sample from the site (April 2012). Comparison of vehicle class distribution data indicates a 2.8 percent increase in the number of Class 9 vehicles. Analysis of Class 9 weight data indicates that front axle weights have increased by 0.9 percent and average Class 9 GVW has increased by 0.5 percent for the April 2012 data. The data indicates an average truck tandem spacing of 4.3, which is identical to the expected average of 4.3.

3 WIM Equipment Discussion

From a comparison between the report of the most recent validation of this equipment on March 30, 2011 and this validation visit, it appears that no changes have occurred during this time to the basic operating condition of the equipment.

3.1 Description

This site was installed on March 1, 1998 by the Washington DOT. It is instrumented with half-lane quartz weighing sensors and an IRD 1060 Series WIM Controller. The Washington DOT also performs routine equipment maintenance and data quality checks of the WIM data.

3.2 Physical Inspection

Prior to the pre-validation test truck runs, a physical inspection of all WIM equipment and support services equipment was conducted. No deficiencies were noted. Photographs of all system components were taken and are presented after Section 7.

3.3 Electronic and Electrical Testing

Electronic and electrical checks of all system components were conducted prior to the pre-validation test truck runs. Dynamic and static electronic checks of the in-road sensors were performed. Electronic tests of the power and communication devices indicated that they were operating normally.

3.4 Equipment Troubleshooting and Diagnostics

The WIM system appeared to collect, analyze and report vehicle measurements normally. No troubleshooting actions were taken.

3.5 Recommended Equipment Maintenance

No unscheduled equipment maintenance actions are recommended.

4 Pavement Discussion

4.1 Pavement Condition Survey

During the pavement condition survey conducted from the shoulder, the distress shown in Photo 4-1 was noted at a location 679 feet prior to the WIM scales. As shown in the photo, high severity transverse cracking extending across the length of the slab was noted at this location. Adverse truck dynamics observed in this area were outside of the 400-foot approach section and did not appear to affect the accuracy of the WIM sensors.

Photo 4-1 – Pavement Distress 679 Feet Prior to WIM

4.2 Profile and Vehicle Interaction

Profile data was collected on February 11, 2012 by the Western Regional Support Contractor using a high-speed profiler, where the operator measures the pavement profile over the entire one-thousand foot long WIM Section, beginning 900 feet prior to WIM scales and ending 100 feet after the WIM scales. Each pass collects International Roughness Index (IRI) values in both the left and right wheel paths. For this site, 10 profile passes were made, 4 in the center of the travel lane and 6 that were shifted to the left and to the right of the center of the travel lane.

From a pre-visit review of the IRI values for the center, right, and left profile runs, the highest IRI value within the 1000 foot WIM section is 150 in/mi and is located approximately 679 feet prior to the WIM scale. The highest IRI value within the 400 foot approach section was 101 in/mi and is located approximately 393 feet prior to the WIM scale. These areas of the pavement were closely investigated during the validation visit, and truck dynamics in this area were closely observed.

Additionally, a visual observation of the trucks as they approach, traverse and leave the sensor area indicated slight truck bouncing which may have affected the accuracy of the WIM scale. Trucks appear to track down the center of the lane.

4.3 LTPP Pavement Profile Data Analysis

The IRI data files are processed using the WIM Smoothness Index software. The indices produced by the software provide an indication of whether or not the pavement roughness may affect the operation of the WIM equipment. The recommended thresholds for WIM Site pavement smoothness are provided in Table 4-1.

Table 4-1 – Recommended WIM Smoothness Index Thresholds

Index	Lower Threshold (m/km)	Upper Threshold (m/km)
Long Range Index (LRI)	0.50	2.1
Short Range Index (SRI)	0.50	2.1
Peak LRI	0.50	2.1
Peak SRI	0.75	2.9

When all values are less than the lower threshold shown in Table 4-1, it is unlikely that pavement conditions will significantly influence sensor output. Values between the threshold values may or may not influence the accuracy of the sensor output and values above the upper threshold would lead to sensor output that would preclude achieving the research quality loading data.

The profile analysis was based on four different indices: Long Range Index (LRI), which represents the pavement roughness starting 25.8 m prior to the scale and ending 3.2 m after the scale in the direction of travel; Short Range Index (SRI), which represents the pavement roughness beginning 2.74 m prior to the WIM scale and ending 0.46 m after the scale; Peak LRI – the highest value of LRI within 30 m prior to the scale; and Peak SRI – the highest value of SRI between 2.45 m prior to the scale and 1.5 m after the scale. The results from the analysis for each of the indices for the right wheel path (RWP) and left wheel path (LWP) values for the 3 left, 3 right and 4 center profiler runs are presented in Table 4-2.

Table 4-2 – WIM Index Values

Profiler Passes			**Pass 1**	**Pass 2**	**Pass 3**	**Pass 4**	**Pass 5**	**Avg**
Left	LWP	LRI (m/km)	1.023	1.030	0.898			0.984
		SRI (m/km)	0.508	0.617	0.409			0.511
		Peak LRI (m/km)	1.124	1.127	0.987			1.079
		Peak SRI (m/km)	1.177	0.957	0.892			1.009
	RWP	LRI (m/km)	1.081	1.047	0.970			1.033
		SRI (m/km)	0.780	0.885	0.417			0.694
		Peak LRI (m/km)	1.199	1.093	1.060			1.117
		Peak SRI (m/km)	0.815	0.943	0.996			0.918
Center	LWP	LRI (m/km)	1.229	1.275	1.157	1.178		1.210
		SRI (m/km)	1.397	1.445	1.396	0.776		1.254
		Peak LRI (m/km)	1.276	1.313	1.239	1.192		1.255
		Peak SRI (m/km)	1.482	1.447	1.478	1.004		1.353
	RWP	LRI (m/km)	1.138	1.088	1.144	1.050		1.105
		SRI (m/km)	0.721	0.675	0.859	0.701		0.739
		Peak LRI (m/km)	1.296	1.402	1.262	1.336		1.324
		Peak SRI (m/km)	0.929	0.786	0.903	0.868		0.872
Right	LWP	LRI (m/km)	0.868	0.752	0.872			0.831
		SRI (m/km)	0.595	0.450	0.579			0.541
		Peak LRI (m/km)	0.899	0.967	0.953			0.940
		Peak SRI (m/km)	*0.598*	*0.466*	*0.602*			*0.555*
	RWP	LRI (m/km)	1.004	0.990	1.433			1.142
		SRI (m/km)	0.524	0.455	0.683			0.554
		Peak LRI (m/km)	**1.152**	**1.448**	**1.511**			**1.370**
		Peak SRI (m/km)	*0.615*	*0.493*	0.948			*0.685*

From Table 4-2 it can be seen that most of the indices computed from the profiles are between the upper and lower threshold values, with the remaining values under the lower threshold. Indices that are below the lower thresholds are shown in italics and indices above the upper thresholds are shown in bold. The highest values, on average, are the Peak LRI values in the right wheel path of the right shift passes (shown in bold and italics).

4.4 Recommended Pavement Remediation

Remediation in the pavement area 679 prior to the WIM scales, where severe transverse cracking was noted, is recommended.

5 Statistical Reliability of the WIM Equipment

The following section provides summaries of data collected during the pre-validation, the calibration, and the post-validation test truck runs, as well as information resulting from the classification and speed studies. All analyses of test truck data and information on necessary equipment adjustments are provided.

5.1 Pre-Validation

The first set of test runs provides a general overview of system performance prior to any calibration adjustments for the given environmental, vehicle speed and other conditions.

The 40 pre-validation test truck runs were conducted on May 1, 2012, beginning at approximately 8:51 AM and continuing until 4:41 PM.

The two test trucks consisted of:

- A Class 9 truck, loaded with concrete blocks, and equipped with air suspension on truck and trailer tandems and with standard tandem spacings on both the tractor and trailer.
- A Class 10 truck, loaded with palletized bagged silicone, and equipped with air suspension on truck tandem with standard tandem spacing, and a tridem on the trailer.

The test trucks were weighed prior to the pre-validation and were re-weighed at the conclusion of the pre-validation. The average test truck weights and measurements are provided in Table 5-1.

Table 5-1 – Pre-Validation Test Truck Weights and Measurements

Test Truck	Weights (kips)							Spacings (feet)						
	GVW	Ax1	Ax2	Ax3	Ax4	Ax5	Ax6	1-2	2-3	3-4	4-5	5-6	AL	OL
1	76.0	11.8	15.7	15.8	16.3	16.4		18.3	4.3	29.3	4.0		55.9	62.3
2	65.0	11.4	12.5	12.4	10.7	9.3	8.7	18.2	4.2	25.3	4.8	5.2	57.7	63.8

Test truck speeds varied by 13 mph, from 46 to 59 mph. The measured pre-validation pavement temperatures varied 21.9 degrees Fahrenheit, from 56.6 to 78.5. The weather conditions prevented the desired 30 degree temperature range. Table 5-2 provides a summary of the pre-validation results.

As shown in Table 5-2, the site did not meet LTPP requirements for measurement error of tridem axles, axle groups, and GVW as a result of the pre-validation test truck runs. In addition, positive bias in tridem, GVW and axle group measurement errors deviate from zero by more than 5.0 percent.

Table 5-2 – Pre-Validation Overall Results – 1-May-12

Parameter	95% Confidence Limit of Error	Site Values	Pass/Fail
Steering Axles	±20 percent	1.0 ± 14.5%	Pass
Tandem Axles	±15 percent	4.3 ± 10.6%	Pass
Tridem Axles	±15 percent	8.2 ± 11.5%	FAIL
Axle Groups	±15 percent	5.3 ± 10.8%	FAIL
GVW	±10 percent	5.1 ± 7.6%	FAIL
Vehicle Length	±3.0 percent (1.9 ft)	0.0 ± 0.8 ft	Pass
Axle Length	± 0.5 ft [150mm]	-0.1 ± 0.1 ft	Pass

Truck speed was manually collected for each test run using a radar gun and compared with the speed reported by the WIM equipment. For this site, the average error in speed measurement over all speeds was -1.0 ± 4.2 mph, which is greater than the ±1.0 mph tolerance established by the LTPP Field Guide. However, since the site is measuring axle spacing length with a mean error of -0.1 feet, and the speed and axle spacing measurements are based on the distance between the axle detector sensors, it can be concluded that the distance factor is set correctly and that the speeds being reported by the WIM equipment are within similar acceptable ranges.

5.1.1 Statistical Speed Analysis

Statistical analysis was conducted on the test truck run data to investigate whether a relationship exists between speed and WIM equipment weight and distance measurement accuracy. The posted speed limit at this site is 60 mph. The test runs were divided into three speed groups - low, medium and high speeds, as shown in Table 5-3.

Table 5-3 – Pre-Validation Results by Speed – 1-May-12

Parameter	95% Confidence Limit of Error	Low	Medium	High
		46.0 to 50.3 mph	50.4 to 54.8 mph	54.9 to 59.0 mph
Steering Axles	±20 percent	3.4 ± 14.3%	-2.7 ± 17.9%	1.3 ± 13.4%
Tandem Axles	±15 percent	5.3 ± 10.5%	4.0 ± 9.8%	3.4 ± 14.6%
Tridem Axles	±15 percent	10.8 ± 8.4%	10.9 ± 9.7%	3.2 ± 13.0%
Axle Groups	±15 percent	6.7 ± 10.0%	5.8 ± 9.8%	3.4 ± 14.2%
GVW	±10 percent	6.5 ± 8.8%	5.1 ± 7.2%	3.5 ± 7.1%
Vehicle Length	±3.0 percent (1.9 ft)	-0.1 ± 0.8 ft	0.1 ± 0.7 ft	0.1 ± 1.0 ft
Vehicle Speed	± 1.0 mph	-0.1 ± 0.1 mph	-0.1 ± 0.1 mph	-0.1 ± 0.1 mph
Axle Length	± 0.5 ft [150mm]	-1.7 ± 6.7 ft	-0.8 ± 1.9 ft	-0.5 ± 2.5 ft

From the table, it can be seen that, on average, the WIM equipment generally overestimates all weights at all speeds. For steering axles, the range in error appears to be greatest at the medium speeds. For all axle groups the range in error is greater at the higher speeds. For GVW, the range in error is consistent throughout the entire speed range.

To aid in the speed analysis, several graphs were developed to illustrate the possible effects of speed on GVW, single axle, and axle group weights, and axle and overall length distance measurements, as discussed in the following sections.

5.1.1.1 GVW Errors by Speed

As shown in Figure 5-1, the WIM equipment positive bias for GVW is greatest at the lower speeds and decreases as speed increases. The range in error is lower at the medium speeds than low and high speeds.

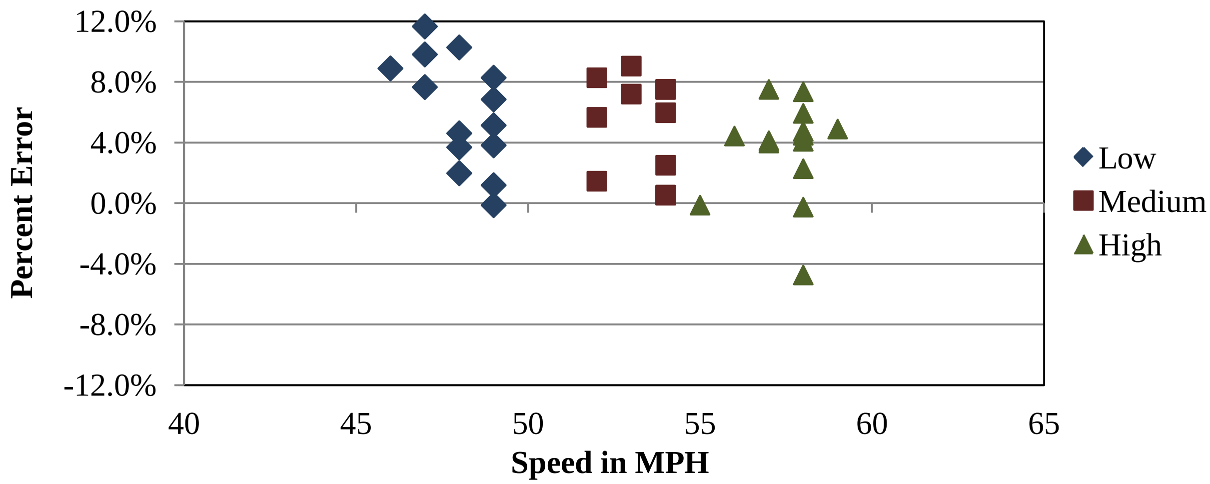


Figure 5-1 – Pre-Validation GVW Error by Speed – 1-May-12

5.1.1.2 Steering Axle Weight Errors by Speed

As shown in Figure 5-2, the equipment estimates steering axle weights with similar bias at all speeds. The range in error is similar throughout the entire speed range.

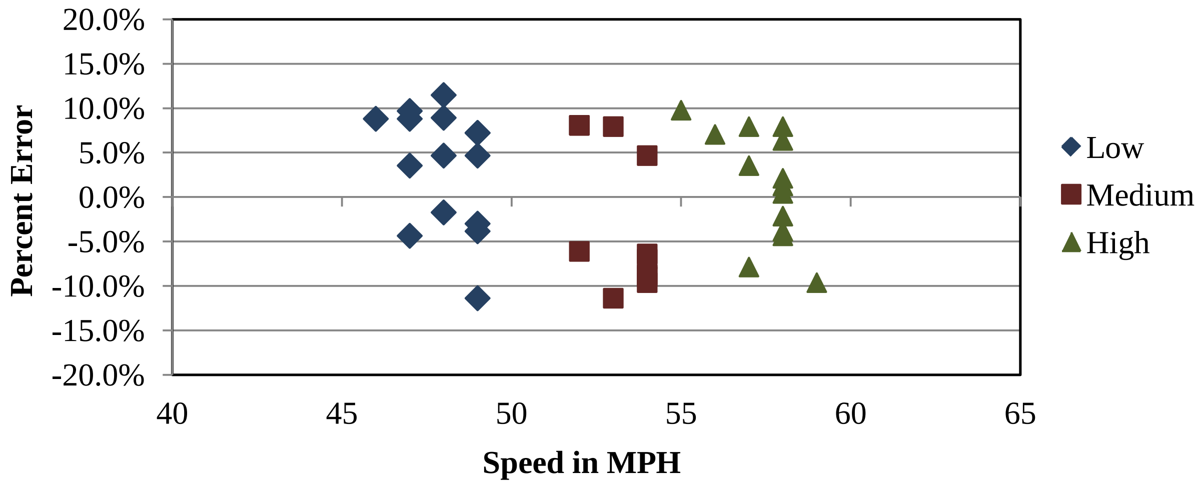


Figure 5-2 – Pre-Validation Steering Axle Weight Errors by Speed – 1-May-12

5.1.1.3 Tandem Axle Weight Errors by Speed

As shown in Figure 5-3, the WIM equipment positive bias for tandem axles is greatest at the lower speeds and decreases as speed increases. The range in error is greater at high speeds when compared to low and medium speeds.

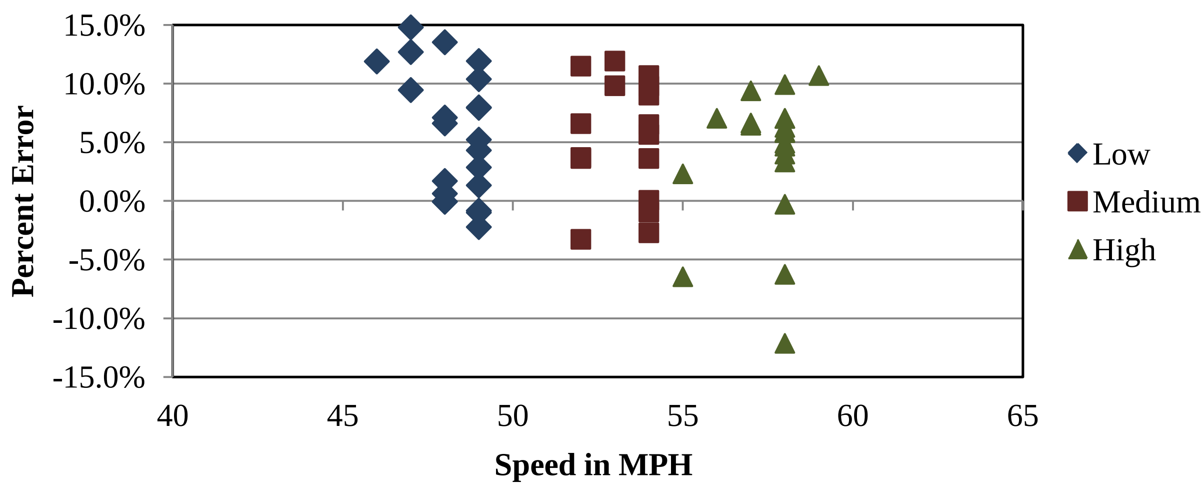


Figure 5-3 – Pre-Validation Tandem Axle Weight Errors by Speed – 1-May-12

5.1.1.4 Tridem Axle Weight Errors by Speed

As shown in Figure 5-4, the WIM equipment overestimates tridem axle weights with greater bias at the lower speeds and medium speeds when compared with the high speeds. The range in error is greater at the high speeds.

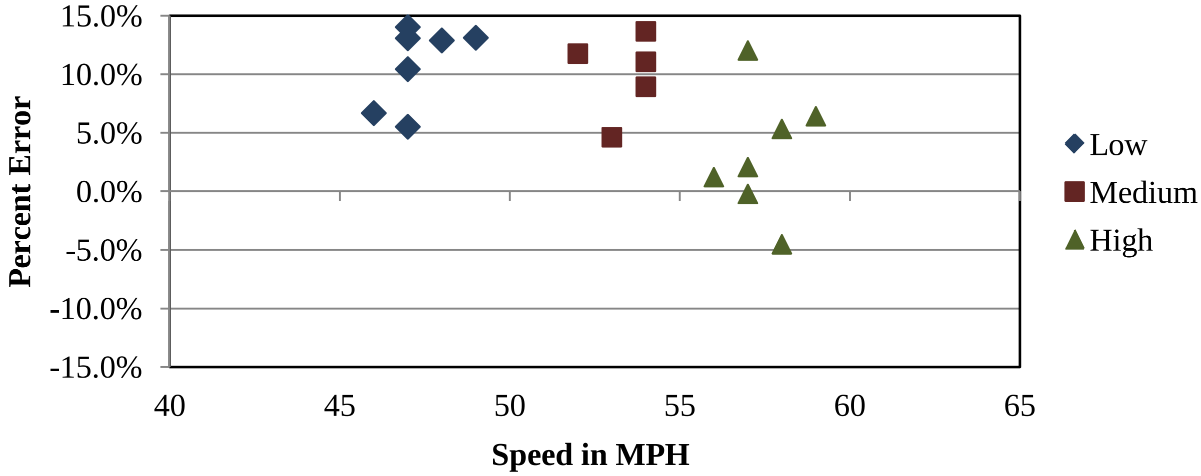


Figure 5-4 – Pre-Validation Tridem Axle Weight Errors by Speed – 1-May-12

5.1.1.5 Axle Group Errors by Speed and Truck Type

As shown in Figure 5-6, the WIM equipment positive bias for axle groups is greatest at the lower speeds and decreases as speed increases. The range in error is greater at high speeds when compared to low and medium speeds.

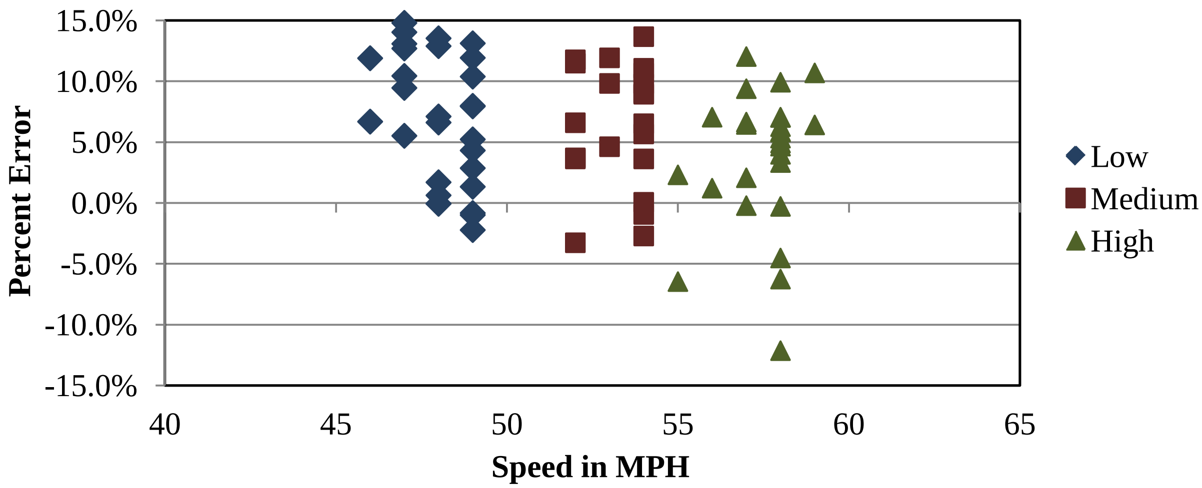


Figure 5-5 – Pre-Validation Axle Group Errors by Truck and Speed – 1-May-12

5.1.1.6 GVW Errors by Speed and Truck Type

When the GVW error for each truck is analyzed as a function of speed, it can be seen that the WIM equipment overestimated GVW for the partially loaded (Secondary) truck to a greater degree than the heavily loaded (Primary) truck. The WIM equipment positive bias for the partially loaded (Secondary) truck is greater at lower speeds and follows a downward trend with an increase in speed. The range in errors is lower for the partially loaded (Secondary) truck than the heavily loaded (Primary) truck. Distribution of errors is shown graphically in Figure 5-6.

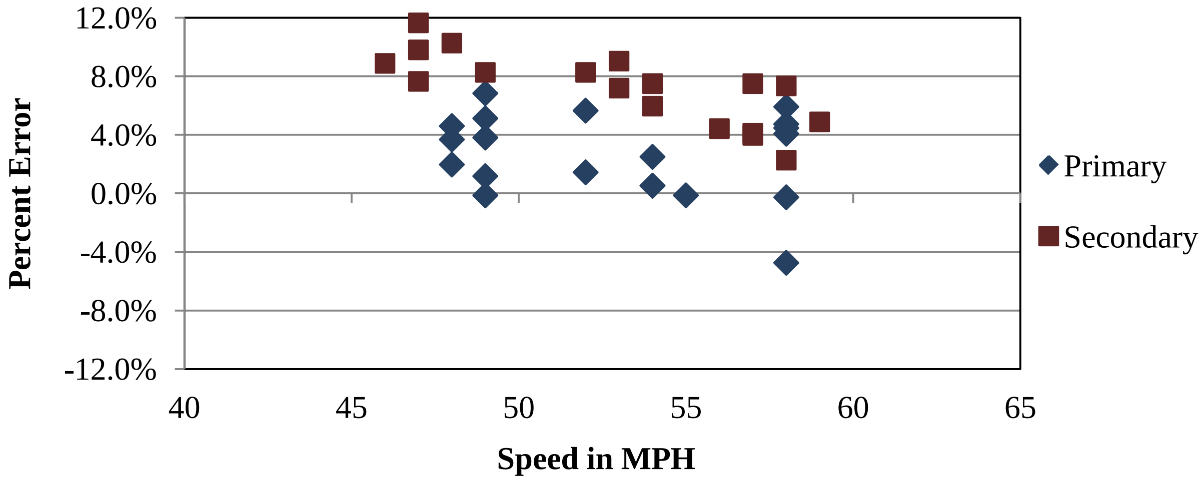


Figure 5-6 – Pre-Validation GVW Errors by Truck and Speed – 1-May-12

5.1.1.7 Axle Length Errors by Speed

For this site, the error in axle length measurement was consistent at all speeds. The range in axle length measurement error ranged from -0.2 feet to 0.1 feet. Distribution of errors is shown graphically in Figure 5-7.

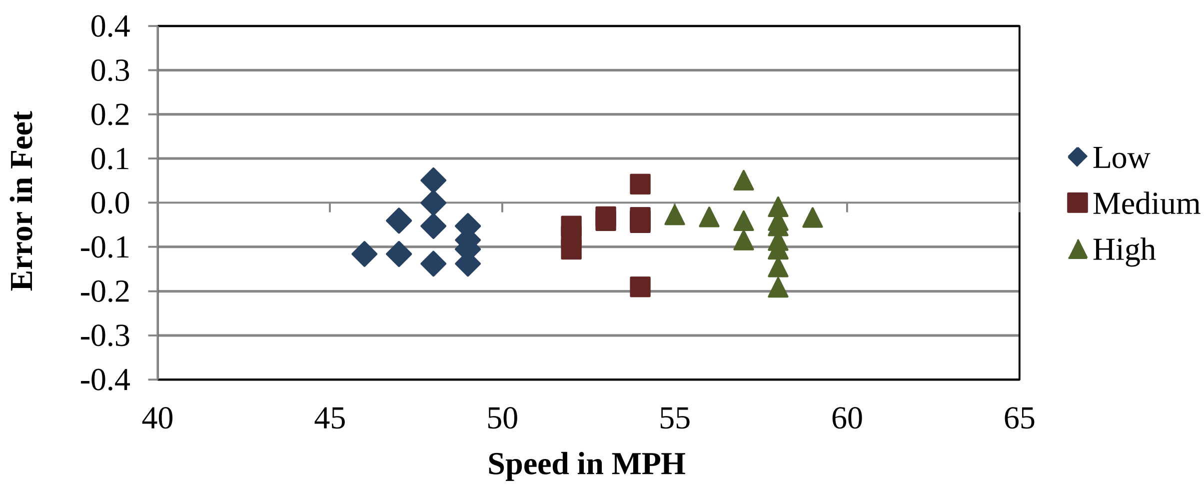


Figure 5-7 – Pre-Validation Axle Length Errors by Speed – 1-May-12

5.1.1.8 Overall Length Errors by Speed

For this system, the WIM equipment estimated overall vehicle length consistently over the entire range of speeds, with an error range of -0.8 to 0.7 feet. Distribution of errors is shown graphically in Figure 5-8.

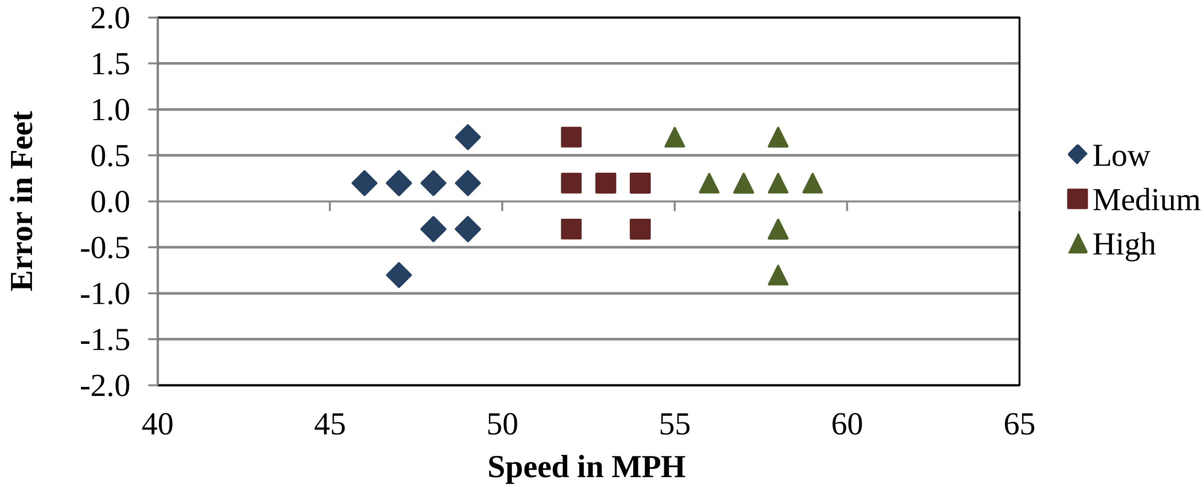


Figure 5-8 – Pre-Validation Overall Length Error by Speed – 1-May-12

5.1.2 Statistical Temperature Analysis

Statistical analysis was performed for the test truck run data to investigate whether a relationship exists between pavement temperature and WIM equipment weight and distance measurement accuracy. The range of pavement temperatures varied 21.9 degrees, from 56.6 to 78.5 degrees Fahrenheit. Since the desired 30 degree temperature range was not met, the pre-validation test runs are being reported under two temperature groups – low and high, as shown in Table 5-4.

Table 5-4 – Pre-Validation Results by Temperature – 1-May-12

Parameter	95% Confidence Limit of Error	Low	High
		56.6 to 67.6 degF	67.7 to 78.5 degF
Steering Axles	±20 percent	0.1 ± 15.1%	2.8 ± 14.6%
Tandem Axles	±15 percent	4.9 ± 9.8%	3.0 ± 14.9%
Tridem Axles	±15 percent	10.2 ± 9.5%	4.5 ± 14.3%
Axle Groups	±15 percent	6.2 ± 9.7%	3.4 ± 14.8%
GVW	±10 percent	5.7 ± 7.2%	3.8 ± 8.9%
Vehicle Length	±3.0 percent (1.9 ft)	0.1 ± 0.7 ft	-0.2 ± 0.8 ft
Vehicle Speed	± 1.0 mph	-0.1 ± 0.1 mph	-0.1 ± 0.1 mph
Axle Length	± 0.5 ft [150mm]	-0.8 ± 2.2 ft	-1.5 ± 7.3 ft

To aid in the analysis, several graphs were developed to illustrate the possible effects of temperature on GVW, single axle, and axle group weights.

5.1.2.1 GVW Errors by Temperature

From Figure 5-9, it can be seen that the equipment generally overestimates GVW across the range of temperatures observed in the field. The range in error is similar for different temperature groups.

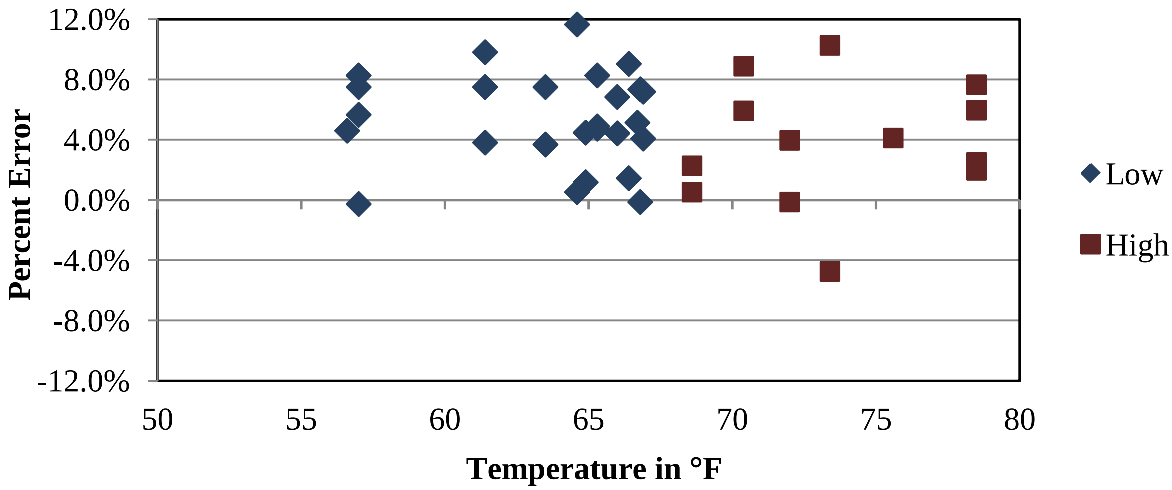


Figure 5-9 – Pre-Validation GVW Errors by Temperature – 1-May-12

5.1.2.2 Steering Axle Weight Errors by Temperature

Figure 5-10 illustrates that for steering axles, the WIM equipment estimates steering axle weights with similar accuracy at all temperatures.

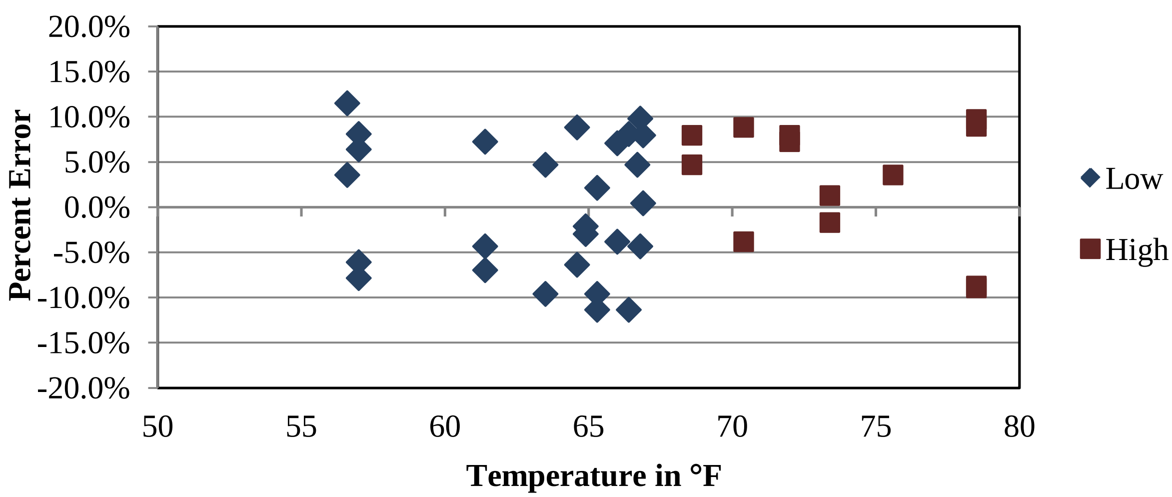


Figure 5-10 – Pre-Validation Steering Axle Weight Errors by Temperature – 1-May-12

5.1.2.3 Tandem Axle Weight Errors by Temperature

As shown in Figure 5-11, the WIM equipment overestimates tandem axle weights with similar bias across the range of temperatures observed in the field. The range in tandem axle errors is greater for the high temperature range.

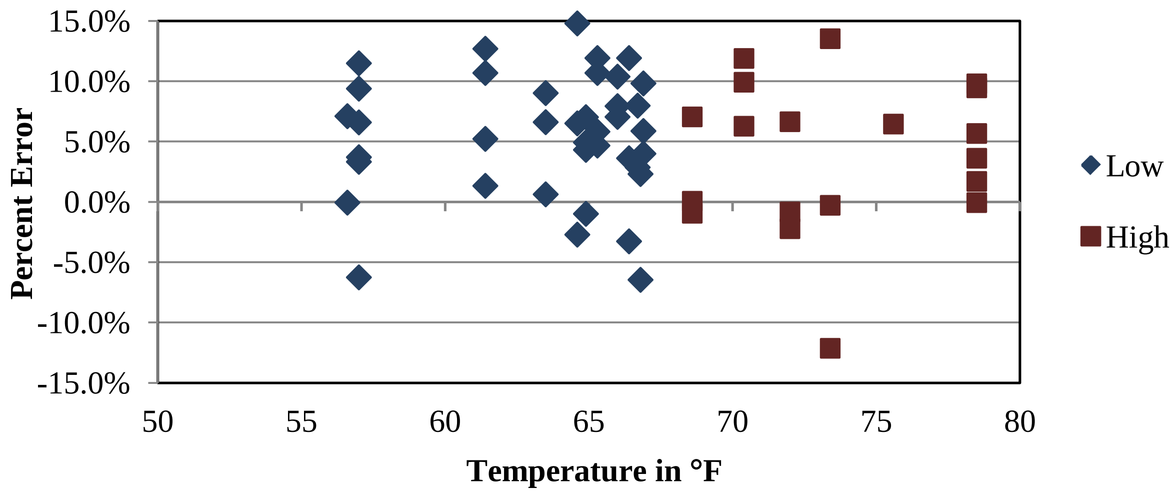


Figure 5-11 – Pre-Validation Tandem Axle Weight Errors by Temperature – 1-May-12

5.1.2.4 Tridem Axle Weight Errors by Temperature

As shown in Figure 5-12, the WIM equipment generally overestimates tridem axle weights across the range of temperatures observed in the field. The range in tridem axle errors is greater for the high temperature group.

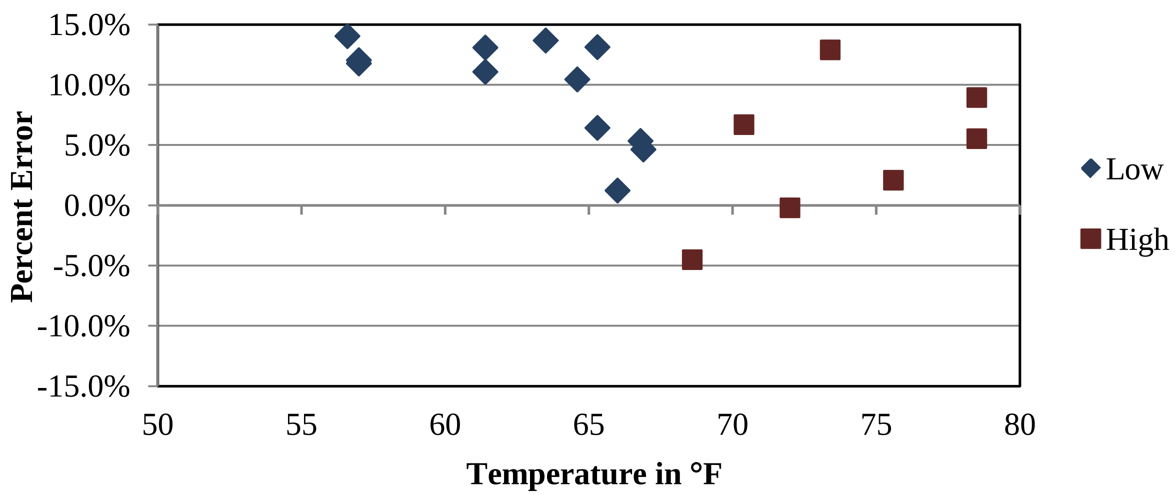


Figure 5-12 – Pre-Validation Tridem Axle Weight Errors by Temperature – 1-May-12

5.1.2.5 Axle Group Weight Errors by Temperature

As shown in Figure 5-13, the WIM equipment overestimates axle group weights with similar bias across the range of temperatures observed in the field. The range in axle group errors is greater for the high temperature group.

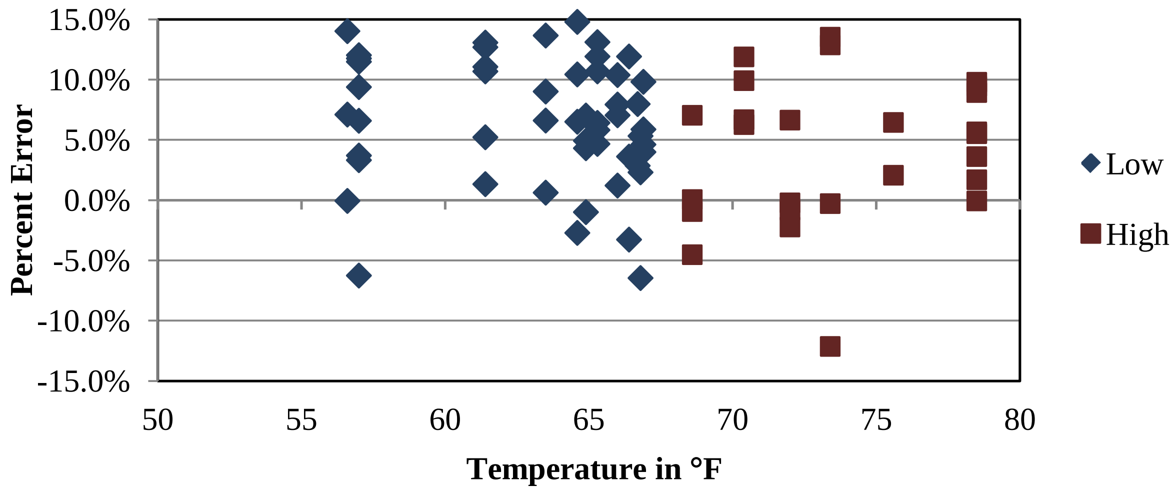


Figure 5-13 – Pre-Validation Axle Group Weight Errors by Temperature – 1-May-12

5.1.2.6 GVW Errors by Temperature and Truck Type

When analyzed for each test truck, it can be seen that the WIM equipment overestimated GVW for the partially loaded (Secondary) truck to a greater degree than the heavily loaded (Primary) truck. For both trucks, the range of errors and bias are consistent over the range of temperatures. Distribution of errors is shown graphically in Figure 5-14.

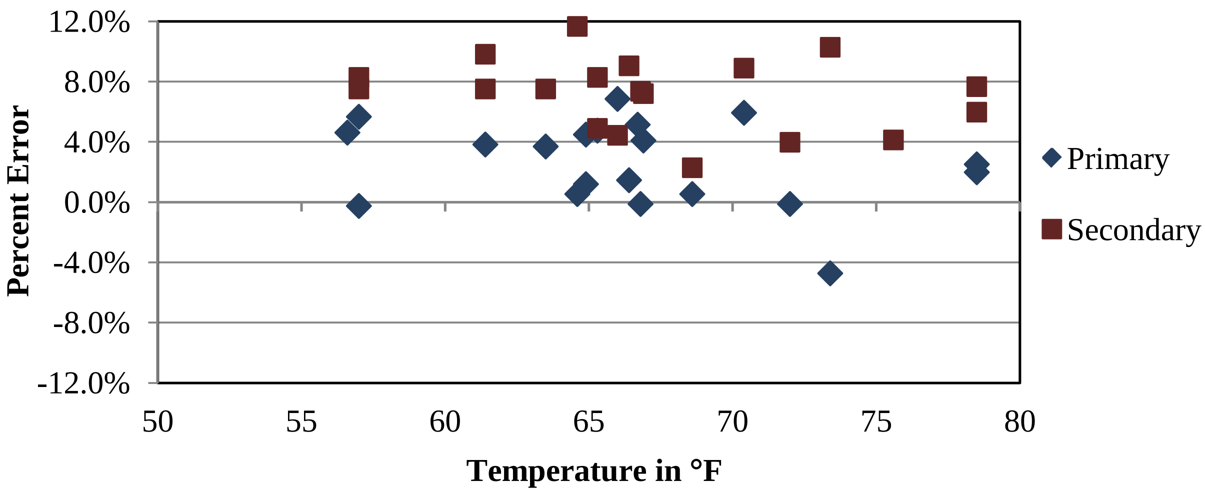


Figure 5-14 – Pre-Validation GVW Error by Truck and Temperature – 1-May-12

5.1.3 Classification and Speed Evaluation

The pre-validation classification and speed study involved the comparison of vehicle classification and speed data collected manually with the information for the same vehicles reported by the WIM equipment.

For the pre-validation classification study at this site, a manual sample of 111 vehicles including 100 trucks (Class 4 through 13) was collected. Video was collected during the study to provide a means for further analysis of misclassifications and vehicles whose classifications could not be determined with a high degree of certainty in the field.

Misclassified vehicles are defined as those vehicles that are manually classified by observation as one class of vehicle but identified by the WIM equipment as another class of vehicle. The misclassifications by pair are provided in Table 5-5. The table illustrates the breakdown of vehicles observed and identified by the equipment for the manual classification study. As shown in Table 5-5, seven Class 3 vehicles were misclassified as Class 8 vehicles, one Class 4 vehicle was misclassified as a Class 5 vehicle, two Class 6 vehicles were misclassified as Class 4 vehicles, and a total of ten Class 5 vehicles were misclassified – two as Class 4 vehicles, seven as Class 8 vehicles, and one as a Class 11 vehicle.

Table 5-5 – Pre-Validation Misclassifications by Pair – 1-May-12

		WIM											
Observed		3	4	5	6	7	8	9	10	11	12	13	14
	3	-					7						
	4		-	1									
	5		2	-			7			1			
	6		2		-								
	7					-							
	8						-						
	9							-					
	10								-				
	11									-			
	12										-		
	13											-	-

As shown in the table, a total of 20 vehicles, including 2 heavy trucks (vehicle classes 6 – 13) were misclassified by the equipment. Based on the vehicles observed during the pre-validation study, the misclassification percentage is 2.5% for heavy trucks (6 – 13), which is greater than the 2.0% acceptability criteria for LTPP SPS WIM sites. The overall misclassification rate for all vehicles (3 – 15) is 18.9%, primarily due to misclassification of lightweight vehicles in Class 3 through 5. The causes for the misclassifications were not investigated in the field.

The combined results produced an undercount of seven Class 3 vehicles, nine Class 5 vehicles and two Class 6 vehicles, and an overcount of three Class 4 vehicles, fourteen Class 8 vehicles, and one Class 11 vehicle as shown in Table 5-6. The misclassified percentage represents the percentage of the misclassified vehicles in the manual sample.

Table 5-6 – Pre-Validation Classification Study Results – 1-May-12

Class	3	4	5	6	7	8	9	10	11	12	13
Observed Count	11	1	21	6	1	2	36	21	1	1	10
WIM Count	4	4	12	4	1	16	36	21	2	1	10
Observed Percent	9.9	0.9	18.9	5.4	0.9	1.8	32.4	18.9	0.9	0.9	9.0
WIM Percent	3.6	3.6	10.8	3.6	0.9	14.4	33.3	18.0	1.8	0.9	9.0
Misclassified Count	7	1	10	2	0	0	0	0	0	0	0
Misclassified Percent	63.6	100.0	47.6	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unclassified Count	0	0	0	0	0	0	0	0	0	0	0
Unclassified Percent	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Unclassified vehicles are defined as those vehicles that cannot be identified by the WIM equipment algorithm. These are typically trucks with unusual trailer tandem configurations and are identified as Class 15 by the WIM equipment. The unclassified vehicles by pair are provided in Table 5-7.

Table 5-7 – Pre-Validation Unclassified Trucks by Pair – 1-May-12

Observed Class	Unclassified	Observed Class	Unclassified	Observed Class	Unclassified
3	0	7	0	11	0
4	0	8	0	12	0
5	0	9	0	13	0
6	0	10	0		

Based on the manually collected sample of the 100 trucks, 0.0 percent of the vehicles at this site were reported as unclassified during the study. This is within the established criteria of 2.0% for LTTP SPS WIM sites.

For speed, the mean error for WIM equipment speed measurement was -0.7 mph; the range of errors was 1.7 mph.

5.2 Calibration

The WIM equipment required three calibration iterations between the pre- and post-validations. Information regarding the basis for changing equipment compensation factors, supporting data for the changes, and the resulting WIM accuracies from the calibrations are provided in this section.

The operating system weight compensation parameters that were in place prior to the pre-validation are shown in Table 5-8.

Table 5-8 – Initial System Parameters – 1-May-12

Speed Point	MPH	Left	Right
		1	2
80	50	6.6426	6.6426
100	62	6.3689	6.3689
120	75	6.3689	6.3689
Axle Distance (cm)		119	
Dynamic Comp (%)		105	
Loop Width (cm)		98	

5.2.1 Calibration Iteration 1

5.2.1.1 Equipment Adjustments

For GVW, the pre-validation test truck runs produced an overall error of 5.1% and errors of 6.33%, 4.42%, and 4.42% at the 50, 55 and 60 mph speed points respectively. To compensate for these errors, the changes in Table 5-9 were made to the compensation factors.

Table 5-9 – Calibration 1 Equipment Factor Changes – 2-May-12

Speed Points	MPH	Old Factors		New Factors	
		Left	Right	Left	Right
		1	2	1	2
80	50	6.6426	6.6426	6.3871	6.3871
100	62	6.3689	6.3689	6.3058	6.3058
120	75	6.3689	6.3689	6.6343	6.6343
Axle Distance (cm)		119		119	
Dynamic Comp (%)		105		109	
Loop Width (cm)		98		99	

5.2.1.2 Calibration 1 Results

The results of the 12 first calibration verification runs are provided in Table 5-10 and Figure 5-15. As can be seen in the table, the mean error of all weight estimates was reduced as a result of the first calibration iteration.

Table 5-10 – Calibration 1 Results – 2-May-12

Parameter	95% Confidence Limit of Error	Site Values	Pass/Fail
Steering Axles	+20 percent	0.0 ± 18.2%	Pass
Tandem Axles	+15 percent	3.5 ± 8.5%	Pass
Tridem Axles	+15 percent	9.6 ± 11.6%	FAIL
Axle Groups	+15 percent	5.0 ± 9.3%	Pass
GVW	+10 percent	4.6 ± 4.4%	Pass
Vehicle Length	±3.0 percent (1.9 ft)	0.0 ± 1.2 ft	Pass
Axle Length	+ 0.5 ft [150mm]	-0.1 ± 0.2 ft	Pass

Figure 5-15 shows that the WIM equipment is overestimating GVW at all speeds.

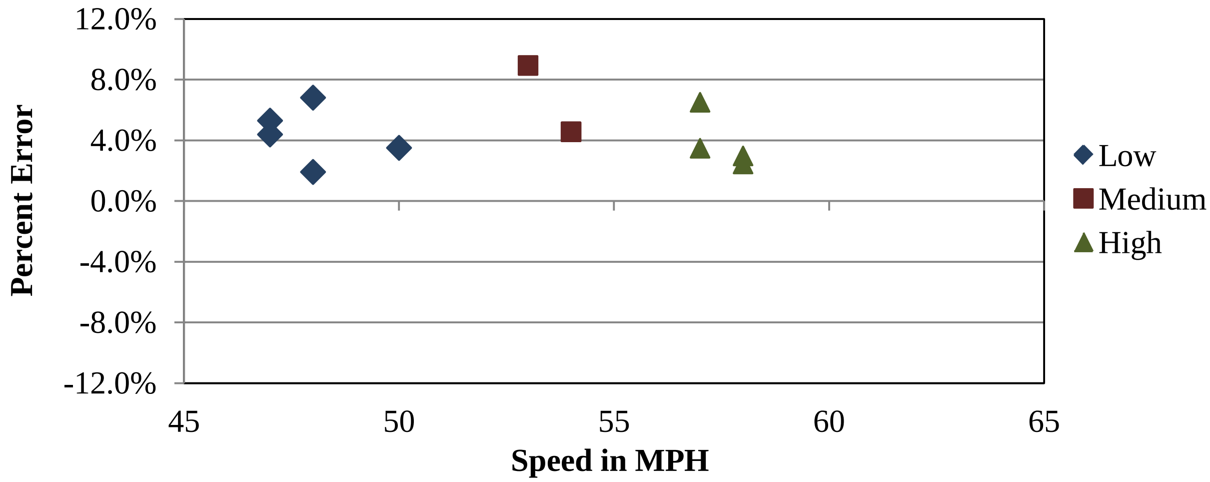


Figure 5-15 – Calibration 1 GVW Error by Speed – 2-May-12

Based on the results of the first calibration, where weight estimate bias was 4.6 percent, and the system did not pass for tridem axle measurement accuracy, a second calibration was considered to be necessary.

5.2.2 Calibration Iteration 2

5.2.2.1 Equipment Adjustments

The first calibration test truck runs produced an overall GVW error of 4.6% and errors of 5.83%, 4.68%, and 4.68% at the 50, 55 and 60 mph speed points, respectively. To compensate for these errors, the following changes to the compensation factors were made:

Table 5-11 – Calibration 2 Equipment Factor Changes – 2-May-12

Speed Points	Old Factors		New Factors	
	Left	Right	Left	Right
	1	2	1	2
80	6.3871	6.3871	6.0354	6.0354
100	6.3058	6.3058	6.0237	6.0237
120	6.3427	6.3427	6.0590	6.0590
Axle Distance (cm)	119		119	
Dynamic Comp (%)	105		110	
Loop Width (cm)	98		99	

5.2.2.2 Calibration 2 Results

The results of the 12 second calibration verification runs are provided in Table 5-10 and Figure 5-15. As can be seen in the table, the mean error of steering and tandem weight estimates increased as a result of the second calibration iteration.

Table 5-12 – Calibration 2 Results – 2-May-12

Parameter	95% Confidence Limit of Error	Site Values	Pass/Fail
Steering Axles	±20 percent	-7.9 ± 12.2%	FAIL
Tandem Axles	±15 percent	-4.6 ± 9.5%	Pass
Tridem Axles	±15 percent	0.0 ± 9.6%	Pass
Axle Groups	±15 percent	-3.4 ± 9.5%	Pass
GVW	±10 percent	-3.4 ± 6.4%	Pass
Vehicle Length	±3.0 percent (1.9 ft)	0.0 ± 0.7 ft	Pass
Axle Length	± 0.5 ft [150mm]	-0.1 ± 0.2 ft	Pass

Figure 5-15 shows that the WIM equipment is generally underestimating GVW at all speeds.

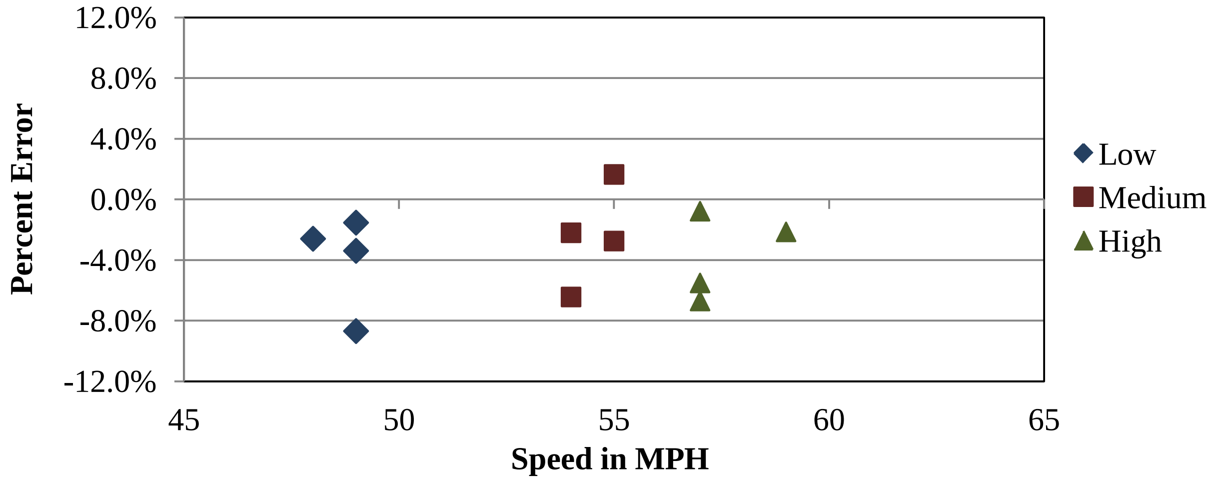


Figure 5-16 – Calibration 2 GVW Error by Speed – 2-May-12

Based on the results of the second calibration, where GVW weight estimate bias was -3.4 percent, and the WIM system failed for steering axle weight estimates, a third calibration was considered to be necessary.

5.2.3 Calibration Iteration 3

5.2.3.1 Equipment Adjustments

The second calibration test truck runs produced an overall error of -3.4% and errors of -2.46%, -3.00%, and -3.00% at the 50, 55 and 60 mph speed points, respectively. To compensate for these errors, the following changes to the compensation factors were made:

Table 5-13 – Calibration 2 Equipment Factor Changes – 2-May-12

Speed Points	Old Factors		New Factors	
	Left	Right	Left	Right
	1	2	1	2
80	6.0354	6.0354	6.1878	6.1878
100	6.0237	6.0237	6.2102	6.2102
120	6.3427	6.3427	6.5391	6.5391
Axle Distance (cm)	119		119	
Dynamic Comp (%)	107		112	
Loop Width (cm)	98		99	

5.2.3.2 Calibration 3 Results

The results of the 12 third calibration verification runs are provided in Table 5-10 and Figure 5-15. As can be seen in the table, the mean error of all weight estimates was reduced as a result of the third calibration iteration.

Table 5-14 – Calibration 3 Results – 2-May-12

Parameter	**95% Confidence Limit of Error**	**Site Values**	**Pass/Fail**
Steering Axles	±20 percent	-1.4 ± 9.9%	Pass
Tandem Axles	±15 percent	-1.3 ± 9.3%	Pass
Tridem Axles	±15 percent	5.0 ± 15.2%	FAIL
Axle Groups	±15 percent	0.3 ± 10.8%	Pass
GVW	±10 percent	0.6 ± 7.8%	Pass
Vehicle Length	±3.0 percent (1.9 ft)	0.0 ± 1.1 ft	Pass
Axle Length	± 0.5 ft [150mm]	-0.1 ± 0.2 ft	Pass

Figure 5-15 shows that as a result of the third calibration, the WIM equipment is estimating GVW with improved accuracy at all speeds.

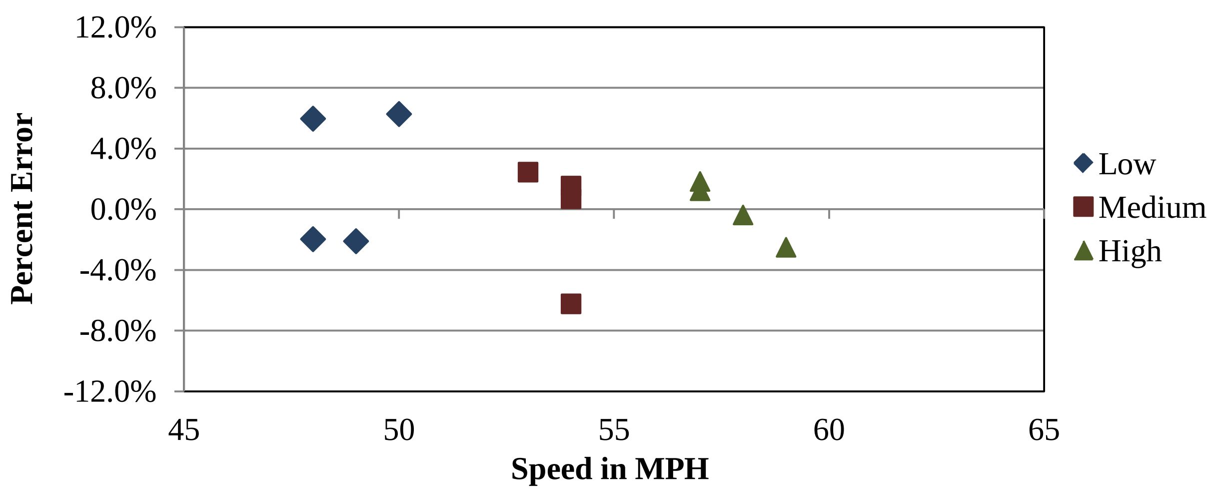


Figure 5-17 – Calibration 3 GVW Error by Speed – 2-May-12

As shown in the figure, GVW estimate bias decreased to 0.6 percent as a result of the third calibration. Although tridem axles did not pass using the 12 calibration only, the 12 calibration runs were combined with 28 additional post-validation runs to complete the WIM system validation.

5.3 Post-Validation

The 42 post-validation test truck runs were conducted on May 2, 2012, beginning at approximately 7:42 AM and continuing until 3:18 PM.

The two test trucks consisted of:

- A Class 9 truck, loaded with concrete blocks, and equipped with air suspension on truck and trailer tandems and with standard tandem spacings on both the tractor and trailer.
- A Class 10 truck, loaded with palletized bagged silicone, and equipped with air suspension and standard tandem spacing on the truck and a tridem on the trailer.

The test trucks were weighed prior to the post-validation and re-weighed at the conclusion of the post-validation. The average test truck weights and measurements are provided in Table 5-15.

Table 5-15 – Post-Validation Test Truck Measurements

Test Truck	Weights (kips)							Spacings (feet)						
	GVW	Ax1	Ax2	Ax3	Ax4	Ax5	Ax6	1-2	2-3	3-4	4-5	5-6	AL	OL
1	75.6	11.9	15.7	15.6	16.2	16.4		18.3	4.3	29.3	4.0		55.9	62.3
2	65.4	11.5	12.7	12.6	11.0	9.3	8.3	18.2	4.2	25.3	4.8	5.2	57.7	63.8

Test truck speeds varied by 12 mph, from 47 to 59 mph. The measured post-validation pavement temperatures varied 38.1 degrees Fahrenheit, from 44.4 to 82.5. The weather conditions provided the desired minimum 30 degree temperature range. Table 5-16 is a summary of post validation results.

Table 5-16 – Post-Validation Overall Results – 2-May-12

Parameter	95% Confidence Limit of Error	Site Values	Pass/Fail
Steering Axles	±20 percent	-3.8 ± 11.9%	Pass
Tandem Axles	±15 percent	1.7 ± 12.1%	Pass
Tridem Axles	±15 percent	6.3 ± 8.2%	Pass
Axle Groups	±15 percent	2.8 ± 11.1%	Pass
GVW	±10 percent	2.1 ± 7.7%	Pass
Vehicle Length	±3.0 percent (1.9 ft)	0.0 ± 0.8 ft	Pass
Axle Length	± 0.5 ft [150mm]	0.0 ± 0.1 ft	Pass

Truck speed was manually collected for each test run using a radar gun and compared with the speed reported by the WIM equipment. For this site, the average error in speed measurement for all speeds was -0.2 ± 2.5 mph, which is greater than the ±1.0 mph tolerance established by the LTPP Field Guide. However, since the site is measuring axle spacing length with a mean error of

0.0 feet, and the speed and axle spacing length measurements are based on the distance between the axle detector sensors, it can be concluded that the distance factor is set correctly and that the speeds being reported by the WIM equipment are within similar acceptable ranges.

5.3.1 Statistical Speed Analysis

Statistical analysis was conducted on the test truck run data to investigate whether a relationship exists between speed and WIM equipment weight and distance measurement accuracy. The posted speed limit at this site is 60 mph. The test runs were divided into three speed groups - low, medium and high speeds, as shown in Table 5-17.

Table 5-17 – Post-Validation Results by Speed – 2-May-12

Parameter	95% Confidence Limit of Error	Low	Medium	High
		47.0 to 51.0 mph	51.1 to 55.1 mph	55.2 to 59.0 mph
Steering Axles	±20 percent	-2.9 ± 16.0%	-3.7 ± 12.4%	-4.7 ± 9.6%
Tandem Axles	±15 percent	-0.6 ± 13.3%	2.4 ± 15.6%	3.3 ± 11.6%
Tridem Axles	±15 percent	8.8 ± 9.5%	5.1 ± 9.8%	5.0 ± 7.1%
Axle Groups	±15 percent	1.7 ± 12.3%	3.1 ± 14.2%	3.7 ± 10.5%
GVW	±10 percent	1.7 ± 9.9%	2.1 ± 8.7%	2.5 ± 6.4%
Vehicle Length	±3.0 percent (1.9 ft)	0.1 ± 0.8 ft	0.0 ± 1.0 ft	0.0 ± 0.8 ft
Vehicle Speed	± 1.0 mph	0.0 ± 0.1 mph	-0.1 ± 0.2 mph	0.0 ± 0.1 mph
Axle Length	± 0.5 ft [150mm]	-0.1 ± 2.4 ft	0.1 ± 3.3 ft	-0.6 ± 2.3 ft

From the table, it can be seen that the WIM equipment underestimates steering axle weights at all speeds. With the exception of steering axle weights and tandem axle weights at the lower speeds, the WIM equipment overestimates all other weights at all speeds. For GVW and steering axle weights, the range in error decreases as speed increases. For axle groups, the range in error is greater at the medium speeds when compared with low and medium speeds. For the population as a whole, there does not appear to be a strong relationship between weight estimates and speed at this site.

To aid in the speed analysis, several graphs were developed to illustrate the possible effects of speed on GVW, single axle, and axle group weights, and axle and overall length distance measurements, as discussed in the following paragraphs.

5.3.1.1 GVW Errors by Speed

As shown in Figure 5-18, the equipment estimated GVW with similar accuracy at all speeds. The range in error is lower at high speeds when compared to low and medium speeds.

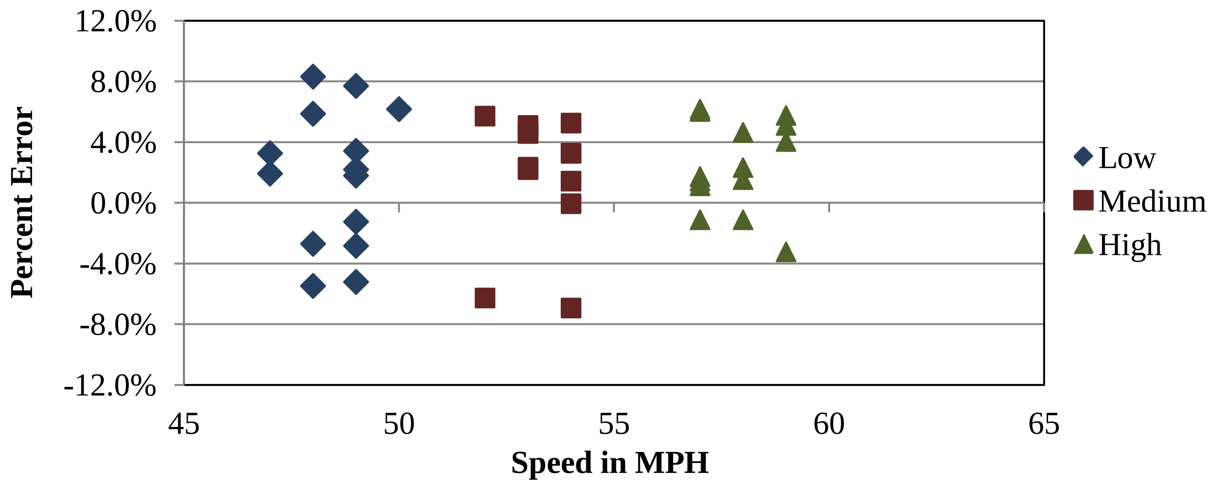


Figure 5-18 – Post-Validation GVW Errors by Speed – 2-May-12

5.3.1.2 Steering Axle Weight Errors by Speed

As shown in Figure 5-19, the equipment underestimates steering axle weights with similar bias at all speeds. The range in error is higher at low speeds. There does not appear to be a correlation between speed and steering axle weight estimates at this site.

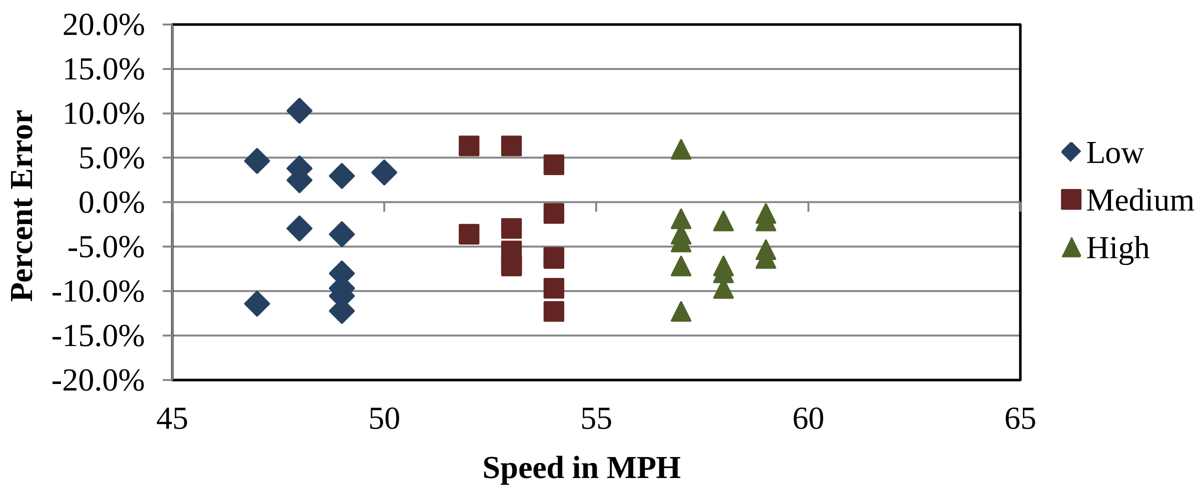


Figure 5-19 – Post-Validation Steering Axle Weight Errors by Speed – 2-May-12

5.3.1.3 Tandem Axle Weight Errors by Speed

As shown in Figure 5-20, the equipment estimated tandem axle weights with similar accuracy at all speeds. The range in error and bias is similar throughout the entire speed range.

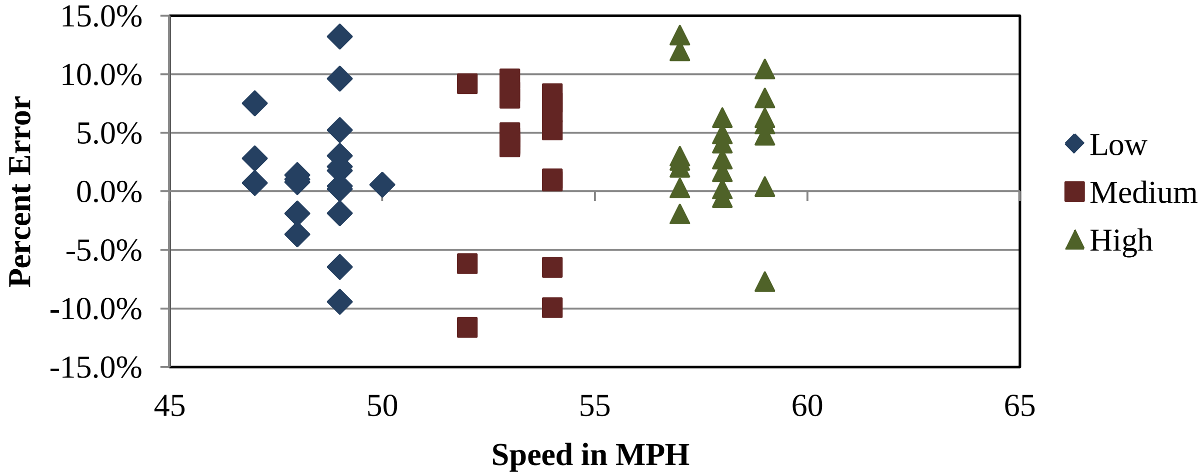


Figure 5-20 – Post-Validation Tandem Axle Weight Errors by Speed – 2-May-12

5.3.1.4 Tridem Axle Weight Errors by Speed

As shown in Figure 5-21, the WIM equipment positive bias for tridem axles is greater at the lower speeds and decreases as speed increases. The range in error is lower at high speeds when compared to low and medium speeds. There does appear to be a slight correlation between tridem axle weight estimation error and speed at this site.

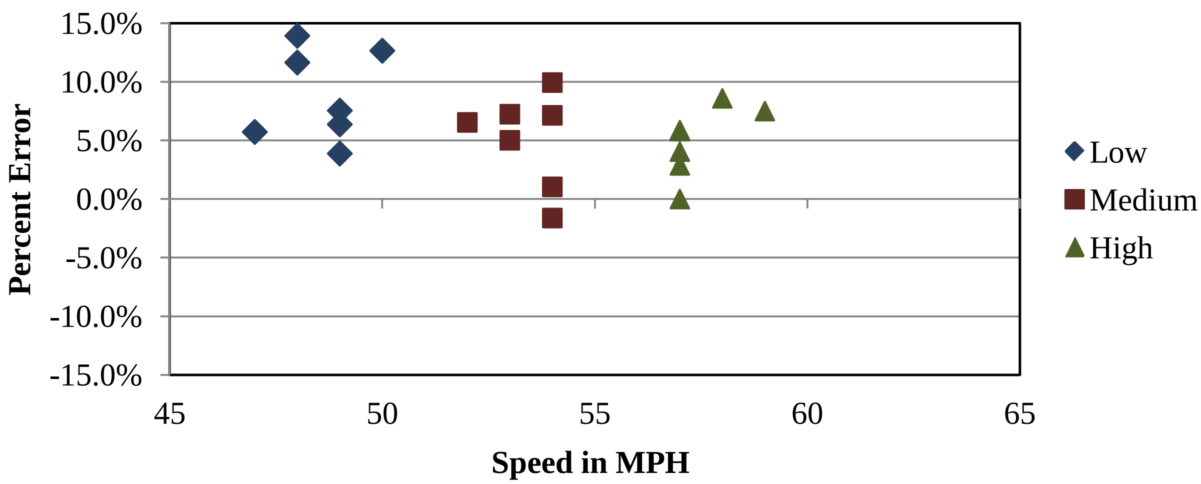


Figure 5-21 – Post-Validation Tridem Axle Weight Errors by Speed – 2-May-12

5.3.1.5 GVW Errors by Speed and Truck Type

It can be seen in Figure 5-22 that when the GVW errors are analyzed by truck type, when the GVW error for each truck is analyzed as a function of speed, it can be seen that the WIM equipment measures GVW for the heavily loaded (Primary) truck with less bias and overestimates GVW for the partially loaded (Secondary) truck over the range of speeds. The range in error is greater for the heavily loaded (Primary) truck.

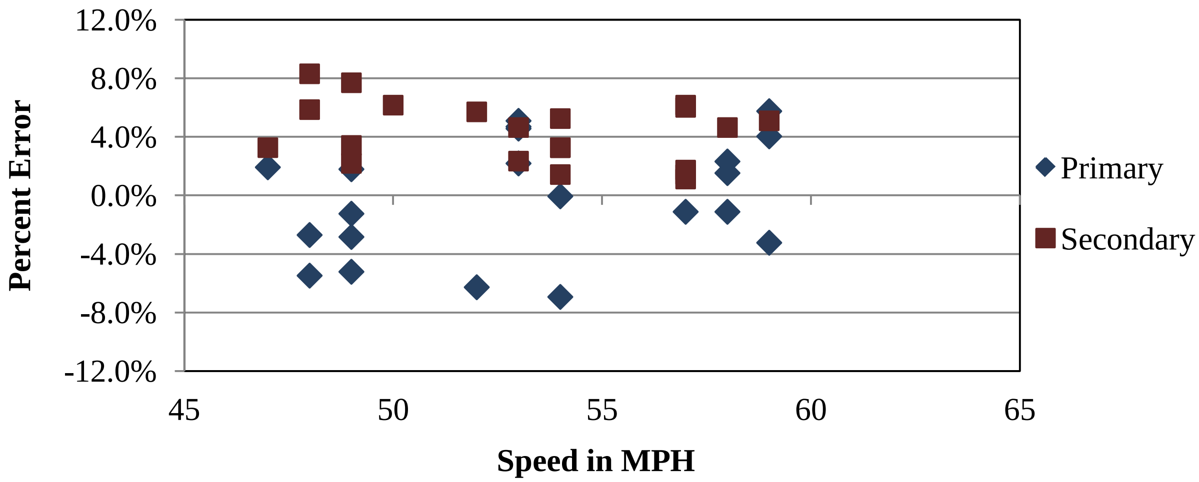


Figure 5-22 – Post-Validation GVW Error by Truck and Speed – 2-May-12

5.3.1.6 Axle Length Errors by Speed

For this site, the error in axle length measurement was consistent at all speeds. The range in axle length measurement error was from -0.2 feet to 0.1 feet. Distribution of errors is shown graphically in Figure 5-23.

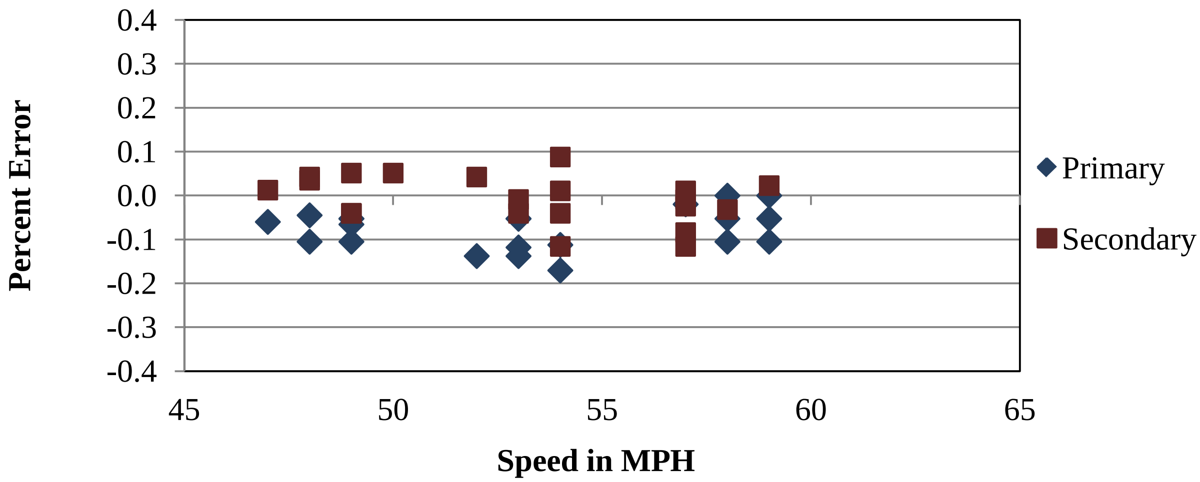


Figure 5-23 – Post-Validation Axle Length Error by Speed – 2-May-12

5.3.1.7 Overall Length Errors by Speed

For this system, the WIM equipment measures overall length consistently over the entire range of speeds, with errors ranging from -0.8 to 1.2 feet. Distribution of errors is shown graphically in Figure 5-24.

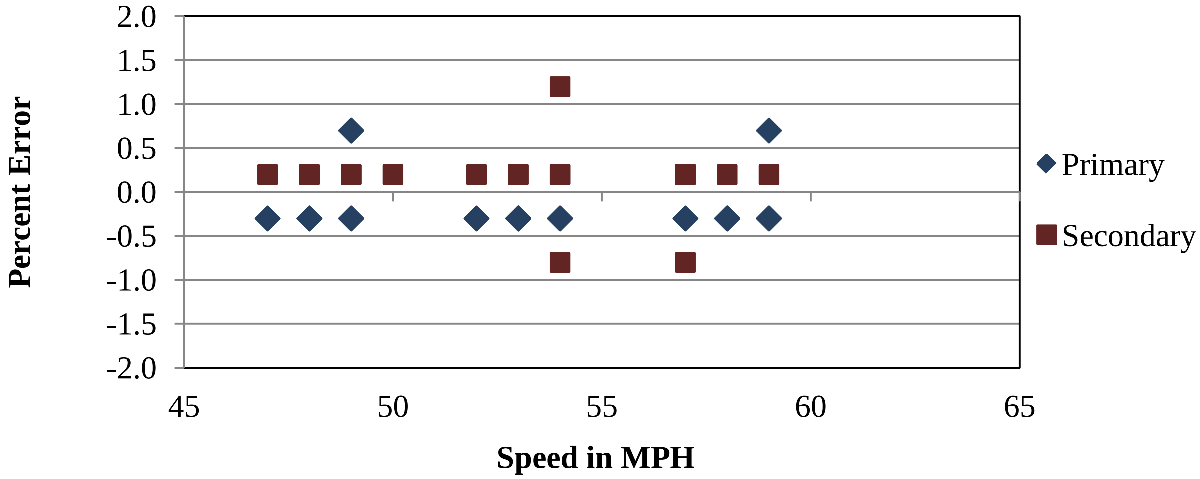


Figure 5-24 – Post-Validation Overall Length Error by Speed – 2-May-12

5.3.2 Statistical Temperature Analysis

Statistical analysis was performed for the test truck run data to investigate whether a relationship exists between pavement temperature and WIM equipment weight and distance measurement accuracy. The range of pavement temperatures was 38.1 degrees, from 44.4 to 82.5 degrees Fahrenheit. Even though the 30-degree temperature range was met, the post-validation test runs are reported under two temperature groups – low and high, as shown in Table 5-18 below. This is done because there were very few temperature readings in the medium category, as demonstrated in the plots below.

Table 5-18 – Post-Validation Results by Temperature – 2-May-12

Parameter	95% Confidence Limit of Error	Low 44.4 to 65 degF	High 65.1 to 83.0 degF
Steering Axles	±20 percent	-4.4 ± 12.9%	-2.5 ± 10.9%
Tandem Axles	±15 percent	3.2 ± 13.0%	-1.3 ± 9.3%
Tridem Axles	±15 percent	6.8 ± 6.5%	5.2 ± 13.3%
Axle Groups	±15 percent	4.1 ± 11.4%	0.3 ± 10.3%
GVW	±10 percent	2.9 ± 7.6%	0.3 ± 7.6%
Vehicle Length	±3.0 percent (1.9 ft)	0.0 ± 0.7 ft	0.0 ± 1.0 ft
Vehicle Speed	± 1.0 mph	0.0 ± 0.1 mph	-0.1 ± 0.2 mph
Axle Length	± 0.5 ft [150mm]	-0.3 ± 2.6 ft	0.0 ± 2.8 ft

To aid in the analysis, several graphs were developed to illustrate the possible effects of temperature on GVW, single axle weights, and axle group weights.

5.3.2.1 GVW Errors by Temperature

From Figure 5-25, it can be seen that the equipment appears to estimate GVW with similar accuracy across the range of temperatures observed in the field. There does not appear to be a correlation between temperature and GVW estimates at this site.

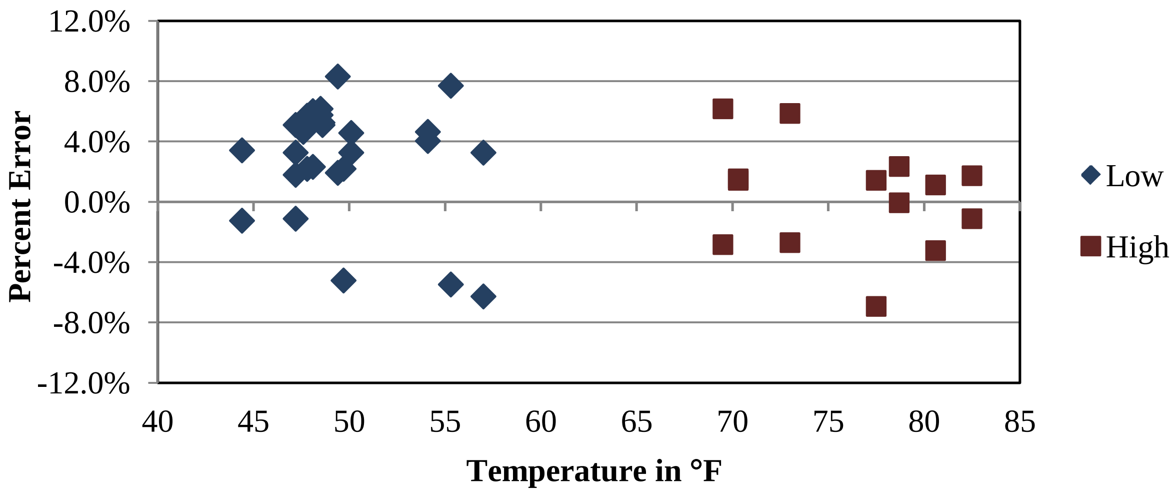


Figure 5-25 – Post-Validation GVW Errors by Temperature – 2-May-12

5.3.2.2 Steering Axle Weight Errors by Temperature

Figure 5-26 demonstrates that the WIM equipment appears to underestimate steering axle weights with similar bias across the range of temperatures observed in the field. There does not appear to be a correlation between temperature and steering axle weight estimates at this site. The range in error is similar for different temperature groups.

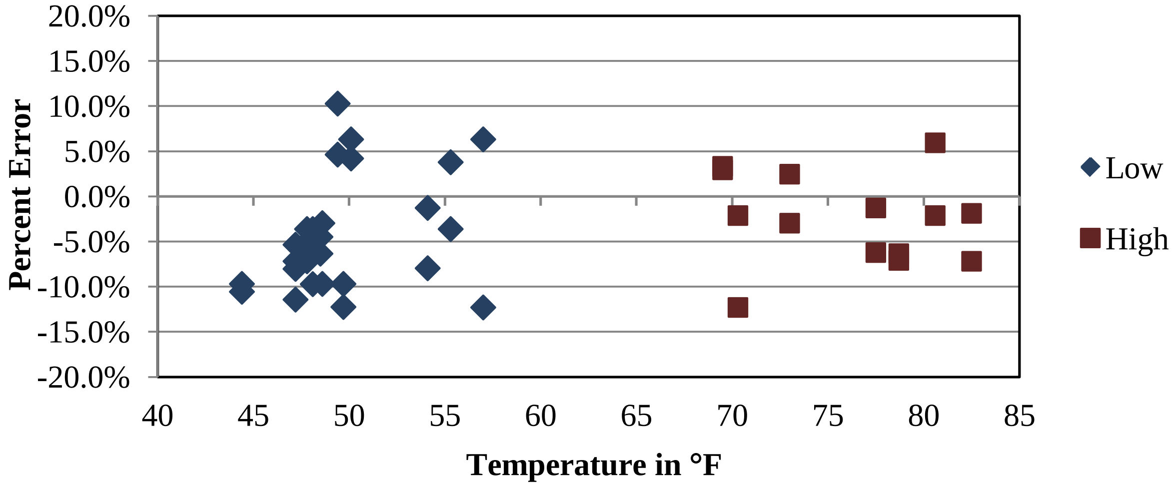


Figure 5-26 – Post-Validation Steering Axle Weight Errors by Temperature – 2-May-12

5.3.2.3 Tandem Axle Weight Errors by Temperature

As shown in Figure 5-27, the WIM equipment appears to estimate tandem axle weights with similar accuracy across the range of temperatures observed in the field. There does not appear to be a correlation between temperature and tandem axle weight estimates at this site. The range in tandem axle errors is greater at the lower temperatures.

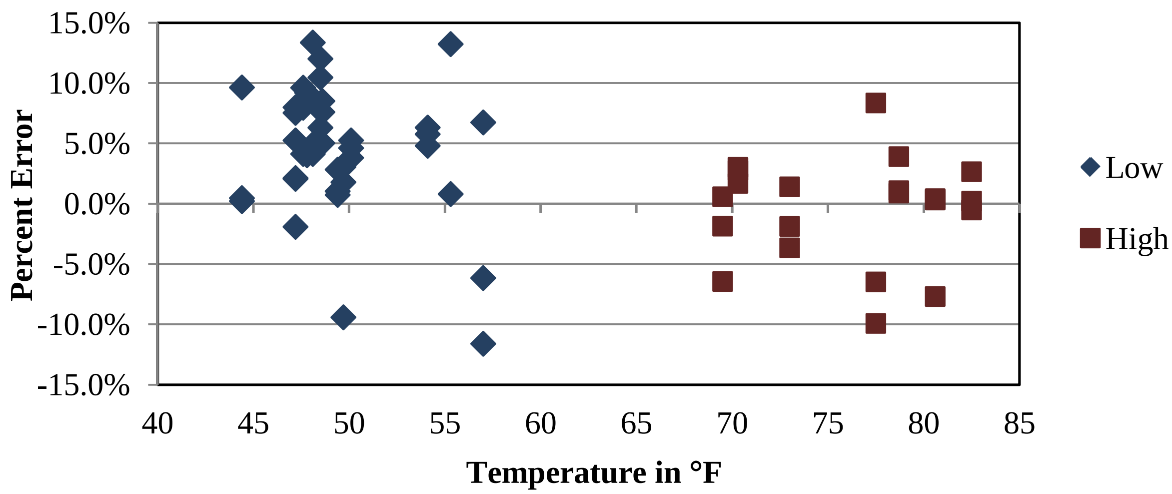


Figure 5-27 – Post-Validation Tandem Axle Weight Errors by Temperature – 2-May-12

5.3.2.4 Tridem Axle Weight Errors by Temperature

As shown in Figure 5-28, the WIM equipment generally overestimates tridem axle weights across the range of temperatures observed in the field. There does not appear to be a correlation between temperature and tridem axle weight estimates at this site. The range in tridem axle errors is consistent for the two temperature groups.

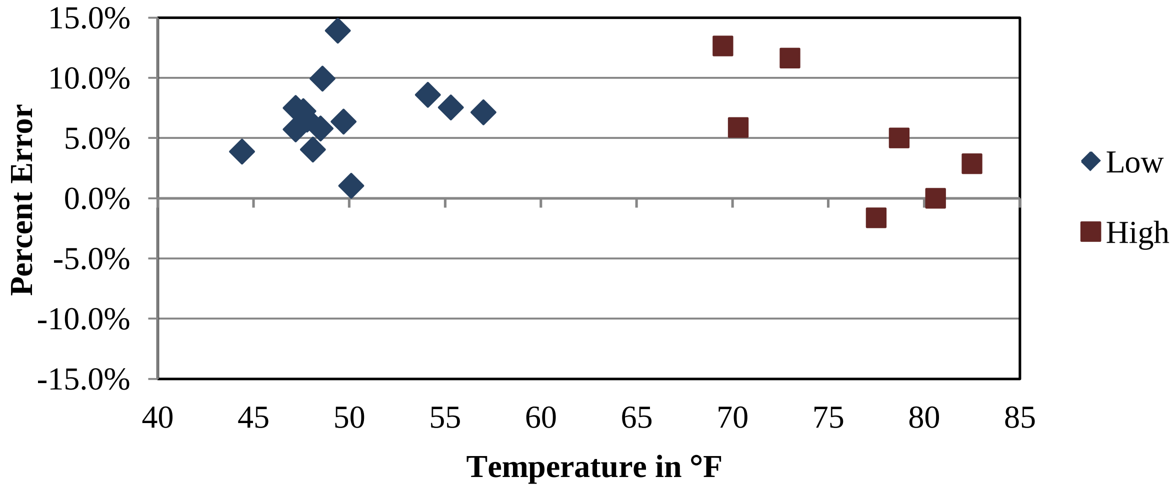


Figure 5-28 – Post-Validation Tridem Axle Weight Errors by Temperature – 2-May-12

5.3.2.5 GVW Errors by Temperature and Truck Type

As shown in Figure 5-29, when analyzed by truck type, it can be seen that the WIM equipment measures GVW for the heavily loaded (Primary) truck with less bias and overestimates GVW for the partially loaded (Secondary) truck over the range of temperatures observed in the field. The range in error is greater for the heavily loaded (Primary) truck.

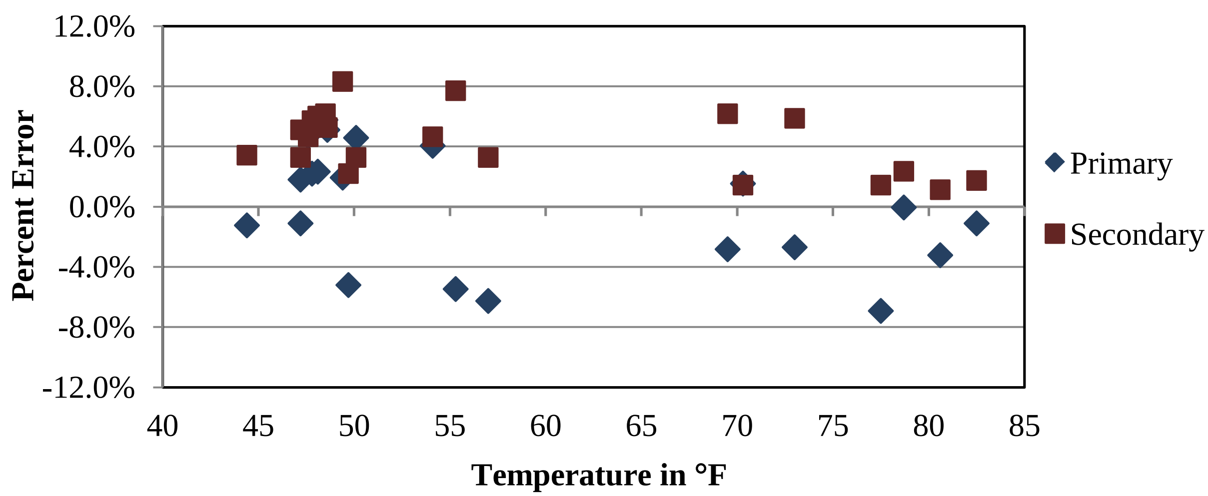


Figure 5-29 – Post-Validation GVW Error by Truck and Temperature – 2-May-12

5.3.3 Classification and Speed Evaluation

The post-validation classification and speed study involved the comparison of vehicle classification and speed data collected manually with the information for the same vehicles reported by the WIM equipment.

For the post-validation classification study at this site, a manual sample of 109 vehicles including 100 trucks (Class 4 through 13) was collected. Video was collected during the study to provide a means for further analysis of misclassifications and vehicles whose classifications could not be determined with a high degree of certainty in the field.

Misclassified vehicles are defined as those vehicles that are manually classified by observation as one type of vehicle but identified by the WIM equipment as another type of vehicle. The misclassifications by pair are provided in Table 5-19. The table illustrates the breakdown of vehicles observed and identified by the equipment for the manual classification study. As shown in Table 5-19, a total of five Class 3 vehicles were misclassified – one as Class 5 vehicle and four as Class 8 vehicles. A total of eight Class 5 vehicles were misclassified – four as Class 3 vehicles, one as a Class 4 vehicle, two as Class 8 vehicles, and one as Class 9 vehicle.

Table 5-19 – Post-Validation Misclassifications by Pair – 2-May-12

		WIM											
Observed		3	4	5	6	7	8	9	10	11	12	13	14
	3	-		1			4						
	4		-										
	5	4	1	-			2	1					
	6				-								
	7					-							
	8						-						
	9							-					
	10								-				
	11									-			
	12										-		
	13											-	-

As shown in the table, a total of 13 vehicles, including zero heavy truck (6 – 13) were misclassified by the equipment. Based on the vehicles observed during the post-validation study, the misclassification percentage is 0.0% for heavy trucks (vehicle classes 6 – 13), which is within the 2.0% acceptability criteria for LTPP SPS WIM sites. The overall misclassification rate for all vehicles (3 – 15) is 11.9 percent, primarily due to misclassification of lightweight vehicles in Classes 3 through 5 as heavy vehicles. The causes for the misclassifications were not investigated in the field.

The combined results of the misclassifications resulted in an undercount of one Class 3 vehicle and seven Class 5 vehicles, and an overcount of one Class 4 vehicle, six Class 8 vehicles, and one Class 9 vehicle, as shown in Table 5-20. The misclassified percentage represents the percentage of the misclassified vehicles in the manual sample.

Table 5-20 – Post-Validation Classification Study Results – 2-May-12

Class	3	4	5	6	7	8	9	10	11	12	13
Observed Count	9	0	14	0	0	2	52	16	3	1	12
WIM Count	8	1	7	0	0	8	53	16	3	1	12
Observed Percent	8.3	0.0	12.8	0.0	0.0	1.8	47.7	14.7	2.8	0.9	11.0
WIM Percent	7.3	0.9	6.4	0.0	0.0	7.3	48.6	14.7	2.8	0.9	11.0
Misclassified Count	5	0	8	0	0	0	0	0	0	0	0
Misclassified Percent	55.6	0.0	57.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unclassified Count	0	0	0	0	0	0	0	0	0	0	0
Unclassified Percent	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Unclassified vehicles are defined as those vehicles that cannot be identified by the WIM equipment algorithm. These are typically trucks with unusual trailer tandem configurations and are identified as Class 15 by the WIM equipment. The unclassified vehicles by pair are provided in Table 5-21.

Table 5-21 – Post-Validation Unclassified Trucks by Pair – 2-May-12

Observed Class	Unclassified	Observed Class	Unclassified	Observed Class	Unclassified
3	0	7	0	11	0
4	0	8	0	12	0
5	0	9	0	13	0
6	0	10	0		

Based on the manually collected sample of the 100 trucks, 0.0 percent of the vehicles at this site were reported as unclassified during the study. This is within the established criteria of 2.0% for LTTP SPS WIM sites.

For speed, the mean error for WIM equipment speed measurement was -0.9 mph; the range of errors was 1.4 mph.

5.3.4 Final WIM System Compensation Factors

The final factors left in place at the conclusion of the validation are provided in Table 5-22.

Table 5-22 – Final Factors

Speed Point	MPH	Left	Right
		1	2
80	50	6.1878	6.1878
100	62	6.2102	6.2102
120	75	6.5391	6.5391
Axle Distance (cm)		119	
Dynamic Comp (%)		107	
Loop Width (cm)		98	

6 Post-Visit Data Analysis

A post-visit data analysis is conducted to further evaluate the validation truck data to determine if any relationships exist between WIM system weight and distance measurement error based on speed, temperature and/or truck type. Additionally, an analysis of the post-visit misclassifications noted during the post-validation classification and speed study is conducted to possibly determine the cause of each truck misclassification.

If necessary, a traffic data sample from the days immediately following the validation to the date of the report submission may be conducted to further investigate anomalies in the traffic data that may have resulted from the calibration of the system or any other changes to the WIM system

6.1 Regression Analysis

This section provides additional results for the analysis carried out to determine the influence of truck type, speed and pavement temperature on WIM measurement errors. Multivariable linear regression analysis was applied to WIM data collected during calibration procedures. The same calibration data analyzed and discussed previously was used for this analysis; however a more comprehensive statistical methodology was applied. The objective of the additional analysis is to investigate if the trends identified using previous analyses are statistically significant, and to quantify these trends.

Multivariable analysis provides additional insight on how factors like speed, temperature, and truck type may affect weight measurement errors for a specific WIM site. It is expected that multivariable analysis done systematically for many sites may reveal overall trends.

6.1.1 Data

All errors from the weight measurement data collected by the equipment during the validation were analyzed. The percent error is defined as percentage difference between the weight measured by the WIM system and the static weight. The weight of "axle group" was evaluated separately for tandem axles on tractors and on trailers. The separate evaluation was carried out because the tandem axles on trailers may have different dynamic response to loads than tandem axles on tractors.

The measurement errors were statistically attributed to the following variables or factors:

- Truck type. Primary truck and Secondary truck.
- Truck test speed. Truck test speed ranged from 47 to 59 mph.
- Pavement temperature. Pavement temperature ranged from 44.4 to 82.5 degrees Fahrenheit.

6.1.2 Results

For analysis of GVW measurement errors, the value of regression coefficients and their statistical properties are summarized in Table 6-1. The value of regression coefficients defines the slope of the relationship between the % error in GVW and the predictor variables (speed, temperature, and truck type). The values of the t-distribution (for the regression coefficients) given in Table 6-1 are for the null hypothesis that assumes that the regression coefficients are equal to zero. The p- value reported in Table 6-1 is for the probability that the regression coefficient occur by chance alone.

Table 6-1 – Table of Regression Coefficients for Measurement Error of GVW

Parameter	Regression coefficients	Standard error	Value of t-distribution	Probability value (p-value)
Intercept	-1.6461	5.7408	-0.2867	0.7760
Speed	0.1660	0.1086	1.5284	0.1352
Temp	-0.1197	0.0325	-3.6863	0.0007
Truck	4.1318	0.8478	4.8739	0.0000

For example, the probability value for temperature given in Table 6-1 is 0.0007. This means that there is about a 0.07 percent chance that the value of regression coefficient for temperature, (-0.1197) can occur by chance alone.

The relationship between temperature and measurement errors is shown in Figure 6-1. The figure includes a trend line for the predicted percent error. In addition to the visual assessment of the relationship, Figure 6-1 provides quantification and statistical assessment of the relationship. The quantification of the relationship is provided by the value of the regression coefficient, in this case -0.1197 (in Table 6-1). This means, for example, that for a 10-degree-increase in temperature, the error is increased by about 1.2 percent (0.1197 x 10). The statistical assessment of the relationship is provided by the probability value of the regression coefficient (0.0007) and is statistically significant at about 1 percent level. However, it should be noted that although the effect of temperature on the measurement errors is statistically significant it is very small and does not have practical influence on the verification and calibration process.

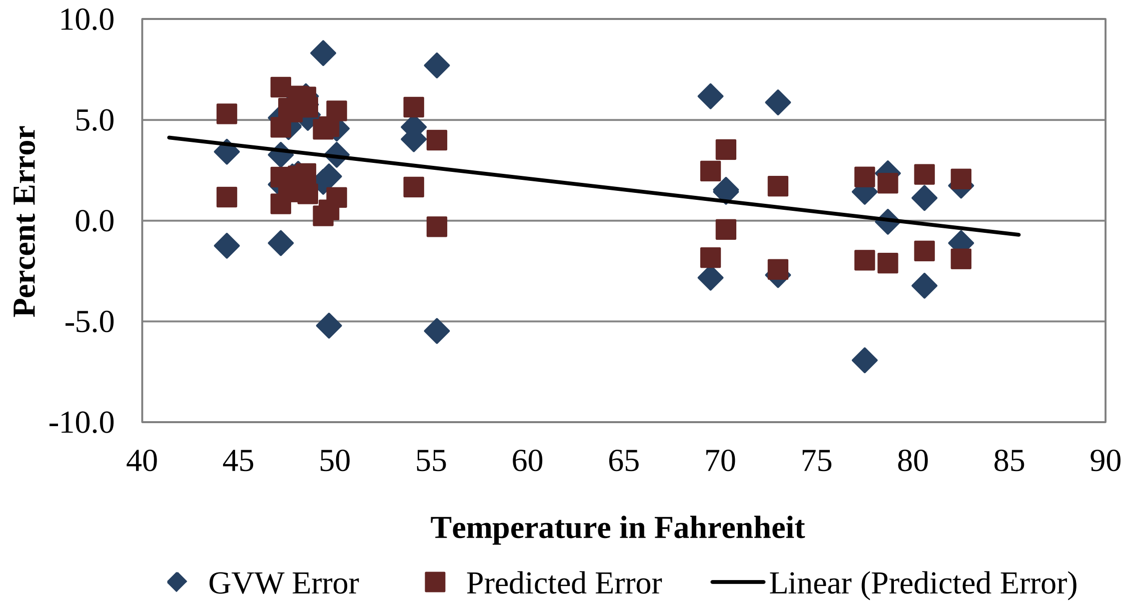


Figure 6-1 – Influence of Temperature on the Measurement Error of GVW

Overall, only temperature and truck type had statistically significant effect on the GVW measurement errors. The lowest probability value given in Table 6-1 was 2.3 10^{-5} for truck type. This means that there is about 0.002 percent chance that the value of regression coefficient for truck type (4.1318) can occur by chance alone. The regression coefficient for truck type in Table 6-1 represents the difference between the mean errors for the Primary and Secondary trucks. (Truck type is an indicator variable with values of 0 or 1). Thus, the average measurement error for the Secondary truck was about 4.1 percent higher than the corresponding error for the Primary truck.

6.1.3 Summary Results

Table 6-2 lists regression coefficients and their probability values for all combinations of factors and percent errors evaluated. Entries in the table are provided only if the probability value was smaller than 0.20. The dash in Table 6-2 indicates that the relationship was not significant (the probability that the relationship can occur by chance alone was greater than 20 percent) and N/A means that there are no applicable results. Only the Primary truck had tandem axles on the trailer, and only the Secondary truck had tridem axles on the trailer. Consequently, it was not possible to evaluate the effect of truck type on the measurement errors of tandem and tridem axles on trailers.

Table 6-2 – Summary of Regression Analysis

Parameter	**Factor**					
	Speed		**Temperature**		**Truck type**	
	Regression coefficient	Probability value (p-value)	Regression coefficient	Probability value (p-value)	Regression coefficient	Probability value (p-value)
GVW	0.1660	0.1352	-0.1197	0.0007	4.1318	$2.21\ 10^{-5}$
Steering axle	–	–	0.1058	0.1305	–	–
Tandem axle tractor	0.3073	0.0080	-0.1784	$3.78\ 10^{-6}$	4.4404	$8.25\ 10^{-6}$
Tandem axle trailer*	0.7725	0.0264	-0.2812	0.0116	–	–
Tridem axle trailer*	-3.725	0.1183	–	–	–	–

Note: *Results are based on 20 observations only

6.1.4 Conclusions

1. According to Table 6-2, speed had a statistically significant effect on only tandem axle measurement errors (assuming that the statistical significance requires $p < 0.05$).

2. Temperature had statistically significant effect on the measurement errors of GVW and tandem axles. Even thought the effect was statistically significant, the values of the regression coefficients are small (close to zero) indicating that this relationship has no practical significance.

3. Truck type had statistically significant effect on GVW and tandem axle on trailers measurement errors. The regression coefficients for truck type in Table 6-2 represent the difference between the mean errors for the Primary and Secondary trucks. The effect of truck type is further analyzed in Section 6.1.5.

4. Even though speed, temperature and truck type had statistically significant effects on measurement errors of some of the parameters, the practical significance of these effects on WIM system calibration tolerances reported in Table 5-16 was relatively small. This conclusion is valid for the range of speed, temperature and truck type used or encountered during the calibration. In addition, the speed and truck type are used in the calibration process and that their influence on measurement errors is mitigated by the selection of compensation factors (Table 5-9).

6.1.5 Contribution of Two Trucks to Calibration

Calibration of WIM systems installed in LTPP lanes is carried out by adjusting calibration factors based on measurement errors of GVW obtained for calibration trucks. During the calibration process, the GVW measurement errors obtained for two calibration trucks are combined when calculating and setting calibration factors. Different calibration factors are used for different speed points (truck speeds). The question posed in this section is: What is the contribution of the individual calibration trucks to the calibration?

The contribution of using Primary and Secondary trucks for the calibration of the WIM system is illustrated using Figure 6-2 and Figure 6-3. Figure 6-2 shows that prior to calibration speed appears to have similar influence on the GVW measurement errors for each truck, however, by different degrees. Both trucks show an overestimation of GVW that decreases as speed increases. The use of a heavily loaded and also a partially loaded truck allows the test truck sample to represent a greater population of regular truck traffic, and therefore allow for more precise GVW estimation for the truck population as a whole.

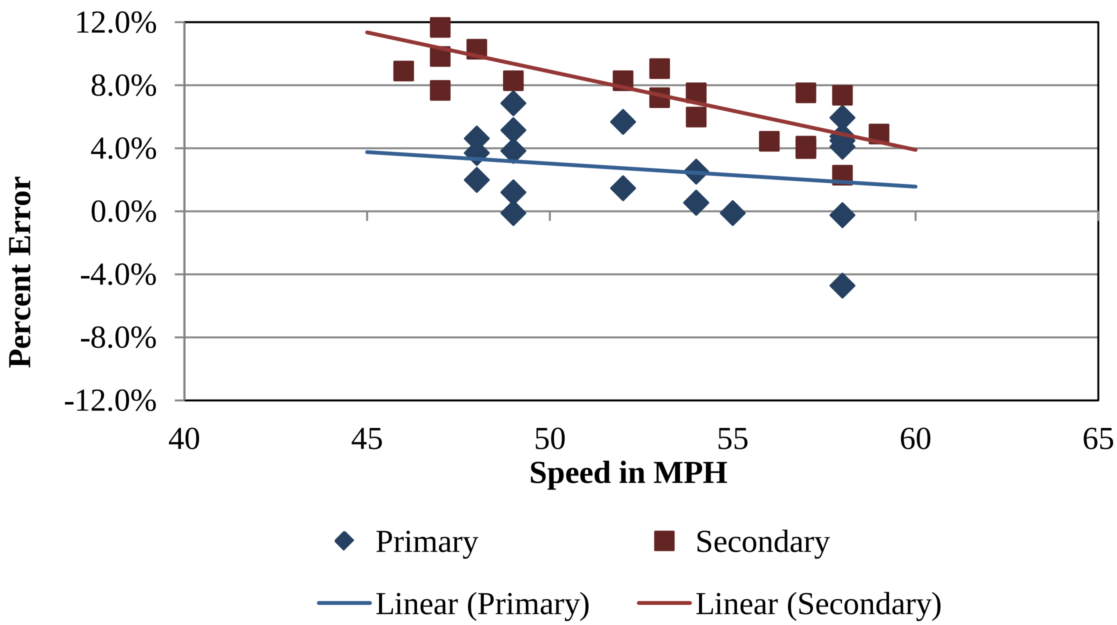


Figure 6-2 – Influence of Speed on the GVW Measurement Error of Primary and Secondary Trucks before Calibration

The results obtained after the calibration are illustrated in Figure 6-3. As a result of the calibration, the primary truck trend now shows an increase in measurement errors (weight estimate) as speed increases and the secondary truck shows a decreasing weight estimate as speed increases but at much lower rate compared with pre-calibration. The opposing trends of the two trucks cancel one another out, and the combined GVW measurement error is closer to zero than either truck alone. The observed trends were found to be not statistically significant: for the Primary truck, the slope of the trend line was 0.29 and its p-value was 0.16; for the Secondary truck, the slope of the trendline was -0.16 and its p-value was 0.22). For both trucks combined, the relation between GVW and speed was also not statistically significant (Table 6-2 gives the p-value of 0.1352).

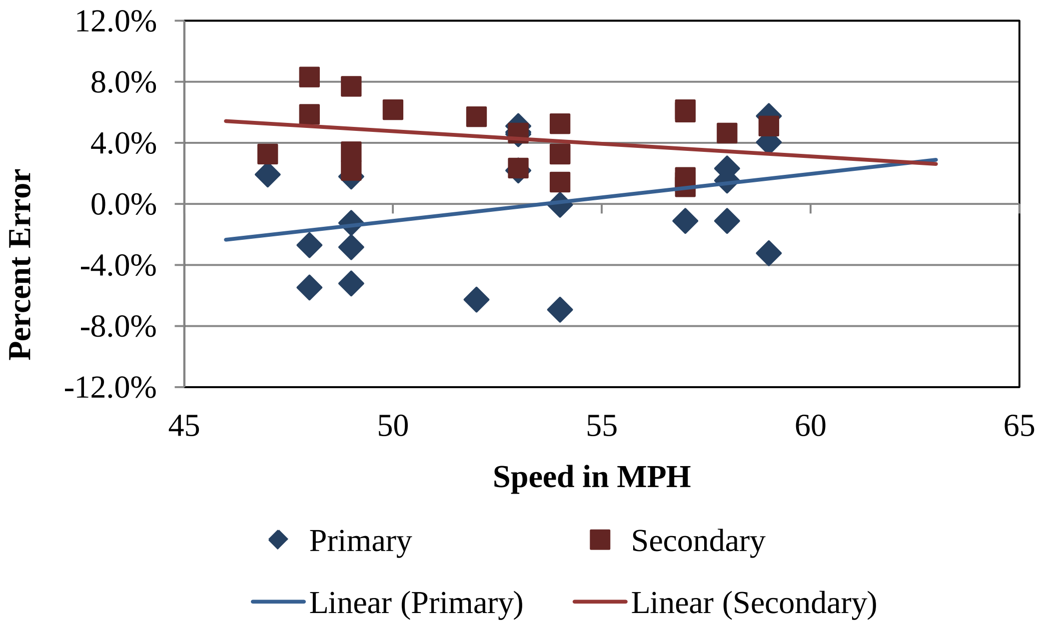


Figure 6-3 – Influence of Speed on the GVW Measurement Error of Primary and Secondary Trucks after Calibration

In addition to relation between speed and GVW errors, the differences in mean GVW errors between two calibration trucks were evaluated. For this site, the use of only one of the trucks (Primary or Secondary) with 20 calibration runs would have resulted in a somewhat different verification and calibration results. For the pre-validation, the mean measurement errors (for all speed combined) for the Primary truck was 2.6 percent, and the corresponding error for the Secondary truck was 7.5 percent; the combined error being 5.1 percent.

For the post-validation, the mean GVW measurement error for the Primary truck was -0.1 percent, and the GVW measurement error for the Secondary truck was 4.2 percent. The combined GVW error for the test truck population was 2.1 percent, a reduction of 3.0 percent from the pre-validation.

More detailed analysis of the influence of calibration trucks on the verification/calibration results would be beneficial. In this case, the Primary and the Secondary trucks were of different vehicle Class (9 versus 10) and the WIM system can be described as a system with rather high variance of measurement errors (as shown subsequently in Table 7.2). Although it might be expected that the tridem axle group may have contributed to the high overall variance in axle group error for this site, Table 5-16 illustrates that the variance in tandem axle error was actually greater than the variance in tridem axle error.

6.2 Misclassification Analysis

A post-visit analysis was conducted on misclassifications involving heavy truck identified during the post-validation classification study conducted in the field. For this site, a total of 13 vehicles, including no heavy trucks (6 – 13) were misclassified by the equipment. Most misclassifications involved Class 3 pick-up trucks towing small trailers, boats or RV campers. An example is shown in Photo 6-1.

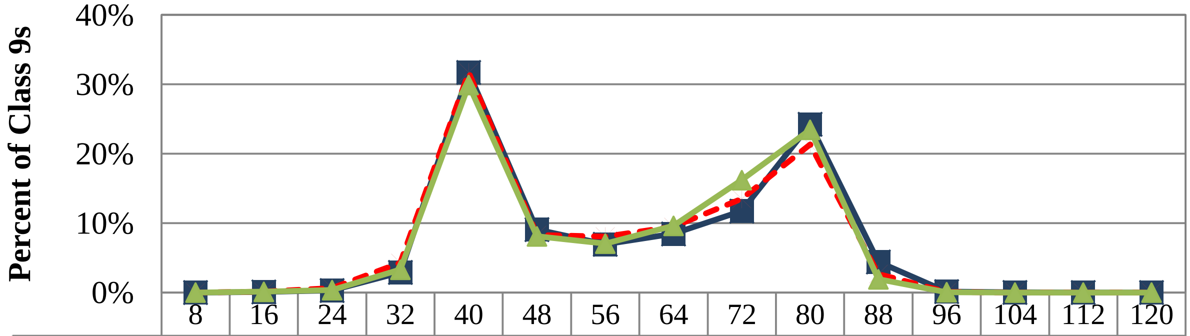
Photo 6-1 – Video Capture of Class 3 Vehicle (Pick-up Truck) Towing a Trailer

Setting minimum weight limit on trailer axles could prevent these types of misclassifications in the future.

6.3 Traffic Data Analysis

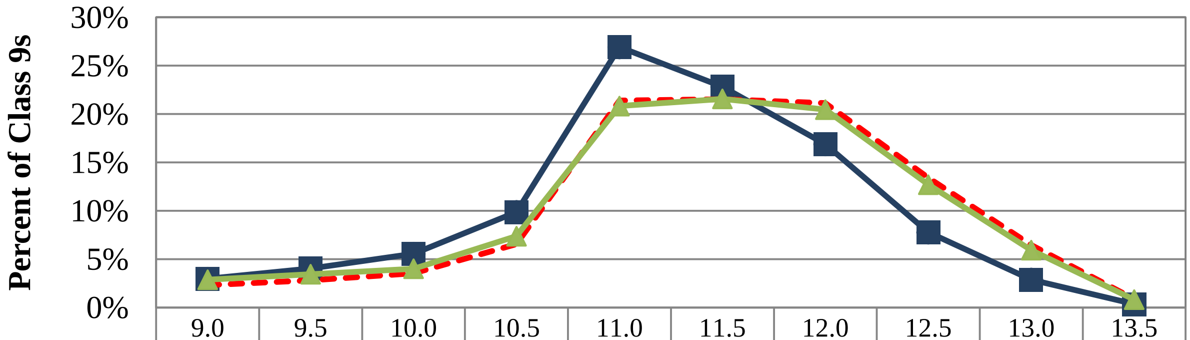
6.3.1 GVW and Steering Axle Weight Distributions

As a result of the Post-Visit Traffic Data Analysis, it appears that the loaded and unloaded peaks for GVW and the steering axle weight distribution from the Post-Visit Sample of May 16, 2012 and the Comparison Data Set of April 14, 2011 are similar, as illustrated in Figure 6-3 and



	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120
Data	0.0%	0.1%	0.3%	2.9%	31.7	9.1%	7.0%	8.4%	11.7	24.3	4.4%	0.1%	0.0%	0.0%	0.0%
CDS	0.0%	0.1%	0.6%	4.2%	31.7	8.3%	8.1%	9.5%	13.5	21.3	2.7%	0.0%	0.0%	0.0%	0.0%
Post	0.0%	0.1%	0.3%	3.3%	29.9	8.1%	7.1%	9.6%	16.2	23.5	1.9%	0.0%	0.0%	0.0%	0.0%

Figure 6-4 – Class 9 GVW Distribution



	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5
Data	3.0%	4.0%	5.5%	9.9%	26.9%	22.8%	16.9%	7.8%	2.9%	0.3%
CDS	2.3%	2.8%	3.5%	6.5%	21.4%	21.5%	21.1%	13.4%	6.5%	0.9%
Post	2.9%	3.4%	4.0%	7.4%	20.8%	21.6%	20.5%	12.7%	5.9%	0.8%

Figure 6-5 – Class 9 Steering Axle Weight Distribution

6.3.2 Imbalance

Since the IRD 1060 WIM System is not configured to provide wheel weights, the imbalance analysis was performed.

6.3.3 WIM System Factor Adjustments

Since the average GVW and steering axle weights provided during the Post-Visit data analysis are similar to those provided by the Comparison Data Set, no further adjustments to the WIM system factors are recommended.

7 Previous WIM Site Validation Information

The information reported in this section provides a summary of the performance of the WIM equipment since it was installed or since the first validation was performed on the equipment. The information includes historical data on weight and classification accuracies as well as a comparison of post-validation results.

7.1 Classification

The information in Table 7-1 data was extracted from the most recent previous validation and was updated to include the results of this validation.

Table 7-1 – Classification Validation History

Date	Misclassification Percentage by Class											Pct Unclass
	3	4	5	6	7	8	9	10	11	12	13	
28-Nov-06	-	-	-	0	0	50	0	0	0	0	0	0
29-Nov-06	-	-	0	0	-	50	0	0	-	0	0	0
11-Jul-07	-	-	-	0	-	-	0	0	0	-	-	0
12-Jul-07	-	-	-	0	-	0	0	0	0	-	-	0
22-Apr-08	-	0	33	0	-	50	2	4	0	-	-	0
23-Apr-08	-	100	33	100	-	25	2	11	0	-	-	0
29-Mar-11	-	0	0	38	0	0	0	0	0	0	0	0
30-Mar-11	-	0	0	50	17	0	0	0	0	0	0	0
1-May-12	64	100	48	33	0	0	0	5	0	0	0	0
2-May-12	56	0	57	0	0	0	2	0	0	0	0	0

7.2 Weight

Table 7-2 data was extracted from the previous validation and was updated to include the results of this validation. The table provides the mean error and standard deviation for GVW, steering and single axles and tandems for prior pre- and post-validations.

Table 7-2 – Weight Validation History

Date	Mean Error and 2SD		
	GVW	**Single Axles**	**Tandem**
28-Nov-06	-6.0 ± 8.6	-12.9 ± 7.3	-4.5 ± 11.7
29-Nov-06	0.3 ± 6.4	-3.7 ± 11.5	1.2 ± 8.4
11-Jul-07	11.7 ± 5.0	6.2 ± 13.3	12.7 ± 6.4
12-Jul-07	-1.0 ± 4.7	0.6 ± 11.2	-1.2 ± 5.7
22-Apr-08	-3.3 ± 4.7	-2.8 ± 9.3	-3.2 ± 7.1
23-Apr-08	1.2 ± 6.9	3.2 ± 9.7	1.0 ± 9.6
29-Mar-11	5.3 ± 7.9	4.8 ± 14.4	5.3 ± 10.9
30-Mar-11	1.0 ± 7.6	-0.4 ± 14.2	0.1 ± 7.9
1-May-12	5.1 ± 7.6	1.0 ± 14.5	4.3 ± 10.6
2-May-12	2.1 ± 7.7	-3.8 ± 11.9	-3.8 ± 12.1

The post-validation bias has remained reasonably consistent since the site was first validated. However, the site does experience significant drift in mean measurement errors between validations. The variability of the measurement errors (expressed in Table 7.2 as two standard deviations) appears to be relatively high, but has not changed much since the scale installation in November 2006. It appears that the measurement errors are due to inherent sensor response rather than due to pavement or sensor deterioration over the past 8 years. The table also demonstrates the effectiveness of the validations in bringing the weight estimations within LTPP SPS WIM equipment tolerances.

8 Additional Information

The following information is provided in the attached appendix:

- Site Photographs
    - Equipment
    - Test Trucks
    - Pavement Condition
- Pre-validation Sheet 16 – Site Calibration Summary
- Post-validation Sheet 16 – Site Calibration Summary
- Pre-validation Sheet 20 – Classification and Speed Study
- Post-validation Sheet 20 – Classification and Speed Study

Additional information is available upon request through LTPP INFO at ltppinfo@dot.gov, or telephone (202) 493-3035. This information includes:

- Sheet 17 – WIM Site Inventory
- Sheet 18 – WIM Site Coordination
- Sheet 19 – Validation Test Truck Data
- Sheet 21 – WIM System Truck Records
- Sheet 22 – Site Equipment Assessment plus Addendum
- Sheet 24A/B – Site Photograph Logs
- Updated Handout Guide

WIM System Field Calibration and Validation - Photos

Washington, SPS-2
SHRP ID: 530200

Validation Date: May 1, 2012

Photo 1 – Cabinet Exterior

Photo 2 – Cabinet Interior

Photo 3 – Leading Loop

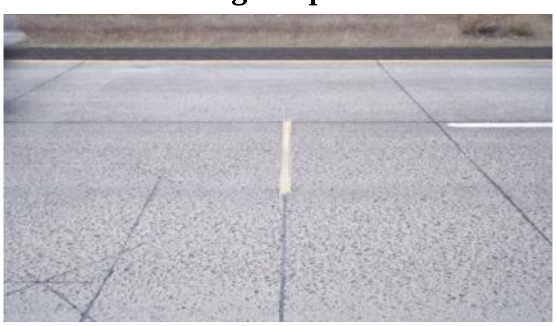


Photo 4 – Leading WIM Sensor

Photo 5 – Trailing WIM Sensor

Photo 6 – Trailing Loop Sensor

Photo 7 – Power Service Box

Photo 8 – Telephone Service Box

Photo 9 – Downstream

Photo 10 – Upstream

Photo 11– Truck 1

Photo 12 – Truck 1 Tractor

Photo 13 – Truck 1 Trailer and Load

Photo 14 – Truck 1 Suspension 1

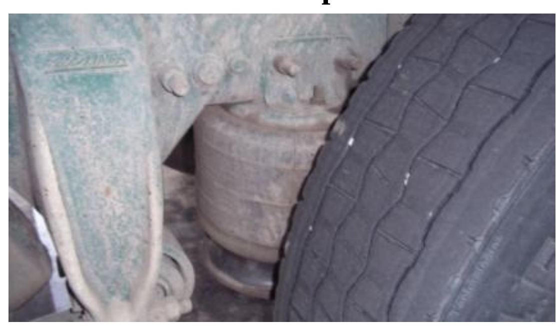


Photo 15 – Truck 1 Suspension 2

Photo 16 – Truck 1 Suspension 3

Photo 17 – Truck 1 Suspension 4

Photo 18 – Truck 1 Suspension 5

Photo 19 – Truck 2

Photo 20 – Truck 2 Tractor

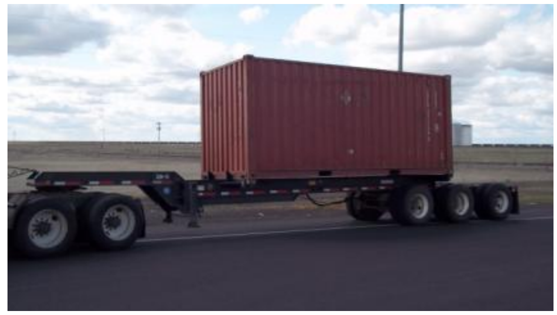


Photo 21 – Truck 2 Trailer and Load

Photo 22 – Truck 2 Suspension 1

Photo 23 – Truck 2 Suspension 2

Photo 24 – Truck 2 Suspension 3

Photo 25 – Truck 2 Suspension 4

Photo 26 – Truck 2 Suspension 5

Photo 3 – Truck 2 Suspension 6

Traffic Sheet 16 LTPP MONITORED TRAFFIC DATA SITE CALIBRATION SUMMARY	STATE CODE:	53
	SPS WIM ID:	530200
	DATE (mm/dd/yyyy)	5/1/2012

SITE CALIBRATION INFORMATION

1. DATE OF CALIBRATION {mm/dd/yy} 5/1/12

2. TYPE OF EQUIPMENT CALIBRATED: Both

3. REASON FOR CALIBRATION: LTPP Validation

4. SENSORS INSTALLED IN LTPP LANE AT THIS SITE (Select all that apply):

a. Inductance Loops c. ____
b. Quartz Piezo d. ____

5. EQUIPMENT MANUFACTURER: IRD 1060 Series

WIM SYSTEM CALIBRATION SPECIFICS

6. CALIBRATION TECHNIQUE USED: Test Trucks

Number of Trucks Compared: ____
Number of Test Trucks Used: 2
Passes Per Truck: 20

	Type	Drive Suspension	Trailer Suspension
Truck 1:	9	steel spring	air
Truck 2:	10	steel spring	standard
Truck 3:			

7. SUMMARY CALIBRATION RESULTS (expressed as a %):

Mean Difference Between -

	Mean		Standard Deviation
Dynamic and Static GVW:	5.1%	Standard Deviation:	3.7%
Dynamic and Static Single Axle:	1.0%	Standard Deviation:	7.2%
Dynamic and Static Double Axles:	4.3%	Standard Deviation:	5.1%

8. NUMBER OF SPEEDS AT WHICH CALIBRATION WAS PERFORMED: 3

9. DEFINE SPEED RANGES IN MPH:

			Low		High	Runs
a.	Low	-	46.0	to	50.3	15
b.	Medium	-	50.4	to	54.8	11
c.	High	-	54.9	to	59.0	14
d.		-		to		
e.		-		to		

Traffic Sheet 16 LTPP MONITORED TRAFFIC DATA SITE CALIBRATION SUMMARY	STATE CODE: SPS WIM ID: DATE (mm/dd/yyyy)	53 530200 5/1/2012

10. CALIBRATION FACTOR (AT EXPECTED FREE FLOW SPEED) 0 | 0

11. IS AUTO- CALIBRATION USED AT THIS SITE? No

If yes , define auto-calibration value(s):

CLASSIFIER TEST SPECIFICS

12. METHOD FOR COLLECTING INDEPENDENT VOLUME MEASUREMENT BY VEHICLE CLASS:

Manual

13. METHOD TO DETERMINE LENGTH OF COUNT: Number of Trucks

14. MEAN DIFFERENCE IN VOLUMES BY VEHICLES CLASSIFICATION:

FHWA Class 9:	3.0	FHWA Class	5	-	-43.0
FHWA Class 8:	700.0	FHWA Class		-	
		FHWA Class		-	
		FHWA Class		-	

Percent of "Unclassified" Vehicles: 0.0%

Validation Test Truck Run Set - Pre

Person Leading Calibration Effort: **Kevin Trousdale**
Contact Information: Phone: 717-975-3550
E-mail: ktrousdale@ara.com

Traffic Sheet 16	STATE CODE:	53
LTPP MONITORED TRAFFIC DATA	SPS WIM ID:	530200
SITE CALIBRATION SUMMARY	DATE (mm/dd/yyyy)	5/2/2012

SITE CALIBRATION INFORMATION

1. **DATE OF CALIBRATION** {mm/dd/yy} 5/2/12

2. **TYPE OF EQUIPMENT CALIBRATED:** Both

3. **REASON FOR CALIBRATION:** LTPP Validation

4. **SENSORS INSTALLED IN LTPP LANE AT THIS SITE** (Select all that apply):
   a. Inductance Loops c. ______
   b. Quartz Piezo d. ______

5. **EQUIPMENT MANUFACTURER:** IRD 1060 Series

WIM SYSTEM CALIBRATION SPECIFICS

6. **CALIBRATION TECHNIQUE USED:** Test Trucks

Number of Trucks Compared: ______
Number of Test Trucks Used: 2
Passes Per Truck: 21

	Type	Drive Suspension	Trailer Suspension
Truck 1:	9	steel spring	air
Truck 2:	10	steel spring	standard
Truck 3:			

7. **SUMMARY CALIBRATION RESULTS** (expressed as a %):

Mean Difference Between -

	Mean		Standard Deviation
Dynamic and Static GVW:	2.1%	Standard Deviation:	3.8%
Dynamic and Static Single Axle:	-3.8%	Standard Deviation:	5.9%
Dynamic and Static Double Axles:	1.7%	Standard Deviation:	5.9%

8. **NUMBER OF SPEEDS AT WHICH CALIBRATION WAS PERFORMED:** 3

9. **DEFINE SPEED RANGES IN MPH:**

			Low		High	Runs
a.	Low	-	47.0	to	51.0	14
b.	Medium	-	51.1	to	55.1	14
c.	High	-	55.2	to	59.0	14
d.		-		to		
e.		-		to		

Traffic Sheet 16 LTPP MONITORED TRAFFIC DATA SITE CALIBRATION SUMMARY	STATE CODE: 53 SPS WIM ID: 530200 DATE (mm/dd/yyyy) 5/2/2012

10. CALIBRATION FACTOR (AT EXPECTED FREE FLOW SPEED) 0 | 0

11. IS AUTO- CALIBRATION USED AT THIS SITE? No

If yes , define auto-calibration value(s):

CLASSIFIER TEST SPECIFICS

12. METHOD FOR COLLECTING INDEPENDENT VOLUME MEASUREMENT BY VEHICLE CLASS:

Manual

13. METHOD TO DETERMINE LENGTH OF COUNT: Number of Trucks

14. MEAN DIFFERENCE IN VOLUMES BY VEHICLES CLASSIFICATION:

FHWA Class 9:	2.0	FHWA Class	5	-	-50.0
FHWA Class 8:	300.0	FHWA Class		-	
		FHWA Class		-	
		FHWA Class		-	

Percent of "Unclassified" Vehicles: 0.0%

Validation Test Truck Run Set - Post

Person Leading Calibration Effort: **Kevin Trousdale**

Contact Information: Phone: 717-975-3550

E-mail: ktrousdale@ara.com

Traffic Sheet 20 LTPP MONITORED TRAFFIC DATA SPEED AND CLASSIFICATION STUDIES	STATE CODE: 53 SPS WIM ID: 530200 DATE (mm/dd/yyyy) 5/1/2012

Count - 111 Time = 4:08:38 Trucks (4-15) - 100 Class 3s - 11

WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class	WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class
58	10	1704	58	10	59	8	2295	60	8
60	8	1706	60	5	62	8	2312	64	3
56	13	1709	55	13	59	9	2328	60	9
58	10	1714	60	10	59	9	2331	60	9
62	10	1717	64	10	54	13	2334	58	13
59	9	1722	60	9	73	8	2346	74	3
58	8	1731	60	5	64	8	2352	65	3
57	9	1743	57	9	60	13	2359	60	13
60	9	1744	59	9	59	10	2360	60	10
57	13	1745	59	13	59	10	2361	59	10
59	13	2218	59	13	57	5	2363	58	5
59	10	2221	61	10	60	8	2489	63	8
59	3	2225	59	3	57	9	2496	55	9
59	10	2232	61	10	70	5	2508	67	5
59	6	2233	59	6	54	5	2584	57	5
59	9	2244	63	9	59	9	2586	60	9
63	10	2245	63	10	67	3	2593	69	3
62	4	2266	64	5	57	8	2604	58	3
60	9	2268	61	9	63	4	2634	65	5
61	9	2269	58	9	59	10	2638	59	10
64	9	2273	64	9	57	7	2640	60	7
60	12	2276	62	12	62	6	2645	65	6
65	8	2279	66	5	60	10	2649	60	10
59	9	2280	60	9	58	13	2658	60	13
59	10	2289	60	10	62	9	2659	61	9

Sheet 1 - 0 to 50 Start: 9:51:00 Stop: 12:13:31

Recorded By: kt Verified By: djw

Validation Test Truck Run Set - Pre

Traffic Sheet 20 LTPP MONITORED TRAFFIC DATA SPEED AND CLASSIFICATION STUDIES	STATE CODE:	53
	SPS WIM ID:	530200
	DATE (mm/dd/yyyy)	5/1/2012

WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class	WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class
60	9	2664	61	9	60	10	2926	63	10
60	9	2666	60	9	**61**	**8**	**2927**	**60**	**5**
60	9	2668	59	9	57	13	2932	59	13
59	**4**	**2687**	**63**	**6**	62	9	2935	63	9
69	**8**	**2703**	**69**	**5**	56	10	2964	54	10
61	10	2707	59	10	60	9	2965	63	9
59	5	2708	59	5	67	5	3062	63	5
60	10	2719	62	10	65	6	3072	61	6
61	9	2766	63	9	63	10	3074	63	10
62	10	2768	63	10	**65**	**8**	**3076**	**66**	**5**
62	9	2803	66	9	67	5	3077	65	5
59	9	2806	61	9	73	5	3080	72	5
60	10	2804	63	10	62	9	3109	60	9
62	9	2811	64	9	62	9	3143	61	9
61	9	2814	62	9	64	9	3145	65	9
59	13	2815	62	13	60	9	3150	61	9
62	9	2869	65	9	**62**	**8**	**3157**	**63**	**5**
59	9	2872	59	9	58	10	3165	59	10
58	**5**	**2874**	**60**	**4**	63	9	3169	63	9
60	9	2877	61	9	60	13	3171	61	13
59	**4**	**2885**	**60**	**6**	64	5	3175	65	5
59	3	2892	63	3	66	3	3184	68	3
62	**9**	**2896**	**63**	**10**	58	5	3187	59	5
57	9	2915	59	9	**56**	**8**	**3207**	**53**	**3**
59	6	2920	57	6	60	11	3209	62	11

Sheet 2 - 51 to 100 Start: 12:14:00 Stop: 13:34:28

Recorded By: kt Verified By: djw

Validation Test Truck Run Set - Pre

Traffic Sheet 20 LTPP MONITORED TRAFFIC DATA SPEED AND CLASSIFICATION STUDIES	STATE CODE: 53 SPS WIM ID: 530200 DATE (mm/dd/yyyy) 5/1/2012

WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class	WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class
60	**11**	**3210**	**60**	**5**					
64	10	3247	63	10					
62	9	3249	62	9					
61	**8**	**3274**	**64**	**3**					
60	9	3315	59	9					
63	13	3320	62	13					
67	**8**	**3339**	**68**	**3**					
57	9	3364	55	9					
63	5	3365	63	5					
60	5	3375	61	5					
62	9	3383	63	9					

Sheet 3 - 101 - 150 Start: 13:34:30 Stop: 13:59:38

Recorded By: kt Verified By: djw

Validation Test Truck Run Set - Pre

Traffic Sheet 20 LTPP MONITORED TRAFFIC DATA SPEED AND CLASSIFICATION STUDIES	STATE CODE: 53 SPS WIM ID: 530200 DATE (mm/dd/yyyy) 5/2/2012

Count - 109 Time = 2:22:18 Trucks (4-15) - 100 Class 3s - 9

WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class	WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class
65	13	940	67	13	58	12	1093	58	12
66	9	944	67	9	63	9	1105	63	9
59	**10**	**945**	**61**	**9**	60	9	1120	60	9
59	9	947	60	9	57	10	1128	58	10
69	3	954	70	3	61	10	1169	61	10
60	10	956	60	10	61	9	1170	60	9
59	9	958	58	9	57	9	1177	58	9
62	9	963	63	9	55	9	1183	55	9
62	9	973	63	9	59	13	1187	61	13
62	13	977	62	13	59	9	1196	60	9
55	9	979	55	9	59	9	1198	61	9
55	9	980	55	9	57	9	1200	59	9
69	**3**	**982**	**71**	**5**	60	11	1216	63	11
61	3	990	61	3	**70**	**5**	**1227**	**66**	**3**
64	10	1030	63	10	62	9	1232	64	9
60	5	1034	62	5	61	9	1239	64	9
59	11	1038	62	11	60	10	1254	61	10
64	9	1040	64	9	62	9	1256	62	9
60	13	1041	62	13	60	9	1267	61	9
60	10	1043	61	10	62	9	1309	65	9
63	10	1049	65	10	62	10	1313	64	10
65	3	1064	65	3	62	10	1316	63	10
61	8	1086	60	8	62	13	1321	64	13
68	9	1090	68	9	63	5	1328	65	5
61	13	1092	59	13	59	13	1330	60	13

Sheet 1 - 0 to 50 Start: 7:54:40 Stop: 8:54:53

Recorded By: kt Verified By: djw

Validation Test Truck Run Set - Post

Traffic Sheet 20 LTPP MONITORED TRAFFIC DATA SPEED AND CLASSIFICATION STUDIES	STATE CODE: 53 SPS WIM ID: 530200 DATE (mm/dd/yyyy) 5/2/2012

WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class	WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class
63	9	1354	66	9	59	9	1550	57	9
61	**3**	**1367**	**62**	**5**	**67**	**8**	**1551**	**68**	**3**
65	9	1371	65	9	**72**	**3**	**1562**	**72**	**5**
62	9	1379	63	9	**71**	**8**	**1622**	**68**	**3**
62	10	1386	63	10	60	9	1624	60	9
64	10	1387	65	10	61	9	1625	60	9
57	5	1392	58	5	64	9	1631	65	9
62	10	1394	63	10	**63**	**3**	**1650**	**66**	**5**
64	3	1397	66	3	61	10	1663	63	10
65	10	1399	64	10	**64**	**9**	**1664**	**67**	**5**
65	13	1402	66	13	58	9	1669	61	9
64	10	1407	66	10	60	9	1670	62	9
73	5	1416	75	5	62	9	1687	63	9
61	**8**	**1473**	**62**	**3**	64	13	1688	65	13
59	9	1483	62	9	61	9	1691	62	9
59	5	1490	63	5	**71**	**8**	**1696**	**70**	**3**
59	8	1501	61	8	60	13	1697	58	13
64	**4**	**1502**	**65**	**5**	64	9	1707	66	9
60	13	1509	63	13	59	11	1723	59	11
64	9	1510	66	9	60	9	1725	60	9
65	9	1514	66	9	62	9	1736	63	9
57	13	1516	59	13	**60**	**8**	**1868**	**63**	**5**
59	9	1531	59	9	57	9	1869	57	9
60	9	1538	62	9	61	9	1874	60	9
61	9	1539	61	9	62	9	1889	63	9

Sheet 2 - 51 to 100 Start: ________ Stop: 10:12:01

Recorded By: kt Verified By: djw

Validation Test Truck Run Set - Post

Traffic Sheet 20 **LTPP MONITORED TRAFFIC DATA** **SPEED AND CLASSIFICATION STUDIES**	STATE CODE: 53 SPS WIM ID: 530200 DATE (mm/dd/yyyy) 5/2/2012

WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class	WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class
59	9	1901	59	9					
60	9	1903	62	9					
60	**8**	**1907**	**63**	**5**					
60	9	1909	61	9					
64	9	1914	64	9					
62	9	1915	62	9					
58	5	1916	59	5					
59	9	1924	61	9					
61	9	1928	62	9					

Sheet 3 - 101 - 150 Start: 10:13:51 Stop: 10:16:58

Recorded By: kt Verified By: djw

Validation Test Truck Run Set - Post