WIM System Field Calibration and Validation Summary Report

Arizona SPS-1
SHRP ID – 040100

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1 Executive Summary

A WIM validation was performed on September 15 and 16, 2010 at the Arizona SPS-1 site located on route US-93 at milepost 52.6, 25 miles north of SR 125.

This site was installed on November 30, 2006. The in-road sensors are installed in the northbound lane. The site is equipped with bending plate WIM sensors and IRD iSINC 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 February 14, 2008 and this validation visit, it appears that no changes have occurred during this time to the basic operating condition of the equipment.

Since this validation, the bridge at the Hoover Dam has been opened to truck traffic. Consequently, a much greater number of trucks will be traveling over the WIM scales at this location. It is recommended that the next validation be performed as soon as it is feasible, preferably during the Spring months to provide for analysis of weight measurement accuracies at opposing weather conditions.

The equipment is in working order. Electronic and electrical checks of all WIM components determined that the WIM equipment was operating within tolerances. Further equipment discussion is provided in Section 3.

During the on-site pavement evaluation, it was noted that no distresses that would affect the performance of the WIM scales were noted. Observations of trucks passing over the site did not detect any motions by the trucks that would affect WIM system accuracies. 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 providing research quality loading data. The summary results of the validation are provided in Table 1.1 below.

Table 1-1 – Post-Validation Results – 16-Sep-10

Parameter	**95% Confidence Limit of Error**	**Site Values**	**Pass/Fail**
Steering Axles	±20 percent	0.1 ± 7.0%	Pass
Tandem Axles	±15 percent	1.0 ± 4.6%	Pass
GVW	±10 percent	0.9 ± 3.2%	Pass
Vehicle Length	±3 percent (1.9 ft)	4.0 ± 1.5 ft	FAIL
Axle Spacing Length	± 0.5 ft [150mm]	-0.1 ± 0.4 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 0.0 ± 1.0 mph, which is within the ±1.0 mph tolerance established by the LTPP Field Operations Guide for SPS WIM Sites.

This site is providing research quality vehicle classification data for heavy trucks (Class 6 – 13). The heavy truck misclassification rate of 0.0% is within the 2.0% acceptability criterion for LTPP SPS WIM sites. The overall misclassification rate of 19.0% from the 21 truck sample (Class 4 – 13) was due to the 4 cross-classifications of Class 3, 4, 5, and 8 vehicles. Low truck volume at this site and small sample size may have affected the objectiveness of this misclassification rate.

There were three test trucks used for the post-validation, although only two trucks were running at any time. Two trucks were used for the calibration. The second truck was switched out between the calibration and 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 refuse.

- The *Secondary* truck was a Class 9 vehicle with air suspension on the tractor tandem, air on the trailer tandem, standard tandem spacing on the tractor and standard tandem on the trailer. The Secondary truck was loaded with refuse.

- The *Third* truck was a Class 9 vehicle, with air suspension on the tractor tandem, air on the trailer tandem, standard tandem spacing on the tractor and standard tandem on the trailer. It was loaded with refuse.

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. 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	1-2	2-3	3-4	4-5	AL	OL
1	75.3	11.1	16.0	16.0	16.2	16.2	14.5	4.3	33.1	4.0	55.9	61.5
2	65.5	10.8	13.4	13.4	14.0	14.0	14.5	4.3	33.4	4.0	56.2	63.6
3	66.1	10.9	13.8	13.8	13.8	13.8	13.3	4.4	33.8	4.1	55.6	63.9

The posted speed limit at the site is 65 mph. During the testing, the speed of the test trucks ranged from to 42 to 66 mph, a variance of 24 mph.

During test truck runs, pavement temperature was collected using a hand-held infrared temperature device. The post-validation pavement surface temperatures varied from 75.0 to 114.2 degrees Fahrenheit, a range of 39.2 degrees Fahrenheit. The partly cloudy weather conditions provided for the desired 30 degree range in temperatures.

A review of the LTPP Standard Release Database 24 shows that there are 22 consecutive months of level "E" WIM data for this site. This site requires at least 3 additional years of data to meet the minimum of five years of research quality data.

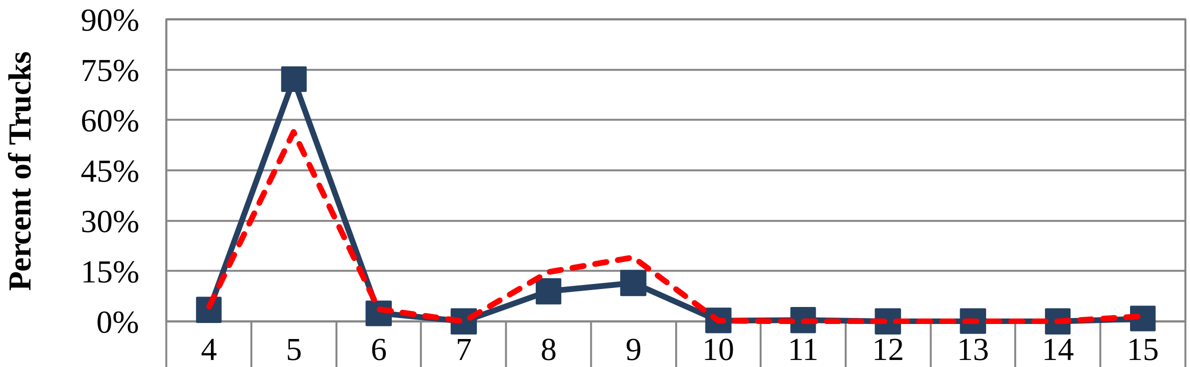
2 Pre-Visit Data Analysis

To assess the quality of the current data, a pre-visit analysis was conducted by comparing a two-week data sample from June 14, 2010 (Data) to the most recent Comparison Data Set (CDS) from February 18, 2008. Due to truck restrictions, there was very limited truck volume data available for conducting the analysis and so definitive conclusions based on this data could not be made.

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 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	3.4%	72.2%	2.4%	0.0%	9.0%	11.4%	0.3%	0.4%	0.0%	0.1%	0.0%	0.8%
CDS	4.4%	56.4%	3.6%	0.0%	14.6%	19.1%	0.1%	0.1%	0.0%	0.0%	0.0%	1.6%

Figure 2-1 – Comparison of Truck Distribution

Table 2-1 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 5 (72.2%) and Class 9 (11.4%). It also indicates that 0.8 percent of the vehicles at this site are unclassified. Table 2-1 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.

Table 2-1 – Truck Distribution from W-Card

Vehicle Classification	CDS		Data		Change
	Date				
	2/18/2008		6/14/2010		
4	144	4.4%	151	3.4%	-0.9%
5	1850	56.4%	3159	72.2%	15.8%
6	119	3.6%	105	2.4%	-1.2%
7	1	0.0%	0	0.0%	0.0%
8	480	14.6%	394	9.0%	-5.6%
9	626	19.1%	501	11.4%	-7.6%
10	3	0.1%	12	0.3%	0.2%
11	2	0.1%	16	0.4%	0.3%
12	1	0.0%	0	0.0%	0.0%
13	1	0.0%	3	0.1%	0.0%
14	0	0.0%	0	0.0%	0.0%
15	53	1.6%	37	0.8%	-0.8%

From the table it can be seen that the number of Class 5 vehicles has increased by 15.8 percent from February 2008 and June 2010. These differences may be attributed to small sample size used to develop vehicle class distributions. During the same time period, the number of Class 9 trucks decreased by -7.6 percent. This may also be attributed to the small truck sample size.

2.2 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 the speed of the test trucks during validation testing. The CDS distribution of speeds is shown in Figure 2-2.

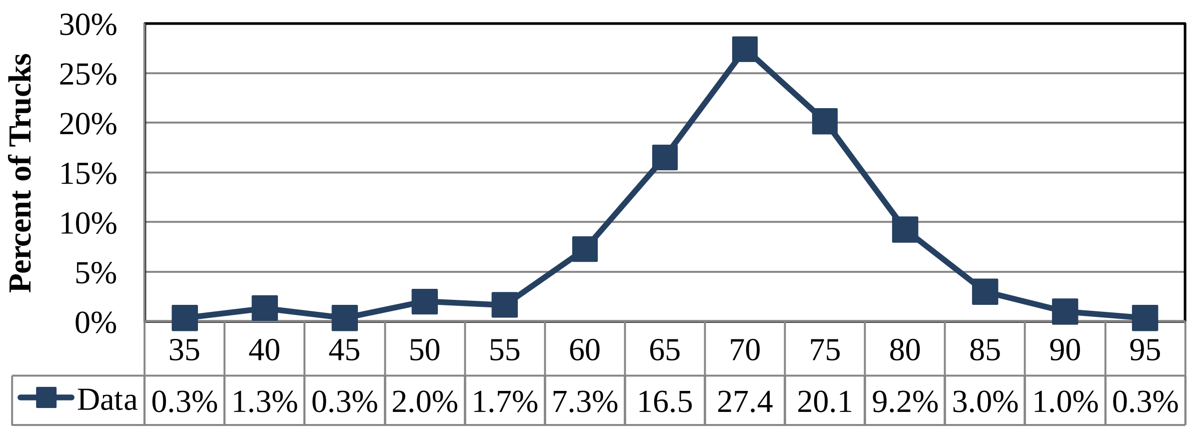


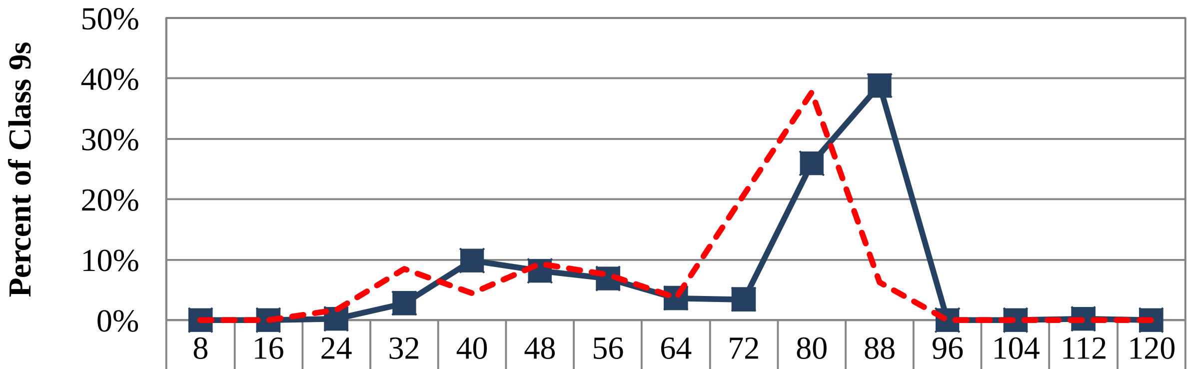
Figure 2-2 – Truck Speed Distribution – 27-Aug-10

As shown in Figure 2-2, the majority of the trucks at this site are traveling between 65 and 75 mph. The posted speed limit at this site is 65 and the 85th percentile speed for trucks at this site is 73 mph. The coverage of truck speeds for the validation will be 45 and 65 mph. Since the 85th percentile speeds for trucks is above the posted speed limit, the post-visit applied calibration will be used to develop compensation factors for speed points from 0 to 0 mph.

2.3 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 June 2010 and the Comparison Data Set from February 2008.

As shown in Figure 2-3, there is a shift to the right for the unloaded and loaded peaks between the February 2008 Comparison Data Set (CDS) and the June 2010 two-week sample W-card dataset (Data). The results indicate that there may have been a change in the system parameter settings or the accuracy has been affected by a change in pavement or sensor condition.



	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120
Data	0.0%	0.0%	0.2%	2.8%	9.9%	8.2%	6.9%	3.6%	3.4%	26.0	38.8	0.0%	0.0%	0.2%	0.0%
CDS	0.0%	0.0%	1.7%	8.5%	4.4%	9.4%	7.5%	3.7%	20.7	37.8	6.3%	0.0%	0.0%	0.0%	0.0%

Figure 2-3 – Comparison of Class 9 GVW Distribution

Table 2-2 is provided to show the statistical comparison between the Comparison Data Set and the current dataset.

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

GVW weight bins (kips)	CDS		Data		Change
	Date				
	2/18/2008		6/14/2010		
8	0	0.0%	0	0.0%	0.0%
16	0	0.0%	0	0.0%	0.0%
24	10	1.7%	1	0.2%	-1.5%
32	50	8.5%	13	2.8%	-5.7%
40	26	4.4%	46	9.9%	5.4%
48	55	9.4%	38	8.2%	-1.2%
56	44	7.5%	32	6.9%	-0.6%
64	22	3.7%	17	3.6%	-0.1%
72	122	20.7%	16	3.4%	-17.3%
80	222	37.8%	121	26.0%	-11.8%
88	37	6.3%	181	38.8%	32.5%
96	0	0.0%	0	0.0%	0.0%
104	0	0.0%	0	0.0%	0.0%
112	0	0.0%	1	0.2%	0.2%
120	0	0.0%	0	0.0%	0.0%
Average =	62.5		68.2		5.7

As shown in the table, the number of unloaded class 9 trucks in the 32 to 40 kips range increased by 5.4 percent while the number of loaded class 9 trucks in the 72 to 80 kips range decreased by 11.8 percent. The number of overweight trucks increased during this time period by 32.8 percent and the overall GVW average for this site increased from 62.5 kips to 68.2 kips. On average, the Class 9 GVW has increased by 5.7 kip or 9.1%.

2.4 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 observed average front axle weight with the expected average front axle weight average for Class 9 trucks of 10.3 kips.

Figure 2-4 shows a comparison between Class 9 front axle weight plots generated by using the two week W-card sample from June 2010 and the Comparison Data Set from February 2008.

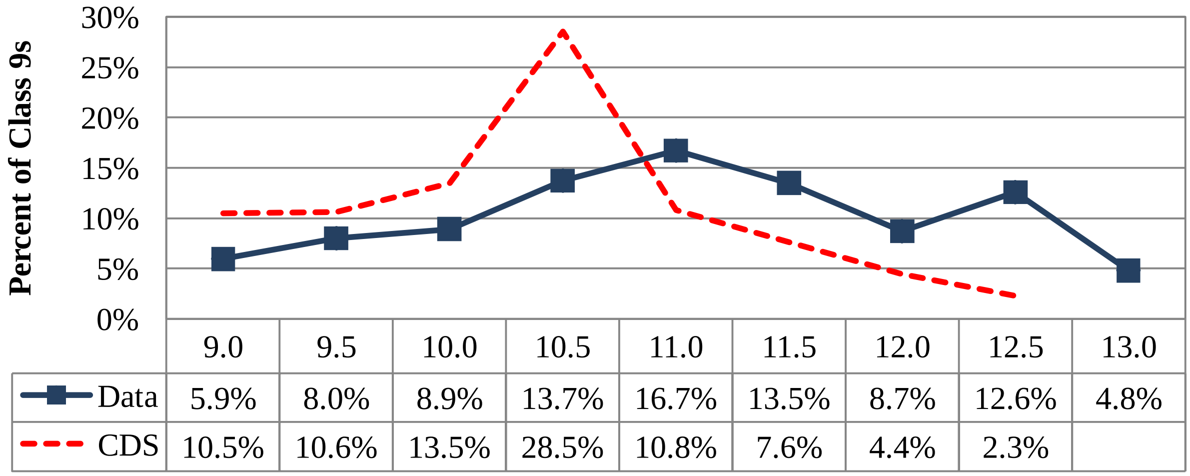


Figure 2-4 – Distribution of Class 9 Front Axle Weights

It can be seen in the figure that the front axle weight has shifted to the right. The average front axle weight appears to have shifted from 10.3 kips for the February 2008 Comparison Data Set (CDS) to 11.0 kips for the June 2010 dataset (Data). In addition, secondary peak at 12.5 kip is observed on the graph based on June 2010 dataset.

Table 2-3 provides the Class 9 front axle weight distribution data for the February 2008 Comparison Data Set (CDS) and the June 2010 dataset (Data).

Table 2-3 – Class 9 Front Axle Weight Distribution from W-Card

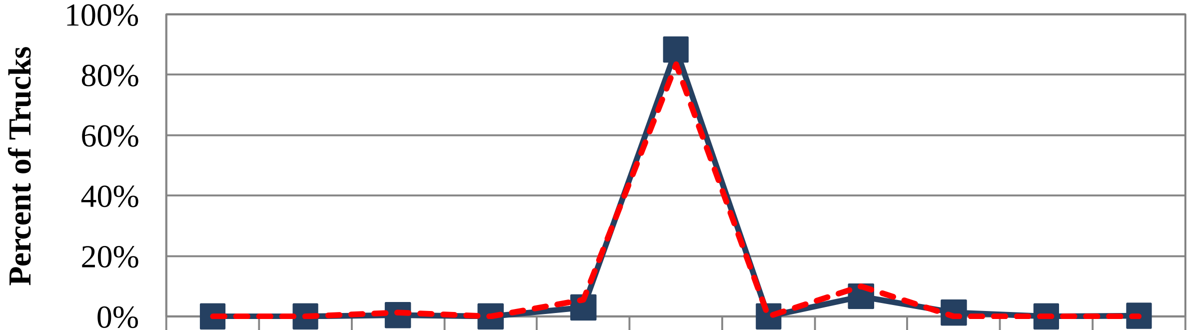
F/A weight bins (kips)	CDS		Data		Change
	Date				
	2/18/2008		6/14/2010		
9.0	58	10.3%	31	7.1%	-3.2%
9.5	59	10.5%	26	5.9%	-4.5%
10.0	60	10.6%	35	8.0%	-2.6%
10.5	76	13.5%	39	8.9%	-4.6%
11.0	161	28.5%	60	13.7%	-14.8%
11.5	61	10.8%	73	16.7%	5.9%
12.0	43	7.6%	59	13.5%	5.9%
12.5	25	4.4%	38	8.7%	4.3%
13.0	13	2.3%	55	12.6%	10.3%
13.5	8	1.4%	21	4.8%	3.4%
Average =	10.6		11.3		0.7

The table shows that the average front axle weight for Class 9 trucks has increased by 0.7 kips, or 6.8 percent. According to the current data, the average front axle weight for Class 9 trucks is 11.3 kips.

2.5 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 with the expected average tractor tandem spacing of 4.25 feet.

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



	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0
Data	0.0%	0.0%	0.4%	0.0%	3.0%	88.4%	0.0%	6.7%	1.3%	0.0%	0.2%
CDS	0.0%	0.0%	1.2%	0.0%	5.4%	83.5%	0.0%	9.9%	0.0%	0.0%	0.0%

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

As seen in the figure, the Class 9 tractor tandem spacing for the February 2008 Comparison Data Set and the June 2010 Data are nearly identical.

Table 2-4 shows the Class 9 axle spacings between the second and third axles for the power unit.

Table 2-4 – Class 9 Axle 3 to 4 Spacing from W-Card

Tandem 1 spacing bins (feet)	CDS		Data		Change
	Date				
	2/18/2008		6/14/2010		
3.0	0	0.0%	0	0.0%	0.0%
3.2	0	0.0%	0	0.0%	0.0%
3.4	7	1.2%	2	0.4%	-0.8%
3.6	0	0.0%	0	0.0%	0.0%
3.8	32	5.4%	14	3.0%	-2.4%
4.0	491	83.5%	412	88.4%	4.9%
4.2	0	0.0%	0	0.0%	0.0%
4.4	58	9.9%	31	6.7%	-3.2%
4.6	0	0.0%	6	1.3%	1.3%
4.8	0	0.0%	0	0.0%	0.0%
5.0	0	0.0%	1	0.2%	0.2%
Average =	4.0		4.0		0.0

From the table it can be seen that the spacing of the tractor tandems for Class 9 trucks at this site is between 3.8 and 4.6 feet. The average tractor tandem spacing is 4.0 feet, which is below the expected average of 4.25 feet. Further analyses are performed during the validation and post-validation analysis.

2.6 Data Analysis Summary

Historical data analysis involved the comparison of the most recent Comparison Data Set (February 2008) based on the last calibration with the most recent two-week WIM data sample from the site (June 2010). Comparison of vehicle class distribution data indicates a 15.8 percent increase in the number of Class 5 vehicles. Analysis of Class 9 weight data indicates that average front axle weights have increased by 6.8 percent (or 0.7 kip) and average Class 9 GVW has increased by 9.1 percent (or 5.7 kip) for the June 2010 data. The data indicates an average truck tandem spacing of 4.0 feet, which is below the expected average of 4.25 feet.

3 WIM Equipment Discussion

From a comparison between the report of the most recent validation of this equipment on March 05, 2008 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 November 30, 2006 by International Road Dynamics. It is instrumented with bending plate weighing sensors and IRD iSINC WIM Controller. As the installation contractor, IRD 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 in 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. All values for the WIM sensors and inductive loops were within tolerances. 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 equipment maintenance actions are recommended.

4 Pavement Discussion

4.1 Pavement Condition Survey

During a visual distress survey of the pavement conducted from the shoulder, no areas of pavement distress that may affect the accuracy of the WIM sensors were noted.

4.2 Profile and Vehicle Interaction

Profile data was collected on January 26, 2010 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, 900 feet prior to WIM scales and 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 248 in/mi and is located approximately 526 feet prior to the WIM scale. The highest IRI value within the 400 foot approach section was 176 in/mi and is located approximately 395 feet prior to the WIM scale. This area of pavement was closely investigated during the validation visit, and truck dynamics in this area were closely observed. There were no distresses observed that would influence truck dynamics in the WIM scale area.

Additionally, a visual observation of the trucks as they approach, traverse and leave the sensor area did not indicate any visible motion of the trucks that would affect the performance of the WIM scales. 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**	**Avg**
Left	LWP	LRI (m/km)	0.738	0.958	0.876		0.857
		SRI (m/km)	1.034	1.086	0.896		1.005
		Peak LRI (m/km)	0.952	0.984	0.999		0.978
		Peak SRI (m/km)	1.084	1.220	1.313		1.206
	RWP	LRI (m/km)	1.068	0.994	0.871		0.978
		SRI (m/km)	0.921	1.070	1.062		1.018
		Peak LRI (m/km)	1.068	1.007	1.051		1.042
		Peak SRI (m/km)	1.123	1.275	1.325		1.241
Center	LWP	LRI (m/km)	1.006	0.761	0.814	0.812	0.848
		SRI (m/km)	1.049	0.822	0.559	0.742	0.793
		Peak LRI (m/km)	1.006	0.870	0.927	0.921	0.931
		Peak SRI (m/km)	1.322	1.023	0.762	0.783	0.973
	RWP	LRI (m/km)	0.940	0.818	0.921	1.073	0.938
		SRI (m/km)	1.467	1.200	1.912	**2.402**	1.745
		Peak LRI (m/km)	1.011	0.992	0.932	1.100	1.009
		Peak SRI (m/km)	1.579	1.555	2.056	**2.584**	1.944
Right	LWP	LRI (m/km)	0.765	0.754	0.842		0.787
		SRI (m/km)	0.819	*0.445*	0.809		0.691
		Peak LRI (m/km)	1.128	1.157	1.207		1.164
		Peak SRI (m/km)	0.881	1.005	1.264		1.050
	RWP	LRI (m/km)	0.733	0.698	0.749		0.727
		SRI (m/km)	0.602	0.596	0.723		0.640
		Peak LRI (m/km)	0.785	0.863	0.840		0.829
		Peak SRI (m/km)	0.803	*0.712*	0.819		0.778

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. The highest values, on average, are the Peak SRI values in the right wheel path of the center passes..

4.4 Recommended Pavement Remediation

No pavement remediation 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 49 pre-validation test truck runs were conducted on September 15, 2010, beginning at approximately 9:03 AM and continuing until 12:59 PM.

The two test trucks consisted of:

- A Class 9 truck, loaded with refuse, and equipped with air suspension on truck and trailer tandems and with standard tandem spacings on both the tractor and trailer.

- A Class 9, 5-axle truck, loaded with refuse, and equipped with air suspension on the tractor, air suspension on the trailer, with standard tandem spacing on the tractor and standard tandem spacing 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	1-2	2-3	3-4	4-5	AL	OL
1	75.5	11.0	16.0	16.0	16.2	16.2	14.5	4.3	33.1	4.0	55.9	61.5
2	65.5	10.8	13.4	13.4	14.0	14.0	14.5	4.3	33.4	4.0	56.2	63.6

Test truck speeds varied by 21 mph, from 44 to 65 mph. The measured pre-validation pavement temperatures varied 28.6 degrees Fahrenheit, from 84.5 to 113.1. The partly cloudy weather conditions nearly provided for reaching the desired 30 degree temperature range. Table 5-2 provides a summary of the pre-validation results.

Table 5-2 – Pre-Validation Overall Results – 15-Sep-10

Parameter	95% Confidence Limit of Error	Site Values	Pass/Fail
Steering Axles	+20 percent	4.4 ± 8.5%	Pass
Tandem Axles	+15 percent	7.7 ± 8.8%	FAIL
GVW	+10 percent	7.0 ± 7.7%	FAIL
Vehicle Length	±3 percent (1.9 ft)	4.3 ± 0.9 ft	FAIL
Vehicle Speed	± 1.0 mph	-0.1 ± 1.4 mph	FAIL
Axle Spacing Length	+ 0.5 ft [150mm]	-0.1 ± 0.5 ft	FAIL

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 -0.1 ± 1.4 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 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 65 mph. The test runs were divided into three speed groups - low, medium and high speeds, as shown in Table 5-3 below.

Table 5-3 – Pre-Validation Results by Speed – 15-Sep-10

Parameter	95% Confidence Limit of Error	Low	Medium	High
		44.0 to 51.0 mph	51.1 to 58.1 mph	58.2 to 65.0 mph
Steering Axles	+20 percent	3.0 ± 5.0%	7.5 ± 8.1%	0.1 ± 4.9%
Tandem Axles	+15 percent	4.3 ± 3.8%	11.9 ± 4.8%	4.8 ± 5.1%
GVW	+10 percent	4.0 ± 2.8%	11.0 ± 3.8%	4.0 ± 3.1%
Vehicle Length	±3 percent (1.9 ft)	4.2 ± 1.2 ft	4.3 ± 0.9 ft	4.4 ± 0.8 ft
Vehicle Speed	± 1.0 mph	-0.1 ± 1.8 mph	0.0 ± 1.1 mph	-0.3 ± 1.5 mph
Axle Spacing Length	+ 0.5 ft [150mm]	-0.1 ± 0.5 ft	-0.2 ± 0.5 ft	-0.1 ± 0.6 ft

From the table, it can be seen that the WIM equipment overestimates all weights at all speeds. The range in steering axle weight errors is greater at the medium speeds. There does not appear to be a significant relationship between tandem axle weight and GVW 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, steering 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 equipment overestimated GVW at all speeds with the greatest overestimation at the medium speeds. The range in error is similar throughout the entire speed range. Distribution of errors is shown graphically in the following figure.

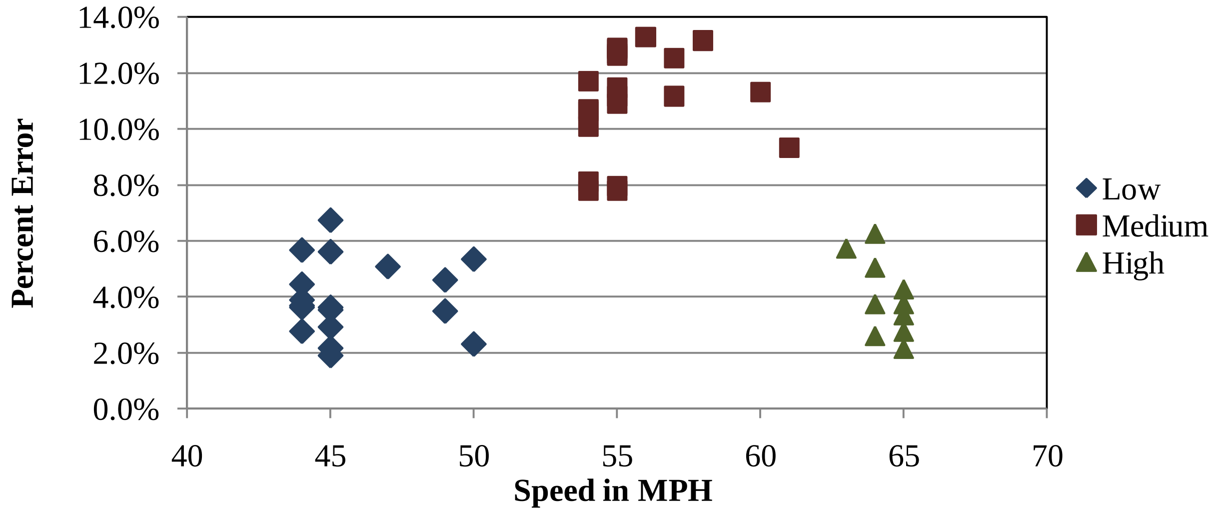


Figure 5-1 – Pre-Validation GVW Error by Speed – 15-Sep-10

5.1.1.2 Steering Axle Weight Errors by Speed

As shown in Figure 5-2, the equipment estimates steering axle weights with reasonable accuracy at the higher speeds and overestimates steering axle weights at the low and medium speeds. The range in error appears to be consistent throughout the entire speed range. Distribution of errors is shown graphically in the following figure.

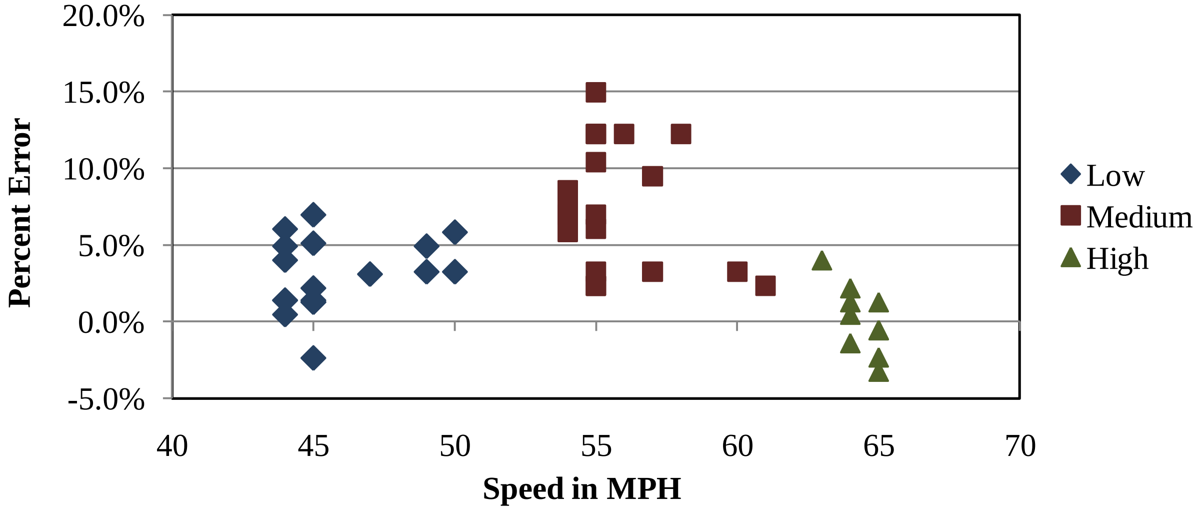


Figure 5-2 – Pre-Validation Steering Axle Weight Errors by Speed – 15-Sep-10

5.1.1.3 Tandem Axle Weight Errors by Speed

As shown in Figure 5-3, the equipment overestimates tandem axle weights at all speeds with the greatest bias at the medium speeds. The range in error is greater at the medium speeds. Distribution of errors is shown graphically in the following figure.

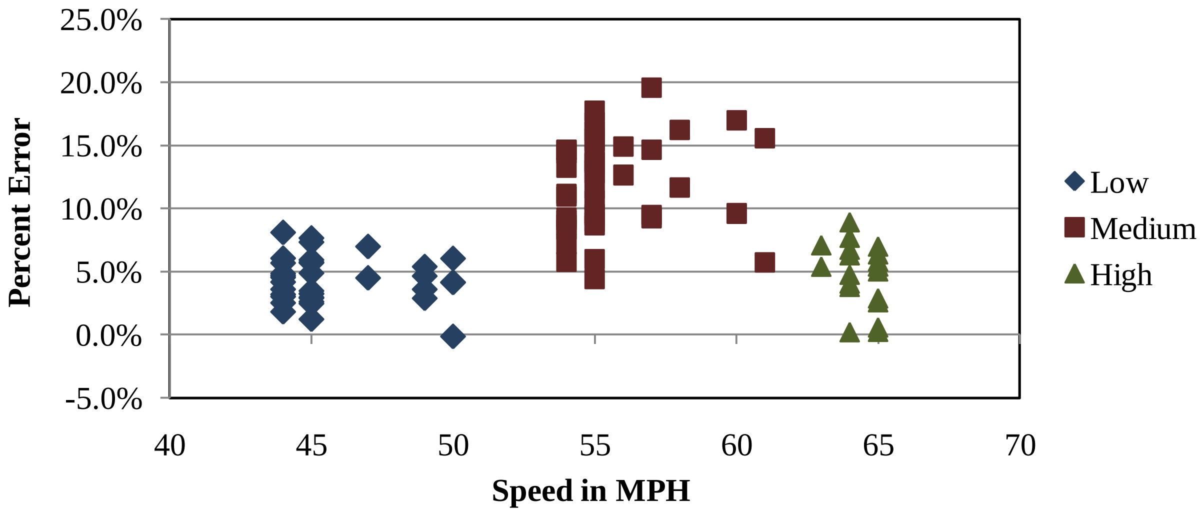


Figure 5-3 – Pre-Validation Tandem Axle Weight Errors by Speed – 15-Sep-10

5.1.1.4 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 precision and bias is similar for both the heavily loaded (Primary) truck and the partially loaded (Secondary) truck. Distribution of errors is shown graphically in Figure 5-4.

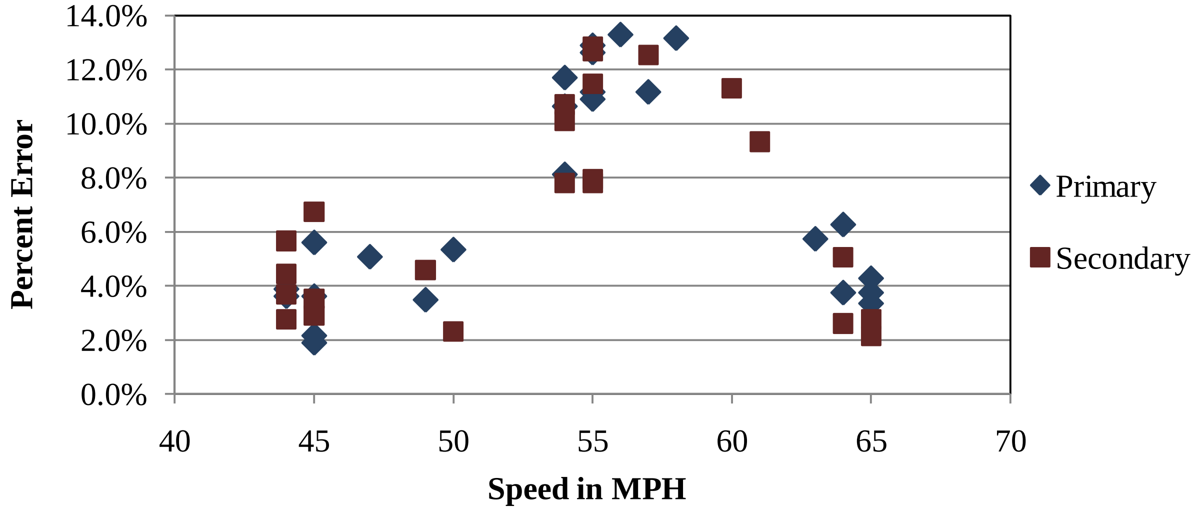


Figure 5-4 – Pre-Validation GVW Errors by Truck and Speed – 15-Sep-10

5.1.1.5 Axle Length Errors by Speed

For this site, the error in axle length measurement was measured with reasonable accuracy at all speeds. The range in axle length measurement error ranged from -0.5 feet to 0.4 feet. Distribution of errors is shown graphically in Figure 5-5.

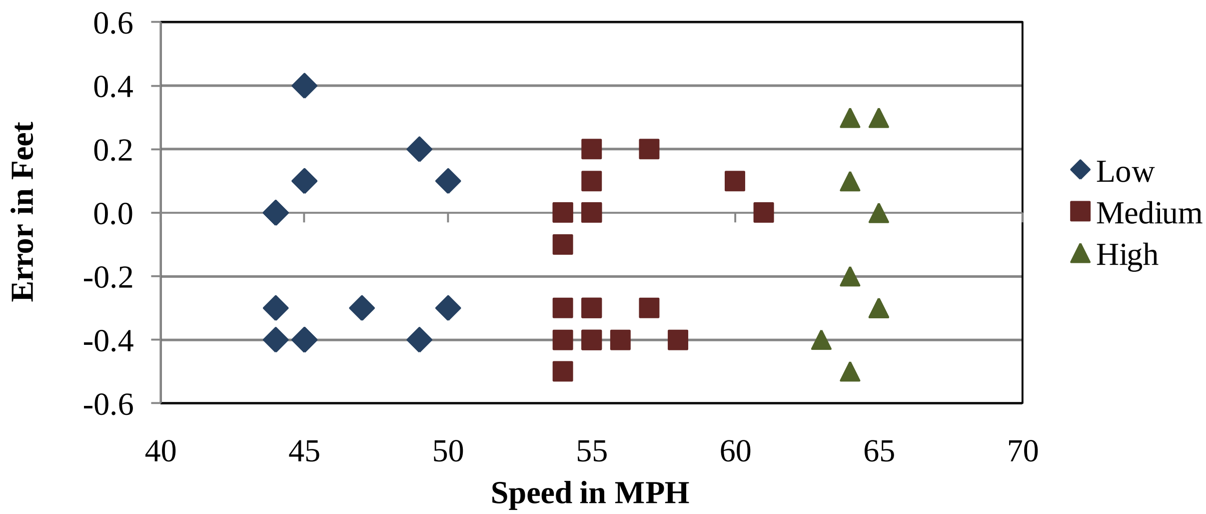


Figure 5-5 – Pre-Validation Axle Length Errors by Speed – 15-Sep-10

5.1.1.6 Overall Length Errors by Speed

For this system, the WIM equipment overestimated overall vehicle length consistently over the entire range of speeds, with an error range of 3.4 to 5.5 feet. Distribution of errors is shown graphically in Figure 5-6.

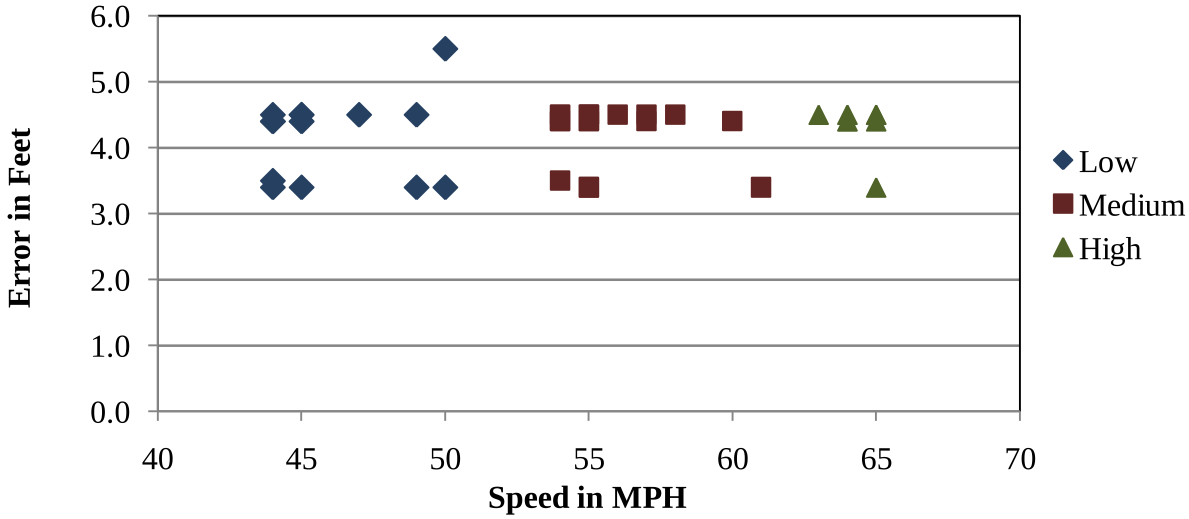


Figure 5-6 – Pre-Validation Overall Length Error by Speed – 15-Sep-10

5.1.2 Statistical Temperature Analysis

Statistical analysis was performed for the test truck run data to investigate whether there is a relation between pavement temperature and WIM equipment weight and distance measurement accuracy. The range of pavement temperatures varied 28.6 degrees, from 84.5 to 113.1 degrees Fahrenheit. The pre-validation test runs are being reported under three temperature groups as shown in Table 5-4.

Table 5-4 – Pre-Validation Results by Temperature – 15-Sep-10

Parameter	**95% Confidence Limit of Error**	**Low**	**Medium**	**High**
		84.5 to 94 degF	**94.1 to 103.7 degF**	**103.8 to 113.1 degF**
Steering Axles	±20 percent	4.1 ± 11.3%	3.9 ± 10.2%	4.8 ± 7.3%
Tandem Axles	±15 percent	6.5 ± 8.6%	8.3 ± 11.1%	7.9 ± 8.6%
GVW	±10 percent	6.0 ± 7.9%	7.4 ± 10%	7.2 ± 7.2%
Vehicle Length	±3 percent (1.9 ft)	4.1 ± 1.1 ft	4.3 ± 0.8 ft	4.3 ± 1 ft
Vehicle Speed	± 1.0 mph	-0.3 ± 1.4 mph	0.1 ± 1.4 mph	-0.1 ± 1.4 mph
Axle Spacing Length	± 0.5 ft [150mm]	-0.1 ± 0.5 ft	-0.2 ± 0.5 ft	-0.1 ± 0.6 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 5-7, it can be seen that the equipment appears to overestimate GVW across the range of temperatures observed in the field. There does not appear to be a correlation between temperature and weight estimates.

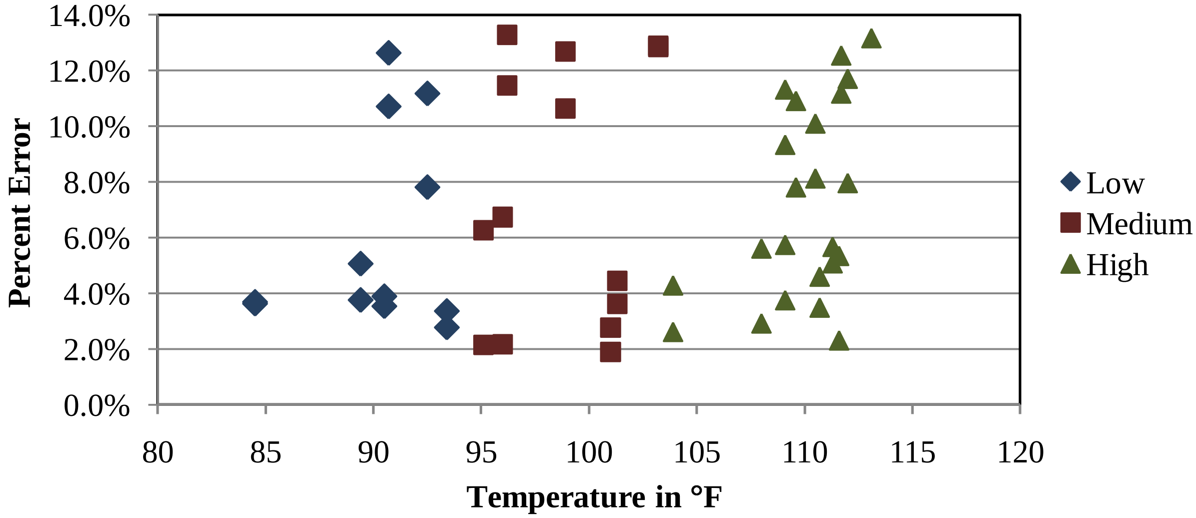


Figure 5-7 – Pre-Validation GVW Errors by Temperature – 15-Sep-10

5.1.2.2 Steering Axle Weight Errors by Temperature

Figure 5-8 demonstrates that for steering axles, the WIM equipment appears to overestimate steering axle weight at all temperatures. The range in error is similar for different temperature groups. Distribution of errors is shown graphically in the following figure.

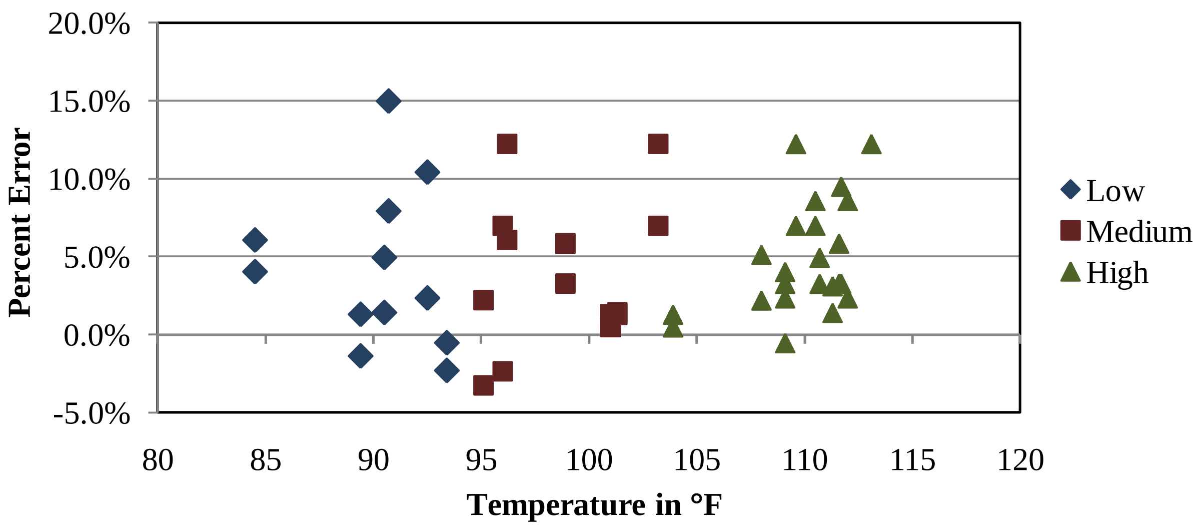


Figure 5-8 – Pre-Validation Steering Axle Weight Errors by Temperature – 15-Sep-10

5.1.2.3 Tandem Axle Weight Errors by Temperature

As shown in Figure 5-9, the equipment overestimates tandem axle weights at all temperatures. The range in tandem axle errors is consistent for the three temperature groups. Distribution of errors is shown graphically in the following figure.

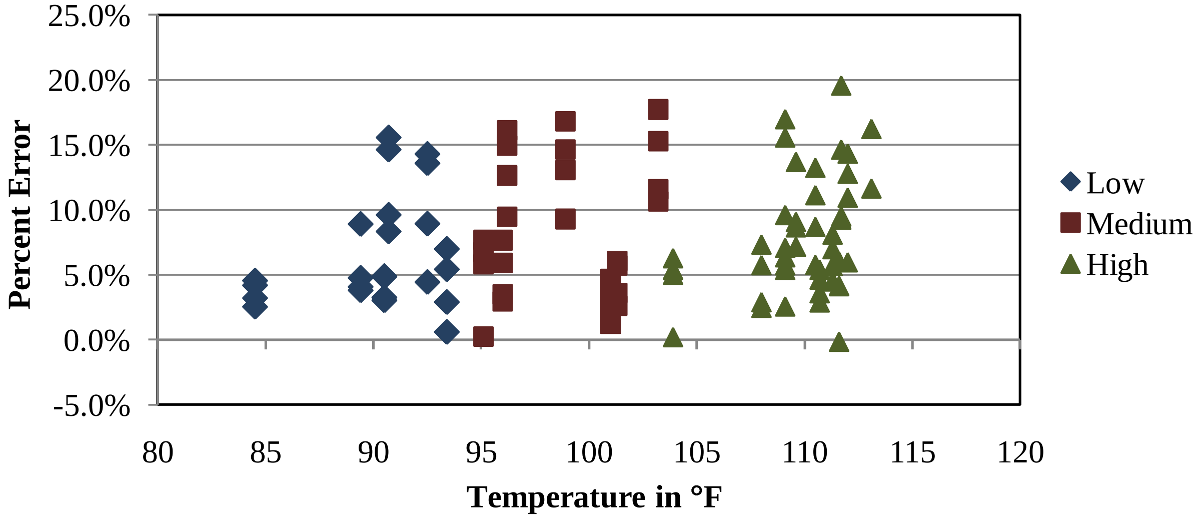


Figure 5-9 – Pre-Validation Tandem Axle Weight Errors by Temperature – 15-Sep-10

5.1.2.4 GVW Errors by Temperature and Truck Type

When analyzed for each test truck, GVW measurement errors for both trucks are generally overestimated by the equipment. For both trucks, the range of errors and bias are reasonably consistent over the range of temperatures. Distribution of errors is shown graphically in Figure 5-10.

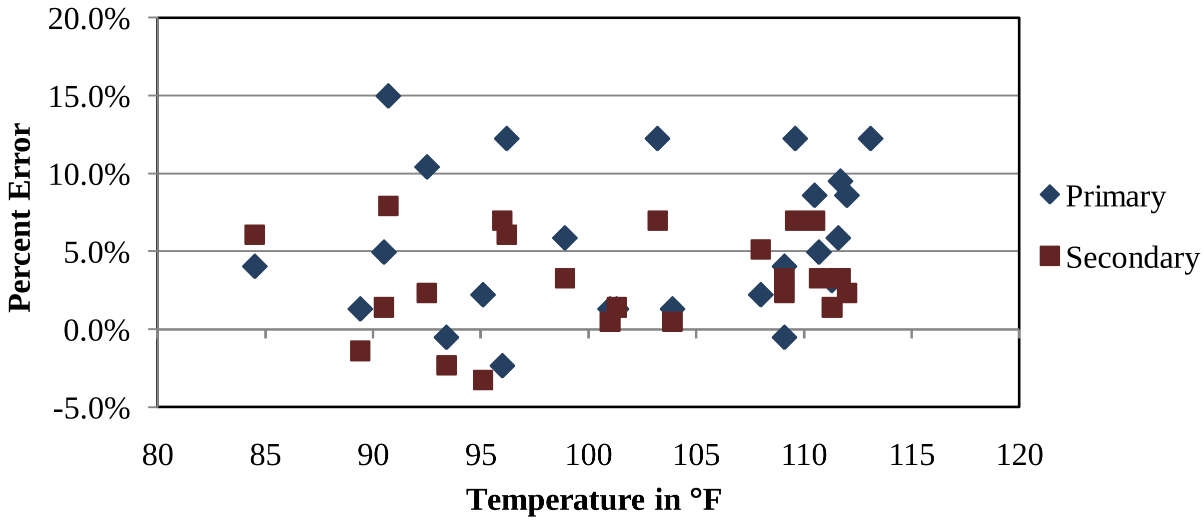


Figure 5-10 – Pre-Validation GVW Error by Truck and Temperature – 15-Sep-10

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 33 vehicles including 32 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. Table 5-5 illustrates the breakdown of vehicles observed and identified by the WIM equipment for the manual classification study.

Table 5-5 – Pre-Validation Classification Study Results – 15-Sep-10

Class	4	5	6	7	8	9	10	11	12	13
WIM Count	0	15	1	0	5	11	0	0	0	0
Observed Count	1	18	1	0	1	11	0	0	0	0
WIM Distribution (%)	0	46	3	0	15	33	0	0	0	0
Obs. Distribution (%)	3	55	3	0	3	33	0	0	0	0
Misclass/Unclass	1	4	0	0	0	0	0	0	0	0
Misclassified (%)	100	22	0	N/A	0	0	N/A	N/A	N/A	N/A

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 misclassified percentage represents the percentage of the misclassified vehicles in the manual sample. The misclassifications by pair are provided in Table 5-6.

Table 5-6 – Pre-Validation Misclassifications by Pair – 15-Sep-10

Observed/ WIM	Number of Pairs	Observed/ WIM	Number of Pairs
3/5	0	8/9	0
3/8	1	9/5	0
4/5	1	9/8	0
4/6	0	9/10	0
5/3	1	10/9	0
5/4	0	10/13	0
5/8	3	11/12	0
6/4	0	12/11	0
7/6	0	13/10	0
8/3	0	13/11	0
8/5	0		

Based on the vehicles observed during the pre-validation study, the misclassification percentage is 0.0% for heavy trucks (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 18.2%.

As shown in the table, a total of 6 vehicles, including zero heavy trucks (6 – 13) were misclassified by the equipment. All of the misclassifications were cross-classifications of Class 3, 4, 5 and 8 vehicles.

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 – 15-Sep-10

Observed/ WIM	Number of Pairs	Observed/ WIM	Number of Pairs
3/15	0	9/15	0
4/15	0	10/15	0
5/15	0	11/15	0
6/15	0	12/15	0
7/15	0	13/15	0
8/15	0		

Based on the manually collected sample of the 32 trucks, 0.0% 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 0.1 mph; the range of errors was 1.6 mph.

5.2 Calibration

The WIM equipment required one calibration iteration 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 – 15-Sep-10

Speed Point	MPH	Left
72	45	3619
80	50	3642
88	55	3766
96	60	3822
105	65	3545
		Right
72	45	3619
80	50	3642
88	55	3766
96	60	3822
105	65	3545
Axle Distance (cm)	371	
Dynamic Comp (%)	100	

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 7.0% and errors of 4.0%, 11.0%, and 4.0% at the 45, 55 and 65 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 – 15-Sep-10

		Old Factors		New Factors	
Speed Points	**Error**	**Right**	**Left**	**Right**	**Left**
72	3.97%	3619	3619	3481	3481
80	3.93%	3642	3642	3504	3504
88	10.91%	3766	3766	3395	3395
96	11.27%	3822	3822	3435	3435
105	3.97%	3545	3545	3410	3410
Axle Distance (cm)	0.25%	371		372	
Dynamic Comp (%)	4.38%	100		102	

5.2.1.2 Calibration 1 Results

The results of the 13 first calibration verification runs are provided in Table 5-10 and Figure 5-11. As can be seen in the table, the mean error of all weight estimates was reduced to less than 2.0 percent as a result of the first calibration iteration.

Table 5-10 – Calibration 1 Results – 16-Sep-10

Parameter	95% Confidence Limit of Error	Site Values	Pass/Fail
Steering Axles	±20 percent	0.1 ± 5.3%	Pass
Tandem Axles	±15 percent	1.6 ± 4.9%	Pass
GVW	±10 percent	1.4 ± 2.7%	Pass
Vehicle Length	±3 percent (1.9 ft)	4.4 ± 1.1 ft	FAIL
Vehicle Speed	± 1.0 mph	0.2 ± 0.8 mph	Pass
Axle Spacing Length	± 0.5 ft [150mm]	0.1 ± 0.6 ft	FAIL

Figure 5-11 shows that the WIM equipment is estimating GVW with reasonable accuracy at all speeds.

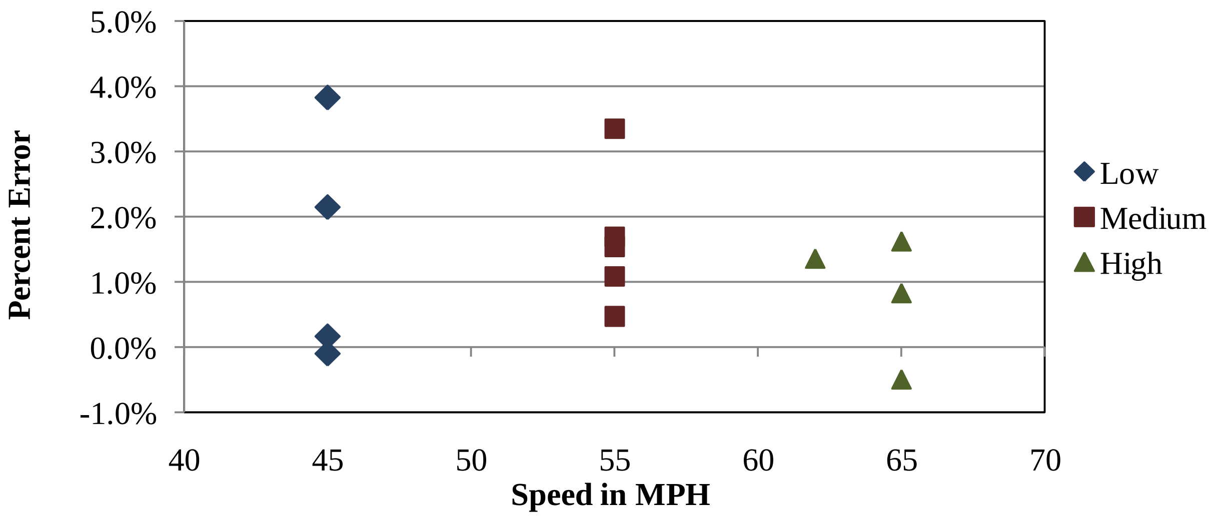


Figure 5-11 – Calibration 1 GVW Error by Speed – 16-Sep-10

The results of the first calibration show that GVW is being estimated with reasonable accuracy by the WIM equipment at all speeds. Based on the results of the first calibration, where GVW estimate bias decreased to less than 2.0 percent, a second calibration was not considered to be necessary. The 13 calibration runs were combined with 29 additional post-validation runs to complete the WIM system validation.

5.3 Post-Validation

The 42 post-validation test truck runs were conducted on September 16, 2010, beginning at approximately 8:05 AM and continuing until 2:38 PM.

Three tests trucks were used for the combination of calibration and post-validation runs. Due to mechanical problems, the secondary truck was replaced after the first day following the calibration test truck runs. The three test trucks consisted of:

- A Class 9 truck, loaded with refuse, and equipped with air suspension on truck and trailer tandems and with standard tandem spacings on both the tractor and trailer.
- A Class 9, 5-axle truck, loaded with refuse, and equipped with air suspension on the tractor, air suspension on the trailer, with standard tandem spacing on the tractor and standard tandem spacing on the trailer.
- A Class 9, 5-axle truck, loaded with refuse, and equipped with air suspension on the tractor, air suspension on the trailer, with standard tandem spacing on the tractor and standard tandem spacing on the trailer.

Test trucks 1 and 2 were weighed prior to and after the calibration. Test truck 3 was weighed prior to and following the post-validation runs performed on the second day. The average test truck weights and measurements are provided in Table 5-11.

Table 5-11 - Post-Validation Test Truck Measurements

Test Truck	Weights (kips)						Spacings (feet)					
	GVW	Ax1	Ax2	Ax3	Ax4	Ax5	1-2	2-3	3-4	4-5	AL	OL
1	75.3	11.1	16.0	16.0	16.2	16.2	14.5	4.3	33.1	4.0	55.9	61.5
2	65.5	10.8	13.4	13.4	14.0	14.0	14.5	4.3	33.4	4.0	56.2	63.6
3	66.1	10.9	13.8	13.8	13.8	13.8	13.3	4.4	33.8	4.1	55.6	63.9

Test truck speeds varied by 24 mph, from 42 to 66 mph. The measured post-validation pavement temperatures varied 39.2 degrees Fahrenheit, from 75.0 to 114.2. The partly cloudy weather conditions provided for reaching the desired 30 degree temperature range. Table 5-12 is a summary of post validation results.

Table 5-12 – Post-Validation Overall Results – 16-Sep-10

Parameter	95% Confidence Limit of Error	Site Values	Pass/Fail
Steering Axles	±20 percent	0.1 ± 7.0%	Pass
Tandem Axles	±15 percent	1.0 ± 4.6%	Pass
GVW	±10 percent	0.9 ± 3.2%	Pass
Vehicle Length	±3 percent (1.9 ft)	4.0 ± 1.5 ft	FAIL
Axle Spacing Length	± 0.5 ft [150mm]	-0.1 ± 0.4 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 0.0 ± 1.0 mph, which is within the ±1.0 mph tolerance established by the LTPP Field Guide.

5.3.1 Statistical Speed Analysis

Statistical analysis was conducted on the test truck run data to investigate whether a relation exists between speed and WIM equipment weight and distance measurement accuracy. The posted speed limit at this site is 65 mph. The test runs were divided into three speed groups - low, medium and high speeds, as shown in Table 5-13 below.

Table 5-13 – Post-Validation Results by Speed – 16-Sep-10

Parameter	**95% Confidence Limit of Error**	**Low**	**Medium**	**High**
		42.0 to 50.0 mph	**50.1 to 58.1 mph**	**58.2 to 66.0 mph**
Steering Axles	±20 percent	0.9 ± 9.1%	1.5 ± 4.7%	-2.1 ± 6.3%
Tandem Axles	±15 percent	0.6 ± 3.5%	1.8 ± 5.2%	0.3 ± 4.5%
GVW	±10 percent	0.6 ± 3.1%	1.9 ± 1.8%	0.0 ± 3.8%
Vehicle Length	±3 percent (1.9 ft)	4.1 ± 1.4 ft	3.9 ± 1.4 ft	4.1 ± 1.9 ft
Vehicle Speed	± 1.0 mph	-0.1 ± 1.4 mph	0.1 ± 0.6 mph	0.0 ± 1.2 mph
Axle Spacing Length	± 0.5 ft [150mm]	-0.1 ± 0.5 ft	0.0 ± 0.5 ft	-0.1 ± 0.3 ft

From the table, it can be seen that the WIM equipment estimates all weights with reasonable accuracy at all speeds. For steering axle weights, the range of errors is greater at the low speeds. For tandem axle weights and GVW, the range in error is reasonably consistent at all speeds. There does appear to be a relationship between steering axle 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 5-12, the equipment estimated GVW with reasonable accuracy at all speeds. The range in error and bias is greater at the low and high speeds. Distribution of errors is shown graphically in the figure.

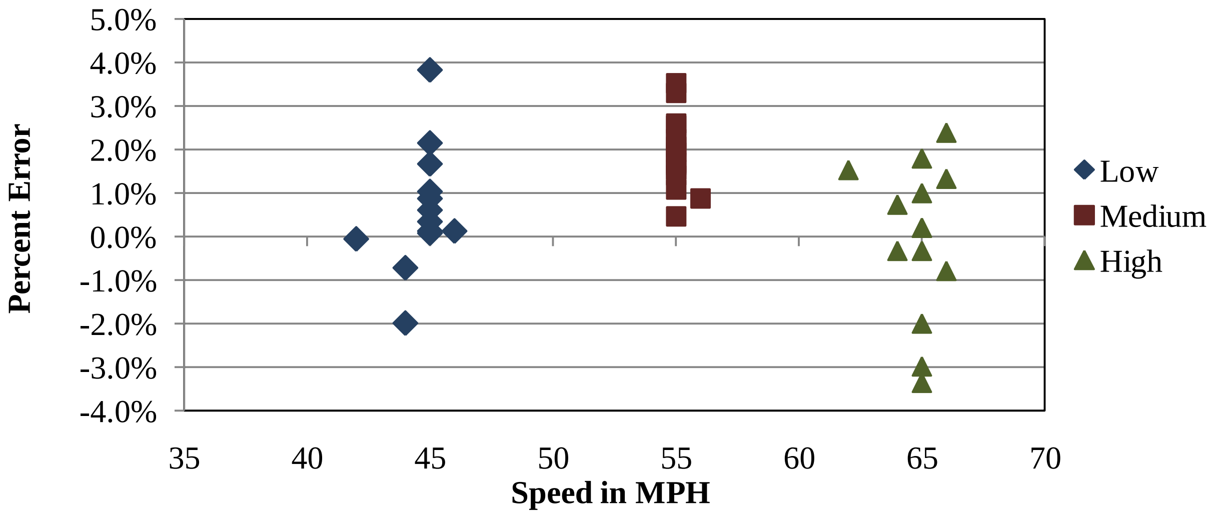


Figure 5-12 – Post-Validation GVW Errors by Speed – 16-Sep-10

5.3.1.2 Steering Axle Weight Errors by Speed

As shown in Figure 5-13, the equipment estimated steering axle weights with reasonable accuracy at all speeds. The range in error is greater at the low speeds. Distribution of errors is shown graphically in the figure.

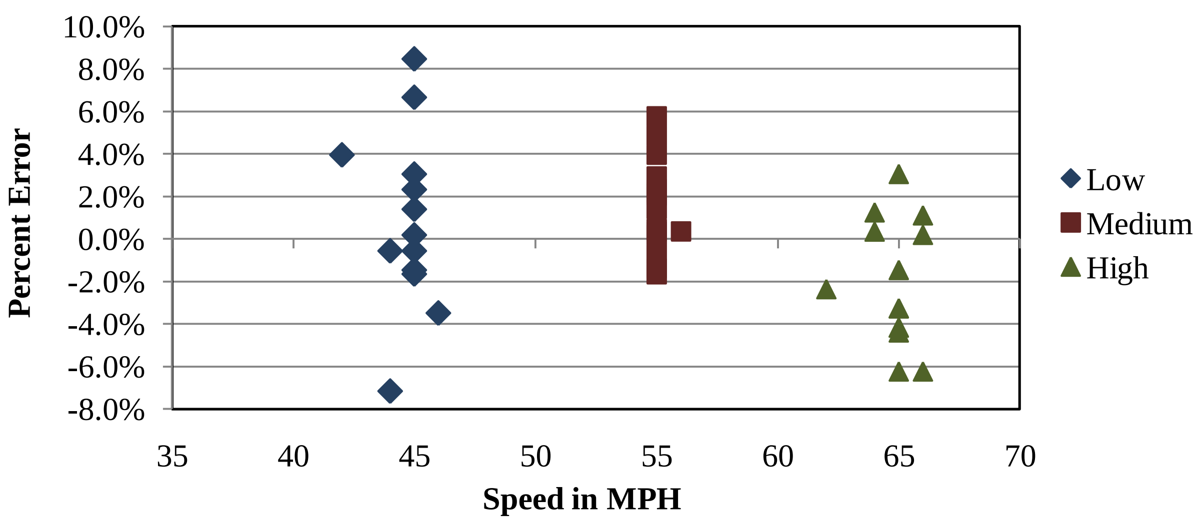


Figure 5-13 – Post-Validation Steering Axle Weight Errors by Speed – 16-Sep-10

5.3.1.3 Tandem Axle Weight Errors by Speed

As shown in Figure 5-14, the equipment estimates tandem axle weights with reasonable accuracy at all speeds. The range in error is greater at the medium speeds. Distribution of errors is shown graphically in the figure.

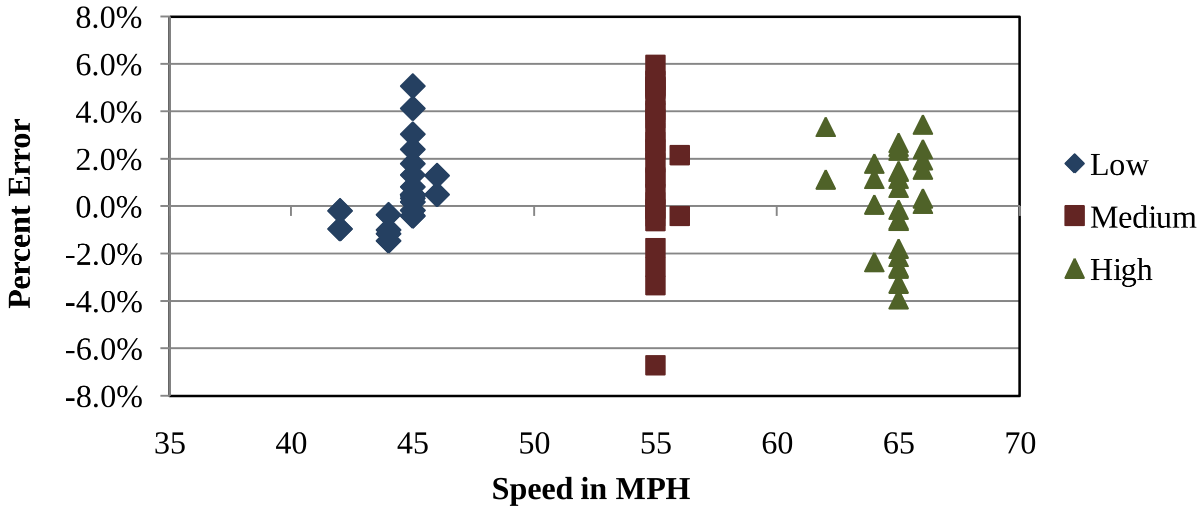


Figure 5-14 – Post-Validation Tandem Axle Weight Errors by Speed – 16-Sep-10

5.3.1.4 GVW Errors by Speed and Truck Type

It can be seen in Figure 5-15 that when the GVW errors are analyzed by truck type, GVW was overestimated for the loaded (Secondary) truck at the low speeds. At the medium and high speeds, the equipment precision and bias is similar for both the heavily loaded (Primary) truck and the partially loaded (Secondary) truck. Distribution of errors is shown graphically in the figure.

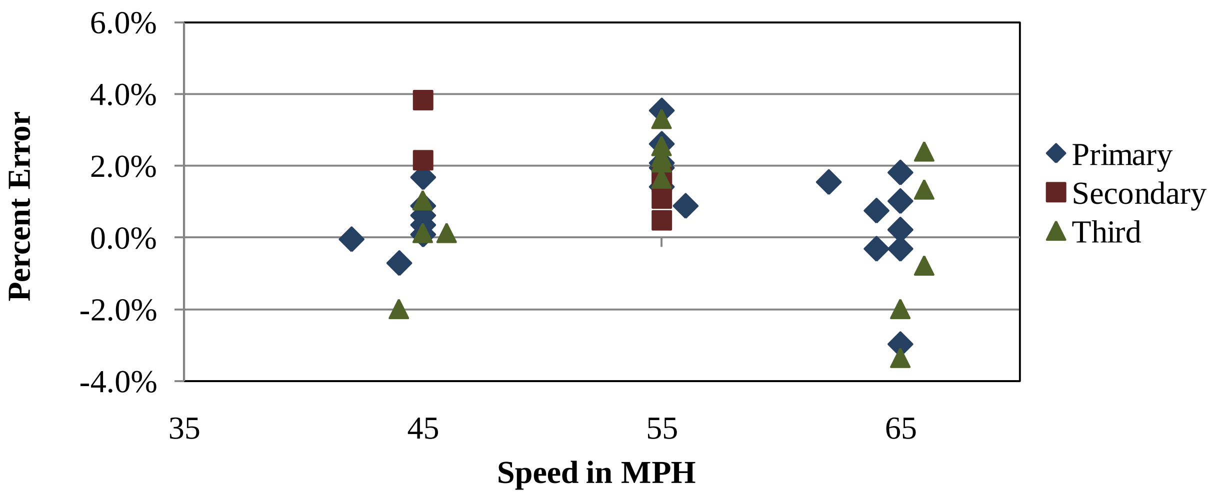


Figure 5-15 – Post-Validation GVW Error by Truck and Speed – 16-Sep-10

5.3.1.5 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 -0.4 feet to 0.4 feet. Distribution of errors is shown graphically in Figure 5-16.

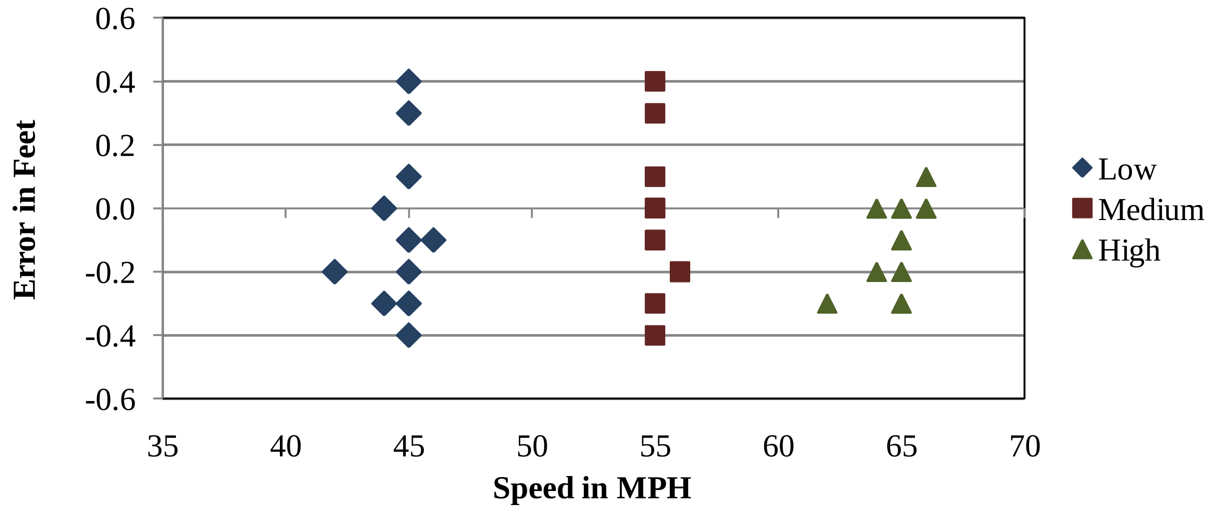


Figure 5-16 – Post-Validation Axle Length Error by Speed – 16-Sep-10

5.3.1.6 Overall Length Errors by Speed

For this system, the WIM equipment overestimates overall length consistently over the entire range of speeds, with errors ranging from 3.1 to 5.5 feet. Distribution of errors is shown graphically in Figure 5-17.

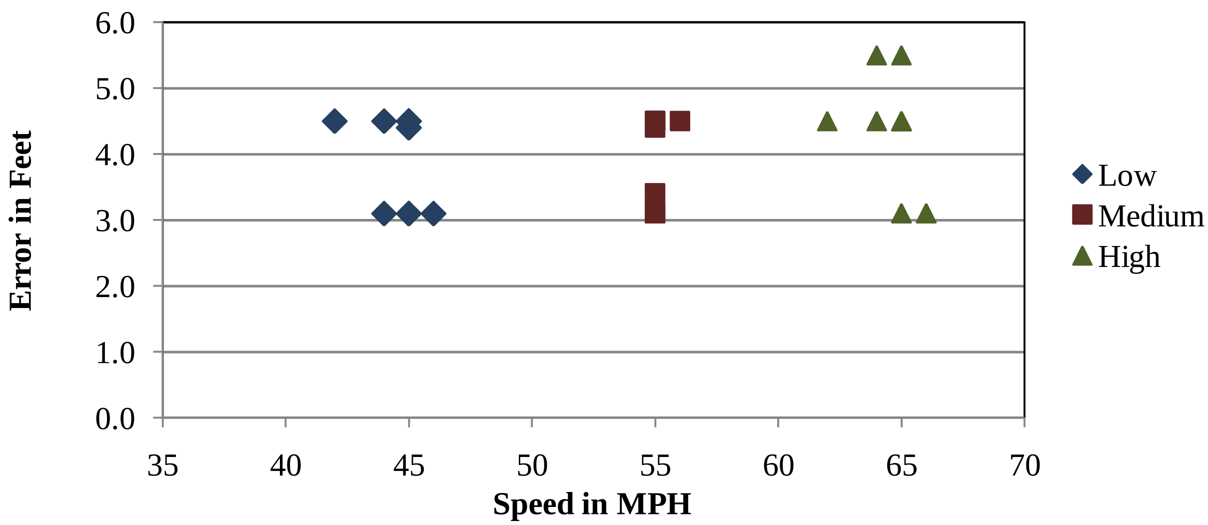


Figure 5-17 – Post-Validation Overall Length Error by Speed – 16-Sep-10

5.3.2 Statistical Temperature Analysis

Statistical analysis was performed for the test truck run data to investigate whether there is a relation between pavement temperature and WIM equipment weight and distance measurement accuracy. The range of pavement temperatures varied 39.2 degrees, from 75.0 to 114.2 degrees Fahrenheit. The post-validation test runs are being reported under three temperature groups as shown in Table 5-14 below.

Table 5-14 – Post-Validation Results by Temperature – 16-Sep-10

Parameter	95% Confidence Limit of Error	Low 75.0 to 88.1 degF	Medium 88.2 to 101.2 degF	High 101.3 to 114.2 degF
Steering Axles	±20 percent	0.0 ± 6.8%	0.7 ± 9.7%	-0.4 ± 5.8%
Tandem Axles	±15 percent	-0.1 ± 5.2%	1.3 ± 3.6%	1.8 ± 4.8%
GVW	±10 percent	0.1 ± 3.7%	1.1 ± 3.2%	1.4 ± 2.7%
Vehicle Length	±3 percent (1.9 ft)	3.8 ± 1.6 ft	3.9 ± 1.8 ft	4.4 ± 1.1 ft
Vehicle Speed	± 1.0 mph	-0.1 ± 1.1 mph	0.0 ± 1.2 mph	0.2 ± 0.8 mph
Axle Spacing Length	± 0.5 ft [150mm]	-0.1 ± 0.3 ft	-0.1 ± 0.3 ft	0.1 ± 0.6 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 5-18, it can be seen that the equipment appears to estimate GVW with acceptable accuracy across the range of temperatures observed in the field. There appears to be a correlation between temperature and weight estimates where temperature causes weight estimates to rise as temperature rises.

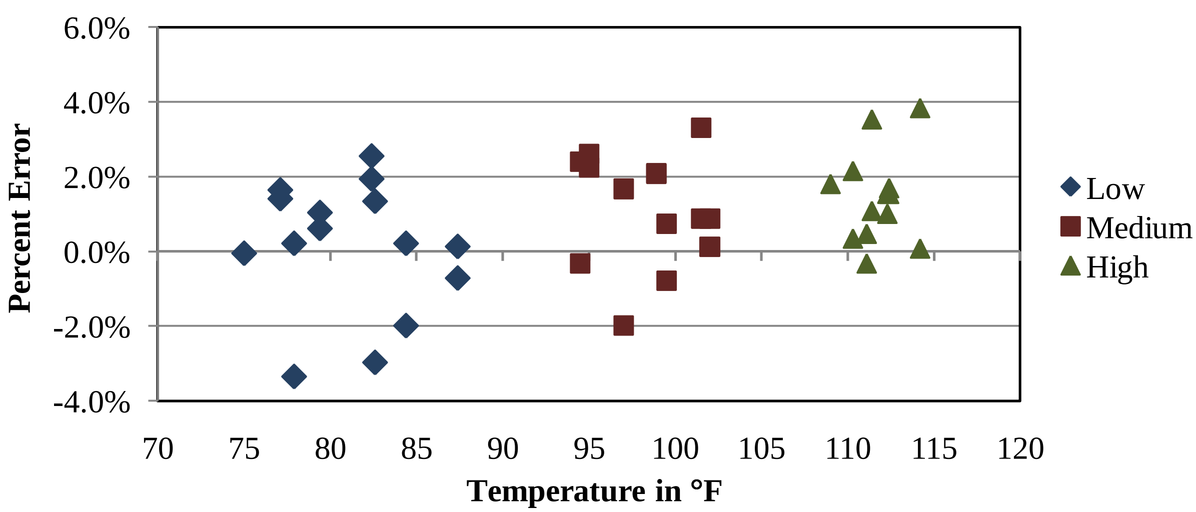


Figure 5-18 – Post-Validation GVW Errors by Temperature – 16-Sep-10

5.3.2.2 Steering Axle Weight Errors by Temperature

Figure 5-19 demonstrates that the WIM equipment appears to estimate steering axle weight accurately at all temperatures. There does not appear to be a correlation between steering axle weights and temperature. Distribution of errors is shown graphically in the following figure.

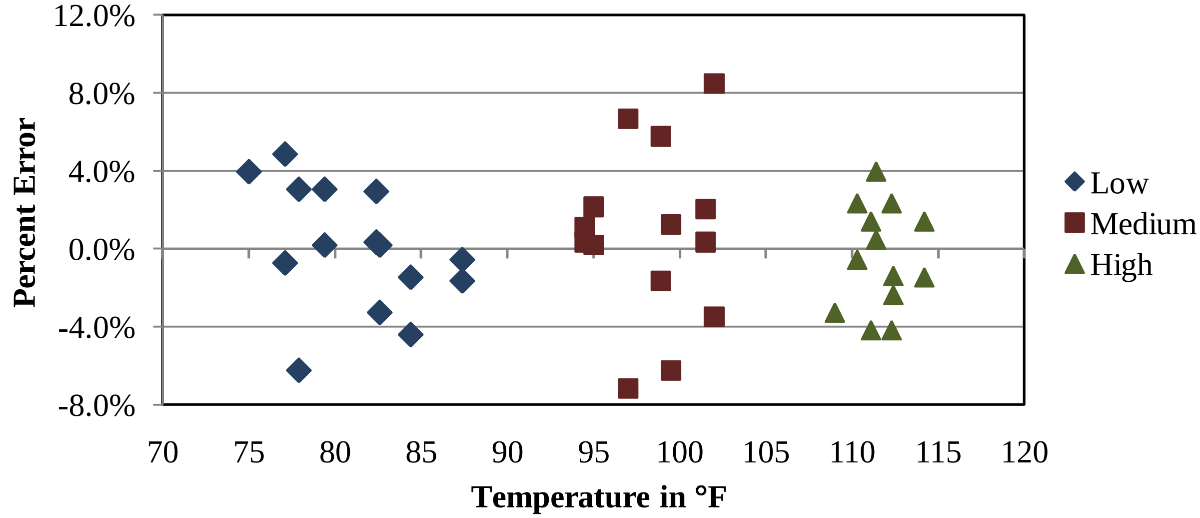


Figure 5-19 – Post-Validation Steering Axle Weight Errors by Temperature – 16-Sep-10

5.3.2.3 Tandem Axle Weight Errors by Temperature

As shown in Figure 5-20, the equipment estimates loaded tandem axle weights with reasonable accuracy at all temperatures. There is a slight increase in bias as temperature increases. The range in tandem axle errors is greater at the lower temperatures. Distribution of errors is shown graphically in the figure.

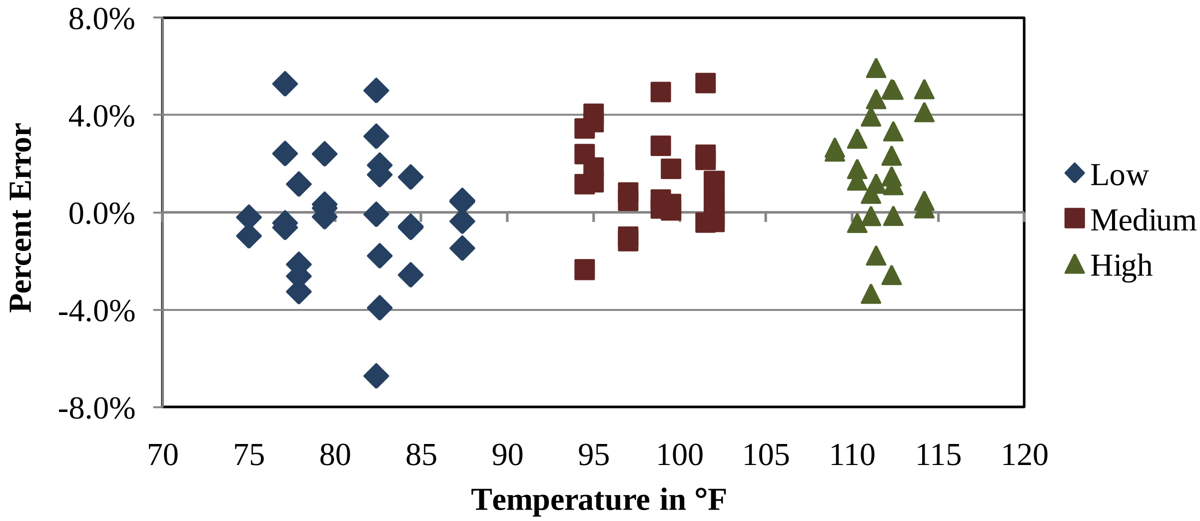


Figure 5-20 – Post-Validation Tandem Axle Weight Errors by Temperature – 16-Sep-10

5.3.2.4 GVW Errors by Temperature and Truck Type

As shown in Figure 5-21, when analyzed by truck type, GVW for the Primary truck is overestimated while GVW for the Secondary truck is underestimated. GVW is measured similarly at the low and high temperatures.

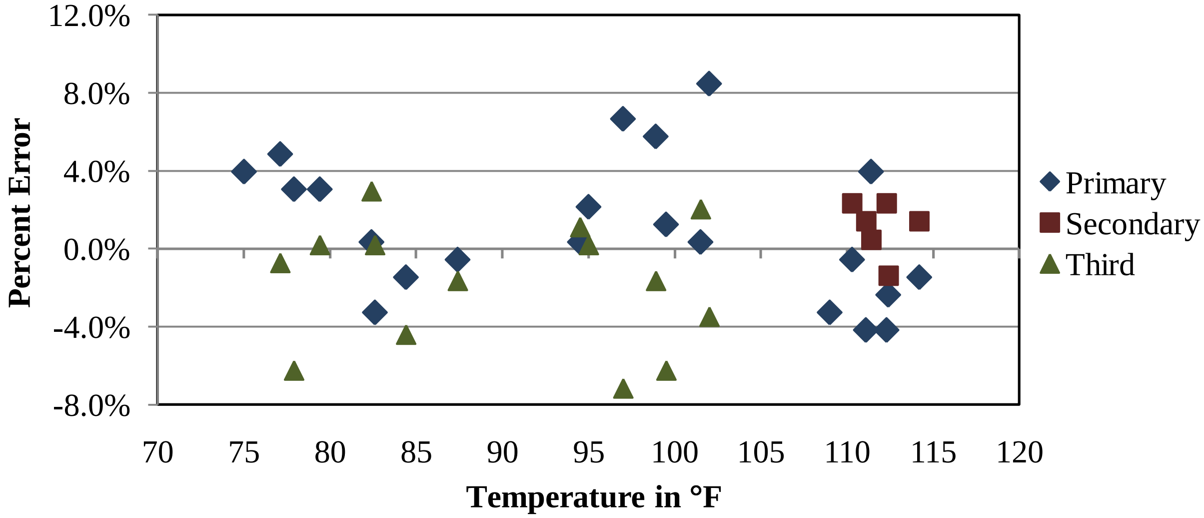


Figure 5-21 – Post-Validation GVW Error by Truck and Temperature – 16-Sep-10

5.3.3 Multivariable Analysis

This section provides additional analysis of post-validation results using a multivariable statistical technique of multiple linear regression. The same calibration data analyzed and discussed previously are analyzed again, but this time using a more sophisticated statistical methodology. 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 analyses provide additional insight on how speed, temperature, and truck type affect weight measurement errors for a specific site. It is expected that multivariable analyses done systematically for many sites will reveal overall trends.

5.3.3.1 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. Compared to analysis described previously, the weight of "axle group" was evaluated separately for tandem axles on tractors and 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 42 to 66 mph.
- Pavement temperature. Pavement temperature ranged from 75.0 to 114.2 degrees Fahrenheit.
- Interaction between the factors such as the interaction between speed and pavement temperature.

5.3.3.2 Results

For analysis of GVW weights, the value of regression coefficients and their statistical properties are summarized in Table 5-15. The value of regression coefficients defines the slope of the relationship between the % error in GVW and the predictor variables. The values of the t-distribution (for the regression coefficients) given in Table 5-15 are for the null hypothesis that assumes that the coefficients are equal to zero. The effects of temperature, speed and truck type were not statistically significant. For example, the probability that the effect of temperature on the measured GVW error occurred by chance alone is about 17 percent.

Table 5-15 – Table of Regression Coefficients for Measurement Error of GVW

Parameter	Regression coefficients	Standard error	Value of t-distribution	Probability value
Intercept	-0.4161	2.8405	-0.1465	0.8844
Speed	-0.0259	0.0293	-0.8826	0.3833
Temperature	0.0307	0.0217	1.4122	0.1665
Truck type	-0.2513	0.4309	-0.5832	0.5634

The relationship between temperature and measurement errors is shown in Figure 5-22. The figure includes trend line for the predicted percent error. Besides the visual assessment of the relationship, Figure 5-22 provides quantification and statistical assessment of the relationship.

The quantification of parameters' influence is provided by the value of the regression coefficients shown in Table 5-15. This means, for example, that for a 20 degree increase in temperature, the % error is increased by about 0.6 % (0.0307 x 20). The statistical assessment of the relationship is provided by the probability value of the regression coefficient.

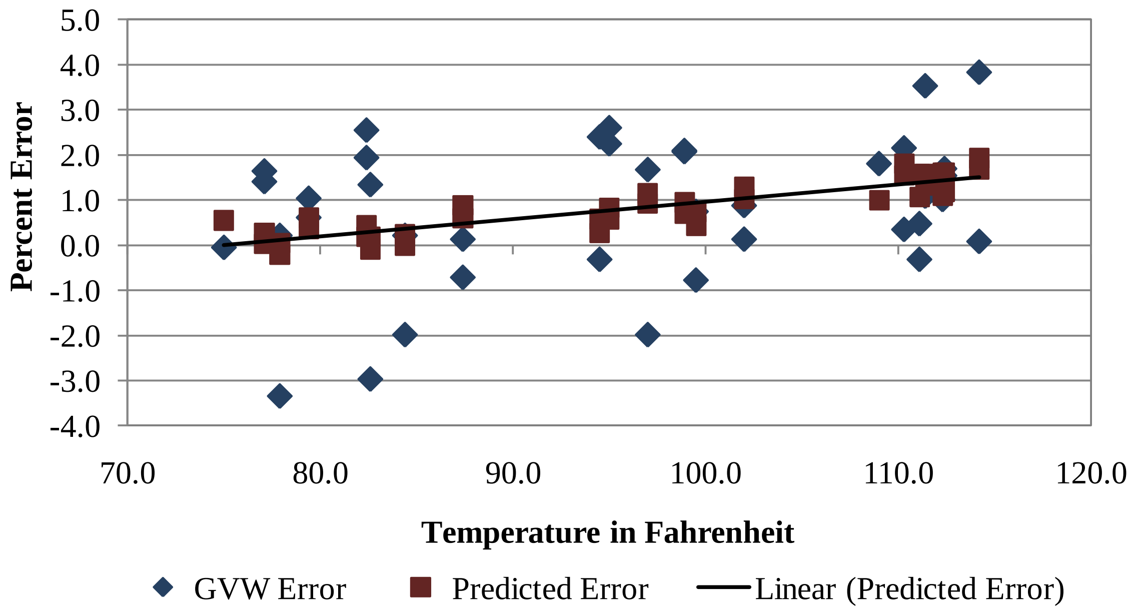


Figure 5-22 – Influence of Temperature on the Measurement Error of GVW

The interaction between speed, temperature, and truck type was investigated by adding an interactive variable (or variables) such as the product of speed and temperature. No interactive variables were statistically significant. The intercept was not statistically significant and does not have practical meaning.

5.3.3.3 Summary Results

Table 5-16 lists regression coefficients and their probability values for all combinations of factors and % errors evaluated. Not listed in the table are factor interactions because the interactions were not statistically significant. Entries in the table are provided only if the probability value was smaller than 0.20. The dash in Table 5-16 indicates that the relationship was not statistically significant (the probability that the relationship can occur by chance alone was greater than 20 percent).

Table 5-16 – Summary of Regression Analysis

	Factor					
	Speed		Temperature		Truck type	
Weight, % error	Regression coefficient	Probability value	Regression coefficient	Probability value	Regression coefficient	Probability value
GVW	-	-	0.0307	0.1665	-	-
Steering axle	-0.1287	0.0338	-0.0987	0.0286	-2.7059	0.0033
Tandem axle tractor	-	-	0.0553	0.0238	0.9757	0.0427
Tandem axle trailer	-	-	0.0612	0.1127	-	-

5.3.3.4 Conclusions

1. Speed, temperature, and truck type do not have statistically significant effect on the measurement errors for GVW and for the weight of tandem axles on trailers.

2. All three variables (speed, temperature and truck type) had statistically significant effect on steering axle weight measurement errors. The effect of truck type was statistically most significant.

3. Speed had a statistically significant effect on the measurement error of steering axles only.

4. Even though speed, temperature and truck type had statistically significant effects on some of the measurement errors, the practical significance of these effects is small and does not affect the validity of the calibration

5.3.4 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 21 vehicles including 21 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. Table 5-17 illustrates the breakdown of vehicles observed and identified by the WIM equipment for the manual classification study.

Table 5-17 – Post-Validation Classification Study Results – 16-Sep-10

Class	4	5	6	7	8	9	10	11	12	13
WIM Count	0	7	0	0	4	9	0	0	0	0
Observed Count	1	9	0	0	1	10	0	0	0	0
WIM Distribution (%)	0	33	0	0	19	43	0	0	0	0
Obs. Distribution (%)	5	43	0	0	5	48	0	0	0	0
Misclass/Unclass	1	3	0	0	0	1	0	0	0	0
Misclassified (%)	100	33	N/A	N/A	0	10	N/A	N/A	N/A	N/A

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 misclassified percentage represents the percentage of the misclassified vehicles in the manual sample. The misclassifications by pair are provided in Table 5-18.

Table 5-18 – Post-Validation Misclassifications by Pair – 16-Sep-10

Observed/ WIM	Number of Pairs	Observed/ WIM	Number of Pairs
3/5	0	8/9	0
3/8	0	9/5	0
4/5	1	9/8	0
4/6	0	9/10	0
5/3	0	10/9	0
5/4	0	10/13	0
5/8	3	11/12	0
6/4	0	12/11	0
7/6	0	13/10	0
8/3	0	13/11	0
8/5	0		

Based on the vehicles observed during the post-validation study, the misclassification percentage is 0.0% for heavy trucks (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 19.0%.

As shown in the table, a total of 4 vehicles, including zero heavy trucks (6 – 13) were misclassified by the equipment. The majority (4) of the misclassifications were Class 5s identified by the WIM equipment as Class 8. One Class 4 vehicle was identified as a Class 5 by the WIM equipment.

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 5-19.

Table 5-19 – Post-Validation Unclassified Trucks by Pair – 16-Sep-10

Observed/ WIM	Number of Pairs	Observed/ WIM	Number of Pairs
3/15	0	9/15	1
4/15	0	10/15	0
5/15	0	11/15	0
6/15	0	12/15	0
7/15	0	13/15	0
8/15	0		

Based on the manually collected sample of the 21 trucks, 4.8% of the vehicles at this site were reported as unclassified during the study. This is not within the established criteria of 2.0% for LTTP SPS WIM sites; however this percentage is based on a very small truck sample. The unclassified vehicle was a Class 9 which could not be identified by the WIM equipment. The cause of the unclassification was not investigated in the field.

For speed, the mean error for WIM equipment speed measurement was 0.0 mph; the range of errors was 0.7 mph.

5.4 Post Visit Applied Calibration

The 85th percentile speed for trucks, based on a small CDS data truck sample, is 73 mph, 8 mph above the posted speed limit of 65 mph. However, since test trucks runs were performed at the highest equipment speed point, applied calibration will not be utilized.

Figure 5-23 is provided to illustrate the predicted GVW error with respect to the post-validation errors by speed. This provides a reasonable expectation for the applied errors.

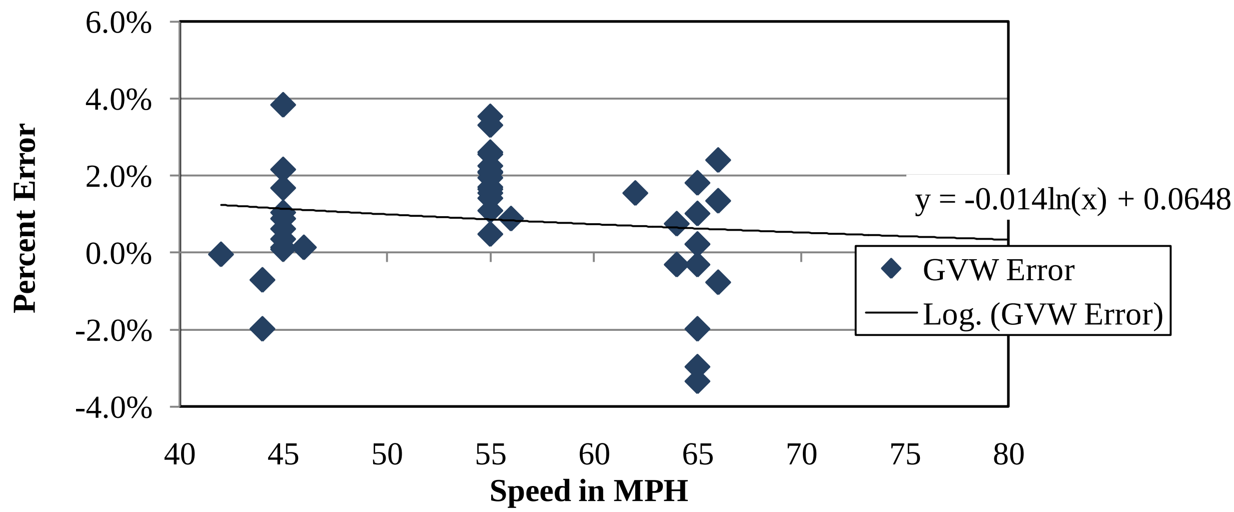


Figure 5-23 – GVW Error Trend

The final speed point factors are provided in Table 5-20.

Table 5-20 – Final Speed Point Compensation Factors

Speed Point	Speed	Left	Right
72	45	3481	3481
80	50	3504	3504
88	55	3395	3395
96	60	3435	3435
104	65	3410	3410

6 Previous WIM Site Validation Information

As of February 14, 2008, the date of the most recent validation, this site required 4 more years of research quality data. Research quality data is defined to be at least 210 days in a year of data of known calibration meeting LTPP's precision requirements. A review of the LTPP Standard Release Database 24 shows that there are 22 consecutive months of level "E" WIM data for this site. This site requires 3 additional years of data to meet the minimum of five years of research quality data.

6.1 Sheet 16s

This site has validation information from one previous visits as well as the current one as summarized in the tables below. Table 6-1 data was extracted from the most recent previous validation and was updated to include the results of this validation.

Table 6-1 – Classification Validation History

Date	Misclassification Percentage by Class										Pct Unclass
	4	5	6	7	8	9	10	11	12	13	
2-May-07	N/A	0	0	N/A	0	0	0	N/A	N/A	N/A	0.0
3-May-07	N/A	0	0	N/A	N/A	0	N/A	N/A	N/A	N/A	0.0
13-Feb-08	N/A	13	0	N/A	22	0	N/A	N/A	N/A	N/A	0.0
14-Feb-08	N/A	27	0	N/A	38	0	N/A	N/A	N/A	N/A	0.0
15-Sep-10	100	22	0	N/A	0	0	N/A	N/A	N/A	N/A	0.0
16-Sep-10	100	33	N/A	N/A	0	10	N/A	N/A	N/A	N/A	4.8

Table 6-2 data was extracted from the most recent previous validation and was updated to include the results of this validation.

Table 6-2 – Weight Validation History

Date	Mean Error and (SD)		
	GVW	Single Axles	Tandem
2-May-07	-26.1 (7.3)	-22.4 (8.5)	-26.5 (9.1)
3-May-07	0.3 (2.9)	-0.6 (4.2)	0.5 (5.8)
13-Feb-08	-2.6 (2.0)	-3.4 (3.4)	-2.4 (3.0)
14-Feb-08	-2.1 (2.3)	-2.6 (3.6)	-2.0 (3.4)
15-Sep-10	7.0 (3.8)	4.4 (4.2)	7.7 (4.4)
16-Sep-10	0.9 (1.6)	0.1 (3.5)	1.0 (2.3)

There is considerable difference between the pre-validation and post-validation measurement errors for the 2007 and 2010 validation studies. From this information, it appears that the system demonstrates a tendency for the equipment weight estimates to drift over time outside the LTPP SPS WIM tolerances. The table demonstrates not only the effectiveness of the validations in bringing the weight estimations closer to LTPP SPS WIM equipment tolerances, but also the need for calibration to maintain the required tolerances. Consideration should be given to validating the operation of this site in about 6 months.

6.2 Comparison of Past Validation Results

A comparison of the post-validation results from previous visits is provided in Table 6-3.

Table 6-3 – Comparison of Post-Validation Results

Parameter	95 %Confidence Limit of Error	Site Values		
		3-May-07	14-Feb-08	16-Sep-10
Single Axles	±20 percent	-0.6 ± 4.2	-2.6 ± 3.6	0.1 ± 7.0
Tandem Axles	±15 percent	0.5 ± 5.8	-2.0 ± 3.4	1.0 ± 4.6
GVW	±10 percent	0.3 ± 2.9	-2.1 ± 2.3	0.9 ± 3.2

From the table, it appears that the variance for single axle weights has increased since the equipment was installed, while variance in tandem axle weights and GVW has remained reasonably constant.

7 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 – Calibration Test Truck Data
- Sheet 21 – WIM System Truck Records
- Sheet 22 – Site Equipment Assessment plus Addendum
- Sheet 23 – WIM Troubleshooting Outline
- Sheet 24A/B/C – Site Photograph Logs
- Updated Handout Guide

WIM System Field Calibration and Validation - Photos

Arizona, SPS-1
SHRP ID: 040100

Validation Date: September 16, 2010
Submitted: 10/28/2010

Photo 1 - Cabinet Exterior

Photo 2 - Cabinet Interior (Back)

Photo 3 - Cabinet Interior (Front)

Photo 4 - Leading Loop

Photo 5 - Leading WIM Sensor

Photo 6 – Trailing WIM Sensor

Photo 7 - Trailing Loop Sensor

Photo 10 - Downstream

Photo 8 – Solar Panel

Photo 9 - Upstream

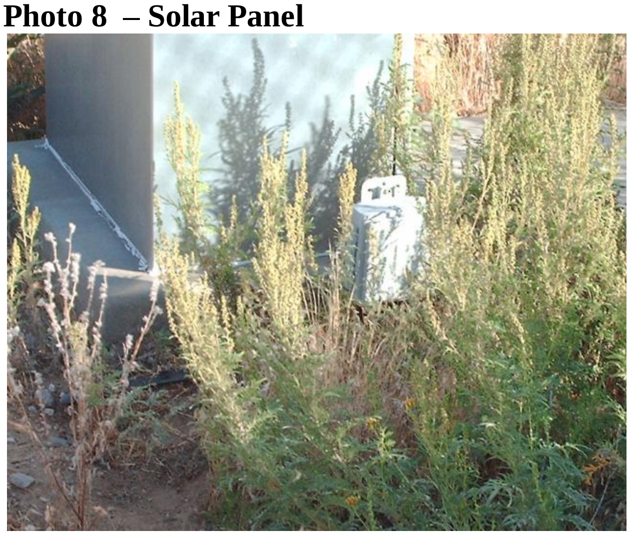


Photo 9 – Telephone Pedestal

Photo 102 – Truck 1

Photo 113 – Truck 1 Tractor

Photo 16 - Truck 1 Suspension 2/3

Photo 124 – Truck 1 Trailer and Load

Photo 17 - Truck 1 Suspension 4

Photo 135 – Truck 1 Suspension 1

Photo 18 – Truck 1 Suspension 5

Photo 19 – Truck 2

Photo 162 – Truck 2 Suspension 1

Photo 140 – Truck 2 Tractor

Photo 23 - Truck 2 Suspension 2/3

Photo 151 – Truck 2 Trailer and Load

Photo 24 - Truck 2 Suspension 4


Photo 25 - Truck 2 Suspension 5

Photo 26 - Truck 3

Photo 27 - Truck 3 Tractor


Photo 28 - Truck 3 Trailer and Load


Photo 29 - Truck 3 Suspension 1


Photo 30 - Truck 3 Suspension 2/3


Photo 31 - Truck 3 Suspension 4


Photo 32 - Truck 3 Suspension 5

Traffic Sheet 16 LTPP MONITORED TRAFFIC DATA SITE CALIBRATION SUMMARY	STATE CODE: SPS WIM ID: DATE (mm/dd/yyyy)	04 040100 9/15/2010

10. CALIBRATION FACTOR (AT EXPECTED FREE FLOW SPEED) 3410 | 3410

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

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

The Auto-cal feature is using a linear progression of numerical values, starting at 1000 for 0 degrees, with a value incremented by 4 for every degree up to 100 degrees.

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:	0.0	FHWA Class		-	
FHWA Class 8:	400.0	FHWA Class		-	
		FHWA Class		-	
		FHWA Class		-	

Percent of "Unclassified" Vehicles: 0.0%

Validation Test Truck Run Set - Pre

Person Leading Calibration Effort: **Dean J. Wolf**

Contact Information: Phone: 717-512-6638

E-mail: dwolf@ara.com

Traffic Sheet 16 LTPP MONITORED TRAFFIC DATA SITE CALIBRATION SUMMARY	STATE CODE: 04 SPS WIM ID: 040100 DATE (mm/dd/yyyy) 9/15/2010

SITE CALIBRATION INFORMATION

1. **DATE OF CALIBRATION** {mm/dd/yy} 9/15/10

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. Bending Plates c. ______
   b. Inductance Loops d. ______

5. **EQUIPMENT MANUFACTURER:** IRD iSINC

WIM SYSTEM CALIBRATION SPECIFICS

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

Number of Trucks Compared: ______
Number of Test Trucks Used: 2
Passes Per Truck: 25

	Type	Drive Suspension	Trailer Suspension
Truck 1:	9	air	air
Truck 2:	9	air	air
Truck 3:	0	0	0

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

Mean Difference Between -

Dynamic and Static GVW:	7.0%	Standard Deviation:	3.8%
Dynamic and Static Single Axle:	4.4%	Standard Deviation:	4.2%
Dynamic and Static Double Axles:	7.7%	Standard Deviation:	4.4%

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

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

			Low		High	Runs
a.	Low	-	44.0	to	51.0	18
b.	Medium	-	51.1	to	58.1	19
c.	High	-	58.2	to	65.0	12
d.	0	-		to		
e.	0	-		to		

Traffic Sheet 16 LTPP MONITORED TRAFFIC DATA SITE CALIBRATION SUMMARY	STATE CODE: 04 SPS WIM ID: 040100 DATE (mm/dd/yyyy) 9/16/2010

SITE CALIBRATION INFORMATION

1. **DATE OF CALIBRATION** {mm/dd/yy} 9/16/10

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. Bending Plates
   b. Inductance Loops
   c. ______
   d. ______

5. **EQUIPMENT MANUFACTURER:** IRD iSINC

WIM SYSTEM CALIBRATION SPECIFICS

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

Number of Trucks Compared: ______
Number of Test Trucks Used: 3
Passes Per Truck: 14

	Type	Drive Suspension	Trailer Suspension
Truck 1:	9	air	air
Truck 2:	9	air	air
Truck 3:	9	air	air

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

Mean Difference Between -

Dynamic and Static GVW:	0.9%	Standard Deviation:	1.6%
Dynamic and Static Single Axle:	0.1%	Standard Deviation:	3.5%
Dynamic and Static Double Axles:	1.0%	Standard Deviation:	2.3%

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

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

			Low		High	Runs
a.	Low	-	42.0	to	50.0	13
b.	Medium	-	50.1	to	58.1	15
c.	High	-	58.2	to	66.0	14
d.	0	-		to		
e.	0	-		to		

Traffic Sheet 16 LTPP MONITORED TRAFFIC DATA SITE CALIBRATION SUMMARY	STATE CODE: SPS WIM ID: DATE (mm/dd/yyyy)	04 040100 9/16/2010

10. CALIBRATION FACTOR (AT EXPECTED FREE FLOW SPEED) 3550 | 3550

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

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

The Auto-cal feature is using a linear progression of numerical values, starting at 1000 for 0 degrees, with a value incremented by 4 for every degree up to 100 degrees.

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:	-10.0	FHWA Class	______	-	______
FHWA Class 8:	300.0	FHWA Class	______	-	______
		FHWA Class	______	-	______
		FHWA Class	______	-	______

Percent of "Unclassified" Vehicles: 4.8%

Validation Test Truck Run Set - Post

Person Leading Calibration Effort: **Dean J. Wolf**

Contact Information: Phone: 717-512-6638

E-mail: dwolf@ara.com

Traffic Sheet 20 LTPP MONITORED TRAFFIC DATA SPEED AND CLASSIFICATION STUDIES	STATE CODE:	04
	SPS WIM ID:	040100
	DATE (mm/dd/yyyy)	9/15/2010

WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class	WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class
65	5	45	65	5	64	5	568	63	5
57	8	46	57	5	62	8	638	64	5
65	9	60	63	9	61	8	657	61	8
71	5	76	75	5	68	9	685	68	9
62	5	119	64	5	65	9	697	66	9
67	8	122	67	3	65	9	698	65	9
63	5	132	63	5	52	5	742	50	4
64	8	217	65	5	57	5	774	55	5
78	5	239	78	5					
73	5	257	75	5					
63	5	259	64	5					
68	5	272	68	5					
70	9	276	71	9					
67	5	280	67	5					
41	9	288	38	9					
61	5	303	59	5					
37	9	338	37	9					
37	9	339	37	9					
37	9	340	38	9					
64	6	350	63	6					
60	5	397	60	5					
68	9	486	68	9					
67	9	487	66	9					
49	5	551	45	5					
67	3	565	68	5					

Validation Test Truck Run Set - Pre

Sheet 1 - 0 to 50 Start: 9:03:00 Stop:

Recorded By: djw Verified By: kt

Traffic Sheet 20 LTPP MONITORED TRAFFIC DATA SPEED AND CLASSIFICATION STUDIES	STATE CODE: 04 SPS WIM ID: 040100 DATE (mm/dd/yyyy) 9/16/2010

WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class	WIM speed	WIM class	WIM Record	Obs. Speed	Obs. Class
52	9	2864	52	9					
65	8	2875	65	8					
50	5	2877	50	5					
64	5	2905	64	5					
62	9	2912	62	9					
37	9	2939	35	9					
70	5	2982	69	5					
67	5	2988	67	5					
60	9	3003	60	9					
65	8	3027	66	5					
67	5	3070	68	5					
34	9	3083	34	9					
34	9	3112	34	9					
66	8	3123	66	5					
33	15	3140	33	9					
65	8	3194	65	5					
68	9	3207	68	9					
64	5	3293	64	4					
64	9	3326	64	9					
63	5	3333	65	5					
65	9	3344	65	9					

Validation Test Truck Run Set - Post

Sheet 1 - 0 to 50 Start: 9:03:00 Stop:

Recorded By: djw Verified By: kt