# WIM System Field Calibration and Validation Summary Report

Minnesota SPS-5
SHRP ID – 270500

Validation Date: April 4, 2012
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APPLIED RESEARCH ASSOCIATES, INC.

U.S. Department of Transportation
Federal Highway Administration

LTPP

# Table of Contents

# List of Figures

# List of Tables

# 1 Executive Summary

A WIM validation was performed on April 3 and 4, 2012 at the Minnesota SPS-5 site located on route US-2, milepost 91.8, 3.3 miles west of SR 2.

This site was installed on October 6, 2006. All lanes at this location are instrumented with WIM sensors. The LTPP lane is the westbound, righthand driving lane. The site is equipped with quartz WIM sensors and an IRD iSINC WIM controller. The LTPP lane is identified as lane 4 in the WIM controller. From a comparison between the report of the most recent validation of this equipment on April 26, 2011 and this validation visit, it appears that sensor 3, which is the trailing WIM sensor in the left wheel path, has been disabled. No other changes appear to have occurred during this time to the basic operating condition of the equipment.

With sensor 3 disabled in the WIM system setup, the equipment is in working order. Electronic and electrical checks of the other WIM components determined that the equipment is operating within the manufacturer's tolerances. None of the in-road sensors in the LTPP lane 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 no 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 did not indicate any adverse dynamics that would affect 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 providing research quality loading data. The summary results of the validation are provided in Table 1-1 below.

**Table 1-1 – Post-Validation Results – 4-Apr-12**

| Parameter | 95% Confidence Limit of Error | Site Values | Pass/Fail |
|---|---|---|---|
| Steering Axles | ±20 percent | -1.3 ± 5.7% | Pass |
| Tandem Axles | ±15 percent | 0.9 ± 4.6% | Pass |
| GVW | ±10 percent | -0.4 ± 3.0% | Pass |
| Vehicle Length | ±3.0 percent (2.2 ft) | 0.1 ± 1.1 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 0.4 ± 1.7 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 0.0% is within the 2.0% acceptability criterion for LTPP SPS WIM sites. The overall misclassification rate of 17.1% from the 35 vehicle sample (Class 4 – 13) was due to the 6 cross-classifications of Class 3, 4, and 5 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 palleted beezwax, pellet fuel, and wood shavings.

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

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 | 1-2 | 2-3 | 3-4 | 4-5 | AL | OL |
| 1 | 74.6 | 12.1 | 16.5 | 15.8 | 15.1 | 15.1 | 17.2 | 4.3 | 34.5 | 4.0 | 60.0 | 71.8 |
| 2 | 62.2 | 11.4 | 14.1 | 14.1 | 11.0 | 11.6 | 17.1 | 4.3 | 35.5 | 4.0 | 60.9 | 71.8 |

The posted speed limit at the site is 65 mph. During the testing, the speed of the test trucks ranged from to 54 to 65 mph, a range of 11 mph.

During test truck runs, pavement temperature was collected using a hand-held infrared temperature device. The post-validation pavement surface temperatures varied from 53.9 to 86.4 degrees Fahrenheit, a range of 32.5 degrees Fahrenheit. The sunny weather conditions provided the desired 30 degree range in temperatures.

A review of the LTPP Standard Release Database 25 shows that there are 5 years of level “E” WIM data for this site. This site requires no additional 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 January 16, 2012 (Data) to the most recent Comparison Data Set (CDS) from April 26, 2011. The assessments performed prior to the site visits are used to develop expected traffic flow characteristics 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 25 shows that there are 5 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 | Number of Months |
|---|---|---|
| 2006 | 55 | 2 |
| 2007 | 363 | 12 |
| 2008 | 366 | 12 |
| 2009 | 365 | 12 |
| 2010 | 364 | 12 |
| 2011 | 273 | 10 |

As shown in the table, this site requires no additional data to meet the minimum of five years of research quality data. The data does not meet the 210-day minimum requirement for calendar year 2006.

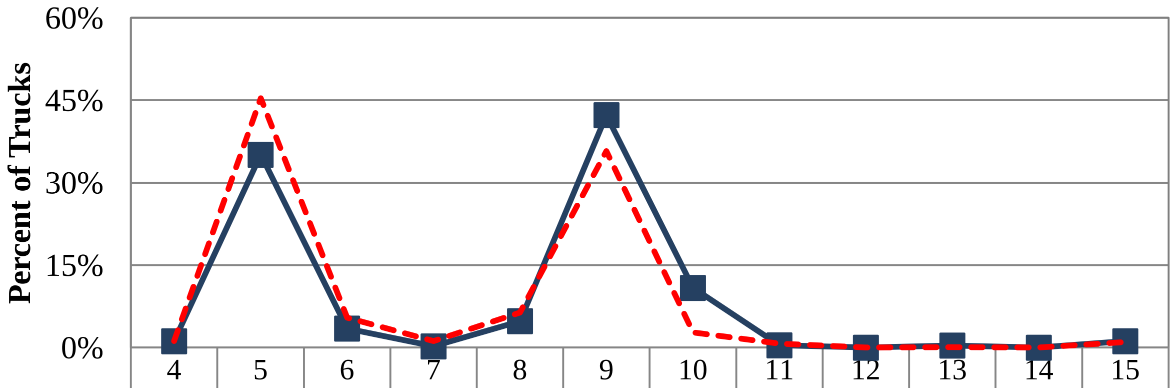
Table 2-2 provides a monthly breakdown of the available data for years 2006 through 2011.

**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 | | | | | | | | | | | 25 | 30 | 2 |
| 2007 | 29 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 | 12 |
| 2008 | 31 | 29 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 | 12 |
| 2009 | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 | 12 |
| 2010 | 30 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 | 12 |
| 2011 | 31 | 28 | 30 | 30 | 31 | 30 | 30 | 31 | 30 | 2 | | | 10 |

## 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 between the sample dataset from January 16, 2012 (Data) and the most recent comparison Data Set (CDS) from April 26, 2011.




| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data | 1.2% | 35.1% | 3.5% | 0.2% | 4.8% | 42.3% | 10.9% | 0.4% | 0.0% | 0.4% | 0.0% | 1.2% |
| CDS | 1.2% | 45.4% | 5.5% | 1.2% | 6.4% | 35.8% | 2.8% | 0.7% | 0.0% | 0.1% | 0.0% | 1.0% |

**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 two most frequent truck types crossing the WIM scale are Class 9 (42.3%) and Class 5 (35.1%) vehicles.

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 1.2 percent of the vehicles at this site are unclassified.

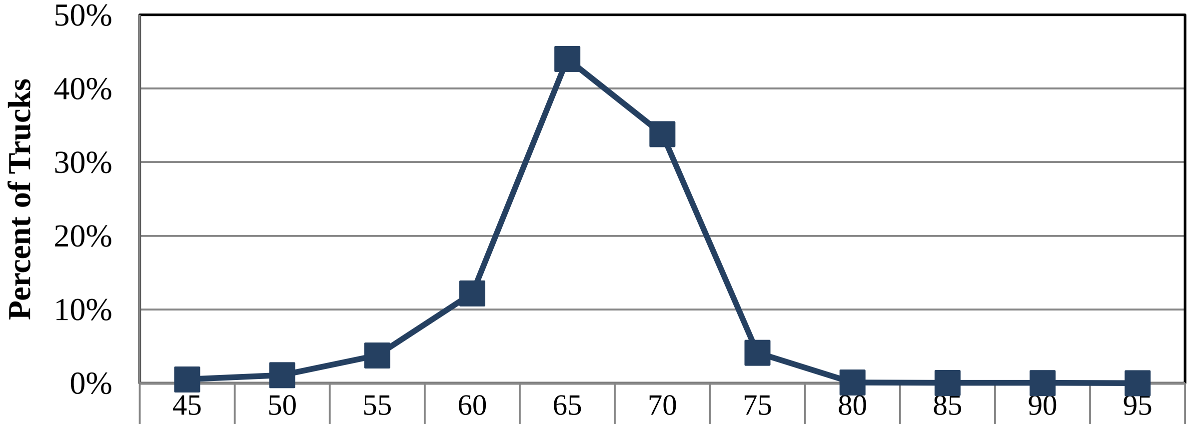
**Table 2-3 – Truck Distribution from W-Card**

| Vehicle Classification | CDS | | Data | | Change |
|---|---|---|---|---|---|
| | Date | | | | |
| | 4/26/2011 | | 1/16/2012 | | |
| 4 | 46 | 1.2% | 54 | 1.2% | 0.0% |
| 5 | 1772 | 45.4% | 1613 | 35.1% | -10.3% |
| 6 | 213 | 5.5% | 160 | 3.5% | -2.0% |
| 7 | 47 | 1.2% | 11 | 0.2% | -1.0% |
| 8 | 250 | 6.4% | 222 | 4.8% | -1.6% |
| 9 | 1396 | 35.8% | 1945 | 42.3% | 6.6% |
| 10 | 108 | 2.8% | 500 | 10.9% | 8.1% |
| 11 | 29 | 0.7% | 20 | 0.4% | -0.3% |
| 12 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 13 | 4 | 0.1% | 18 | 0.4% | 0.3% |
| 14 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 15 | 39 | 1.0% | 54 | 1.2% | 0.2% |

From the table it can be seen that the percentage of Class 9 vehicles has increased by 6.6 percent from April 2011 and January 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 percentage of Class 5 trucks decreased by 10.3 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.




| | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Data | 0.5% | 1.1% | 3.8% | 12.2% | 44.0% | 33.8% | 4.1% | 0.1% | 0.0% | 0.0% | 0.0% |

**Figure 2-2 – Truck Speed Distribution – 16-Jan-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 65 and the 85th percentile speed for trucks at this site is 68 mph. The range of truck speeds for the validation will be 55 to 65 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 January 2012 and the Comparison Data Set from April 2011.

As shown in Figure 2-3, there have been few changes in the GVW distributions, but the location of the loaded and unloaded peaks for the April 2011 Comparison Data Set (CDS) and the January 2012 two-week sample W-card dataset (Data) have not changed.

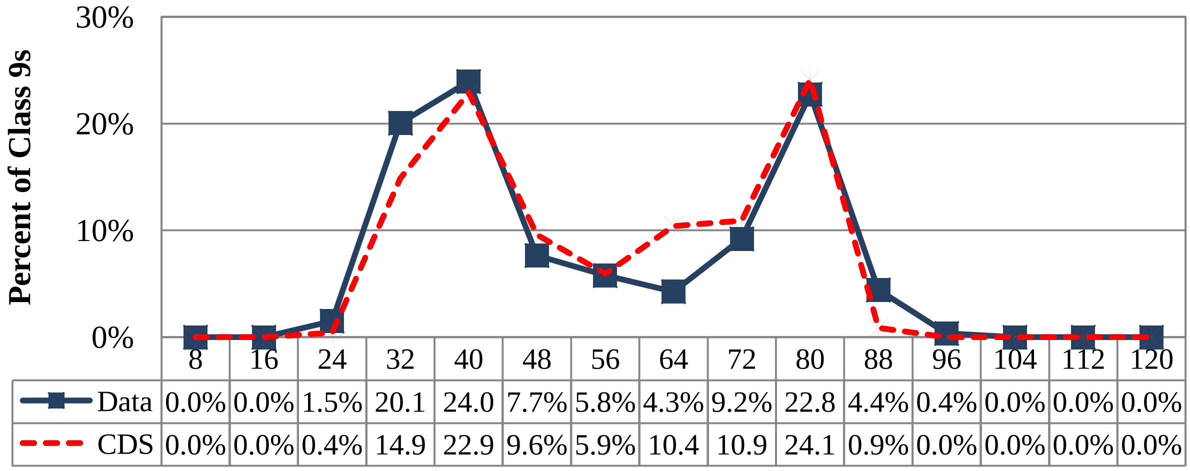



**Figure 2-3 – Comparison of Class 9 GVW Distribution**

Table 2-4 is provided to show the statistical comparison for Class 9 GVW between the Comparison Data Set and the January 2012 dataset.

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

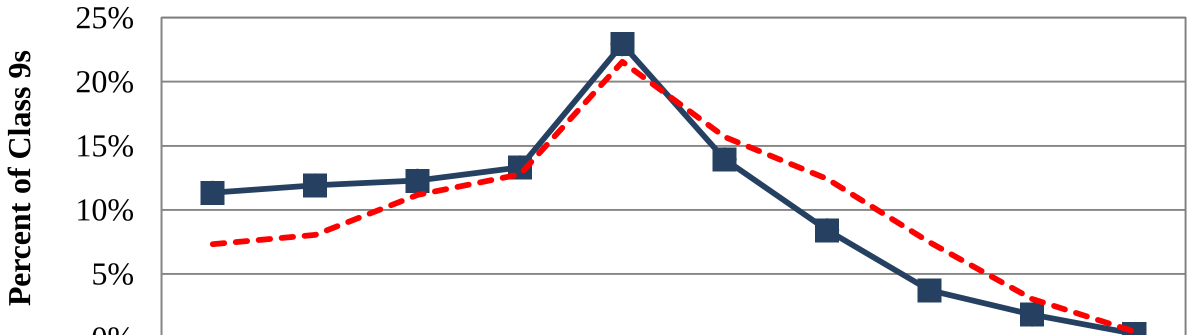
| GVW weight bins (kips) | CDS | | Data | | Change |
|---|---|---|---|---|---|
| | Date | | | | |
| | 4/26/2011 | | 1/16/2012 | | |
| 8 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 16 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 24 | 6 | 0.4% | 29 | 1.5% | 1.1% |
| 32 | 206 | 14.9% | 385 | 20.1% | 5.2% |
| 40 | 317 | 22.9% | 460 | 24.0% | 1.1% |
| 48 | 133 | 9.6% | 147 | 7.7% | -1.9% |
| 56 | 82 | 5.9% | 111 | 5.8% | -0.1% |
| 64 | 144 | 10.4% | 82 | 4.3% | -6.1% |
| 72 | 151 | 10.9% | 177 | 9.2% | -1.7% |
| 80 | 334 | 24.1% | 437 | 22.8% | -1.4% |
| 88 | 12 | 0.9% | 85 | 4.4% | 3.6% |
| 96 | 0 | 0.0% | 7 | 0.4% | 0.4% |
| 104 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 112 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 120 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| Average = | 52.6 kips | | 51.0 kips | | -1.6 kips |

As shown in the table, the percentage of unloaded class 9 trucks in the 32 to 40 kips range increased by 1.1 percent while the percentage of loaded class 9 trucks in the 72 to 80 kips range decreased by 1.4 percent. During this time period the percentage of overweight trucks increased by 4.0 percent. Based on the average Class 9 GVW values from the per vehicle records, the GVW average for this site decreased by 3.0 percent, from 52.6 to 51.0 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 January 2012 and the Comparison Data Set from April 2011. The percentage of light axles (9.5 to 10.5 kips) increased by approximately 1.6 percent and the percentage of heavy axles (11.5 to 12.5 kips) decreased by approximately 7.8 percent, indicating possible negative bias (underestimation of loads) in front axle measurement.




| | 9.0 | 9.5 | 10.0 | 10.5 | 11.0 | 11.5 | 12.0 | 12.5 | 13.0 | 13.5 |
|---|---|---|---|---|---|---|---|---|---|---|
| Data | 11.3% | 11.9% | 12.3% | 13.3% | 22.9% | 13.9% | 8.4% | 3.7% | 1.8% | 0.3% |
| CDS | 7.3% | 8.1% | 11.2% | 12.8% | 21.6% | 15.7% | 12.4% | 7.5% | 3.0% | 0.5% |

**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 10.5 and 11.5 kips. The percentage of trucks in this range is similar between the April 2011 Comparison Data Set (CDS) and the January 2012 dataset (Data).

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

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

| F/A weight bins (kips) | CDS | | Data | | Change |
|---|---|---|---|---|---|
| | Date | | | | |
| | 4/26/2011 | | 1/16/2012 | | |
| 9.0 | 101 | 7.3% | 217 | 11.3% | 4.0% |
| 9.5 | 111 | 8.1% | 228 | 11.9% | 3.9% |
| 10.0 | 154 | 11.2% | 235 | 12.3% | 1.1% |
| 10.5 | 176 | 12.8% | 255 | 13.3% | 0.5% |
| 11.0 | 297 | 21.6% | 439 | 22.9% | 1.3% |
| 11.5 | 216 | 15.7% | 267 | 13.9% | -1.8% |
| 12.0 | 171 | 12.4% | 161 | 8.4% | -4.0% |
| 12.5 | 103 | 7.5% | 71 | 3.7% | -3.8% |
| 13.0 | 42 | 3.0% | 35 | 1.8% | -1.2% |
| 13.5 | 7 | 0.5% | 6 | 0.3% | -0.2% |
| Average = | 10.7 kips | | 10.4 kips | | -0.3 kips |

The table shows that the average front axle weight for Class 9 trucks has decreased by 0.5 kips, or 2.8 percent. According to the values from the per vehicle records, the average front axle weight for Class 9 trucks is 10.4 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.

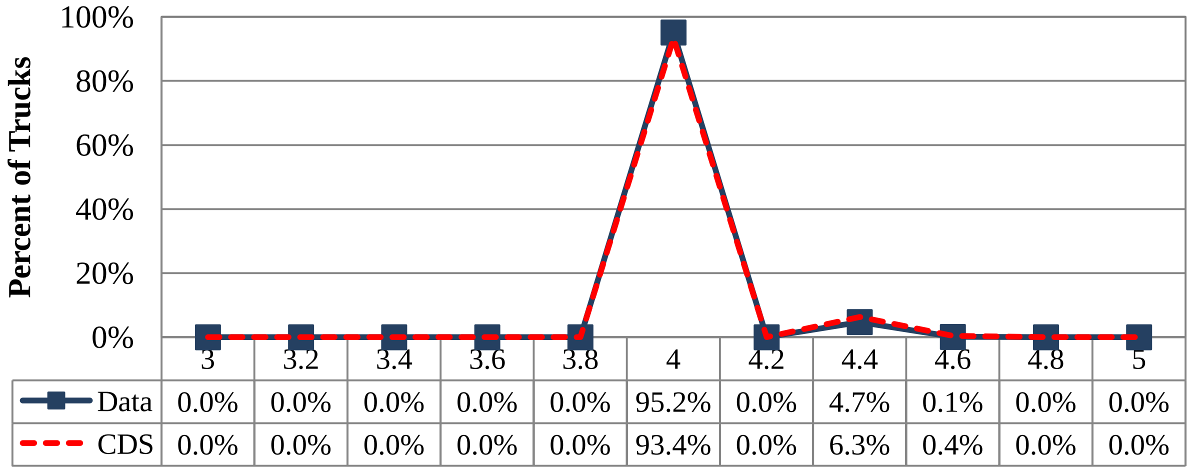



**Figure 2-5 – Comparison of Class 9 Tractor Tandem Spacing**

As seen in the figure, the Class 9 tractor tandem spacings for the April 2011 Comparison Data Set and the January 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 | | | | |
| | 4/26/2011 | | 1/16/2012 | | |
| 3.0 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 3.2 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 3.4 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 3.6 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 3.8 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 4.0 | 1293 | 93.4% | 1827 | 95.2% | 1.8% |
| 4.2 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 4.4 | 87 | 6.3% | 91 | 4.7% | -1.5% |
| 4.6 | 5 | 0.4% | 2 | 0.1% | -0.3% |
| 4.8 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| 5.0 | 0 | 0.0% | 0 | 0.0% | 0.0% |
| Average = | 4.0 feet | | 4.0 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 4.0 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 4.0, which is identical to to the expected average of 4.0 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 (January 2012). Comparison of vehicle class distribution data indicates a 6.6 percent increase in the percentage of Class 9 vehicles. Analysis of Class 9 weight data indicates that front axle weights have decreased by 2.8 percent and average Class 9 GVW has decreased by 3.0 percent for the January 2012 data. The data indicates an average truck tandem spacing of 4.0 feet, which is identical to the expected average of 4.0 feet.

# 3 WIM Equipment Discussion

From a comparison between the report of the most recent validation of this equipment on April 26, 2011 and this validation visit, sensor number 3, which is the trailing WIM sensor in the left wheel path, has been disabled in the WIM controller. Additionally, it appears that the loop sensors are indicating leakage to ground, sensor number 2 indicates low resistance, and sensor 3 indicates high capacitance.

## 3.1 Description

This site was installed on October 6, 2006 by International Road Dynamics. It is instrumented with quartz weighing sensors and an 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 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. Loop resistance to ground indicated leakage. WIM sensor 2 indicated low on resistance tests, and sensor 3 indicated a high level of capacitance. 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 for the LTPP lane normally. No troubleshooting actions were taken.

## 3.5 Recommended Equipment Maintenance

It is recommended that WIM sensors 2 and 3 be replaced, and that further investigation of the loops be conducted to determine cause of low resistance to ground.

# 4 Pavement Discussion

## 4.1 Pavement Condition Survey

During a visual distress survey of the pavement conducted from the shoulder, transverse cracking as shown in Photo 4-1 through Photo 4-3 was observed throughout the WIM section. No adverse truck dynamics were noted in these areas and the distresses did not appear to affect the accuracy of the WIM sensors.

**Photo 4-1 – Pavement Distress in WIM Section**

**Photo 4-2 – Pavement Distress in WIM Section**

**Photo 4-3 – Pavement Distress in WIM Section**

## 4.2 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 5 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) | 0.564 | *0.472* | *0.477* | | | 0.504 |
| | | SRI (m/km) | *0.254* | *0.249* | *0.298* | | | *0.267* |
| | | Peak LRI (m/km) | 0.667 | 0.577 | 0.626 | | | 0.623 |
| | | Peak SRI (m/km) | *0.359* | *0.359* | *0.352* | | | *0.357* |
| | RWP | LRI (m/km) | 0.536 | 0.594 | 0.537 | | | 0.556 |
| | | SRI (m/km) | *0.379* | 0.528 | *0.426* | | | *0.444* |
| | | Peak LRI (m/km) | 0.610 | 0.638 | 0.635 | | | 0.628 |
| | | Peak SRI (m/km) | *0.687* | 0.805 | 0.775 | | | 0.756 |
| Center | LWP | LRI (m/km) | *0.448* | *0.457* | *0.450* | *0.434* | *0.459* | *0.450* |
| | | SRI (m/km) | *0.223* | *0.289* | *0.280* | *0.194* | *0.224* | *0.242* |
| | | Peak LRI (m/km) | 0.571 | 0.614 | 0.607 | 0.562 | 0.593 | 0.589 |
| | | Peak SRI (m/km) | *0.328* | *0.366* | *0.378* | *0.350* | *0.367* | *0.358* |
| | RWP | LRI (m/km) | 0.586 | 0.583 | 0.555 | 0.598 | 0.615 | 0.587 |
| | | SRI (m/km) | 0.598 | 0.642 | 0.588 | 0.648 | 0.615 | 0.618 |
| | | Peak LRI (m/km) | 0.700 | 0.695 | 0.697 | 0.744 | 0.725 | 0.712 |
| | | Peak SRI (m/km) | 0.773 | 0.791 | *0.741* | 0.812 | 0.911 | 0.806 |
| Right | LWP | LRI (m/km) | 0.584 | 0.596 | 0.620 | | | 0.600 |
| | | SRI (m/km) | *0.366* | *0.379* | *0.449* | | | *0.398* |
| | | Peak LRI (m/km) | 0.650 | 0.685 | 0.656 | | | 0.664 |
| | | Peak SRI (m/km) | *0.579* | *0.580* | *0.553* | | | *0.571* |
| | RWP | LRI (m/km) | 0.743 | 0.762 | 0.743 | | | 0.749 |
| | | SRI (m/km) | 0.588 | *0.479* | 0.515 | | | 0.527 |
| | | Peak LRI (m/km) | **0.927** | **0.978** | **0.939** | | | **0.948** |
| | | Peak SRI (m/km) | 0.781 | *0.575* | *0.697* | | | *0.684* |

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. The highest values, on average, are the Peak LRI values in the right wheel path of the right shift passes (shown in bold).

## 4.3 Profile and Vehicle Interaction

Profile data was collected on May 10, 2011 by the North Central 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, 11 profile passes were made, 5 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 137 in/mi and is located approximately 444 feet prior to the WIM scale. The highest IRI value within the 400 foot approach section was 104 in/mi and is located approximately 347 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. There were no distresses observed at these locations 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.

### 4.4 Recommended Pavement Remediation

Sealing (or routing and sealing) of the transverse cracks in the vicinity of the WIM scale is recommended.

# 5 Statistical Reliability of the WIM Equipment

This 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 April 3, 2012, beginning at approximately 10:22 AM and continuing until 3:37 PM.

The two test trucks consisted of:

- A Class 9 truck, loaded with palleted beezwax, pellet fuel, and wood shavings, and equipped with air suspension on truck and trailer tandems and with standard tandem spacings on both the tractor and trailer.

- A Class 9 truck, loaded with palletized wood shavings, 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 | 74.6 | 12.2 | 17.0 | 16.1 | 14.8 | 14.6 | 17.2 | 4.3 | 34.5 | 4.0 | 60.0 | 71.8 |
| 2 | 62.2 | 11.4 | 14.4 | 14.3 | 10.7 | 11.4 | 17.1 | 4.3 | 35.5 | 4.0 | 60.9 | 71.8 |

Test truck speeds varied by 11 mph, from 54 to 65 mph. The measured pre-validation pavement temperatures varied 29.6 degrees Fahrenheit, from 56.0 to 85.6. The sunny weather conditions nearly provided 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 met all LTPP requirements for loading measurements as a result of the pre-validation test truck runs; however, all weight measurements showed small negative bias. The site did not meet the LTPP requirements for vehicle length measurements.

**Table 5-2 – Pre-Validation Overall Results – 3-Apr-12**

| Parameter | 95% Confidence Limit of Error | Site Values | Pass/Fail |
|---|---|---|---|
| Steering Axles | ±20 percent | -4.9 ± 6.4% | Pass |
| Tandem Axles | ±15 percent | -1.4 ± 5.7% | Pass |
| GVW | ±10 percent | -3.7 ± 3.5% | Pass |
| Vehicle Length | ±3.0 percent (2.2 ft) | 1.7 ± 1.2 ft | FAIL |
| 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 over all speeds was 0.5 ± 1.9 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 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 65 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 – 3-Apr-12**

| Parameter | 95% Confidence Limit of Error | Low | Medium | High |
|---|---|---|---|---|
| | | 54.0 to 57.7 mph | 57.8 to 61.4 mph | 61.5 to 65.0 mph |
| Steering Axles | ±20 percent | -5.5 ± 7.2% | -3.7 ± 5.8% | -5.5 ± 7.2% |
| Tandem Axles | ±15 percent | -4.5 ± 5.7% | -2.5 ± 5.9% | -4.0 ± 5.8% |
| GVW | ±10 percent | -4.4 ± 2.8% | -2.5 ± 3.7% | -4.1 ± 3.5% |
| Vehicle Length | ±3.0 percent (2.2 ft) | 1.6 ± 1.1 ft | 1.7 ± 1.4 ft | 1.6 ± 1.4 ft |
| Vehicle Speed | ± 1.0 mph | 0.7 ± 1.4 mph | 0.7 ± 3.0 mph | 0.1 ± 1.4 mph |
| Axle Length | ± 0.5 ft [150mm] | 0.0 ± 0.1 ft | -0.1 ± 0.1 ft | 0.0 ± 0.0 ft |

From the table, it can be seen that the WIM equipment underestimates all weights at all speeds. Variability in error is similar at all speeds.

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 equipment generally underestimated GVW at all speeds. The bias is larger at low and high speed groups than at the medium speed group. The range in error is similar throughout the speed range.

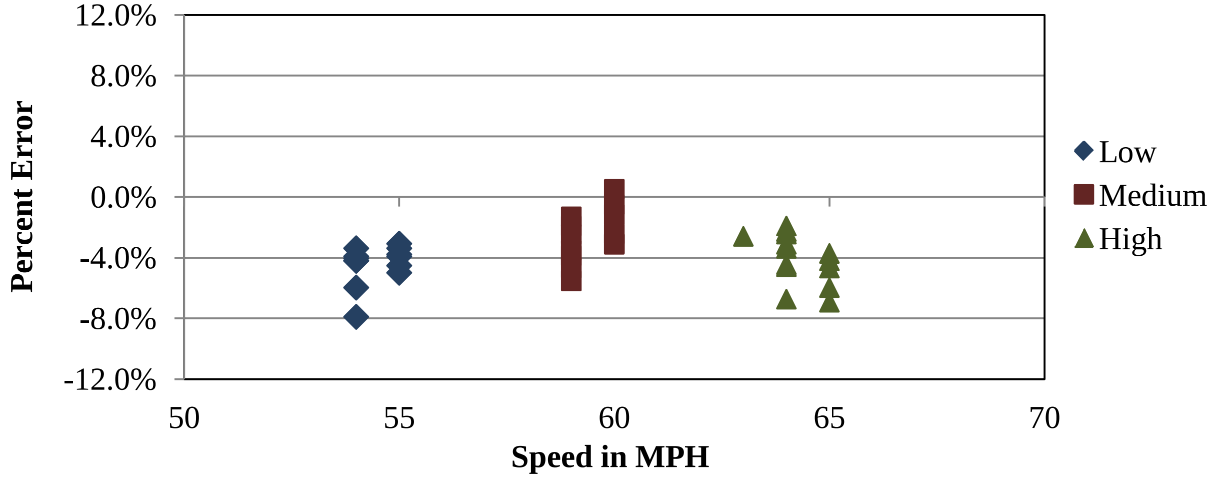



**Figure 5-1 – Pre-Validation GVW Error by Speed – 3-Apr-12**

#### 5.1.1.2 Steering Axle Weight Errors by Speed

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

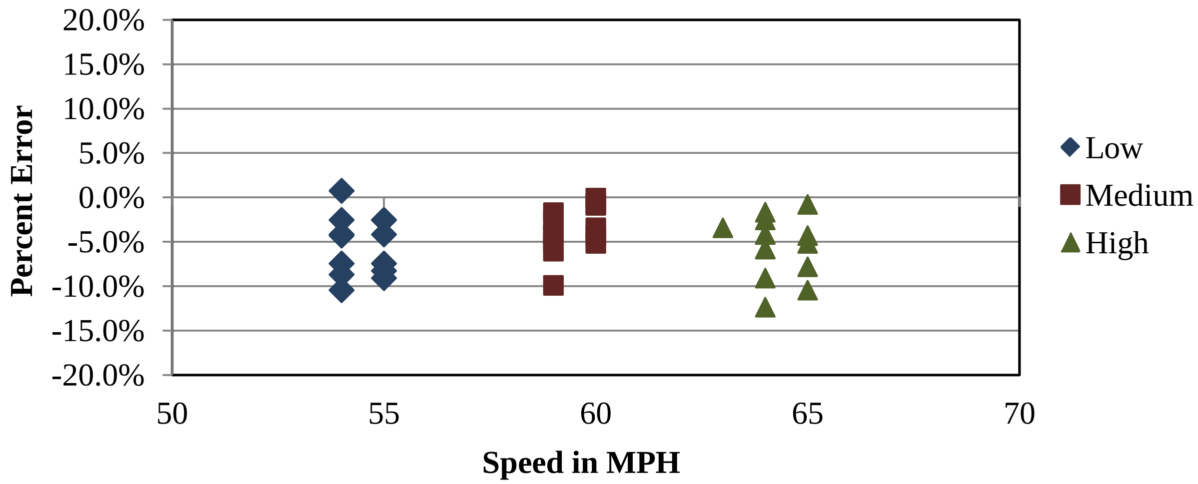



**Figure 5-2 – Pre-Validation Steering Axle Weight Errors by Speed – 3-Apr-12**

#### 5.1.1.3 Tandem Axle Weight Errors by Speed

As shown in Figure 5-3, the equipment estimates tandem axle weights with similar accuracy at all speeds. The range in error is greater at medium speeds.

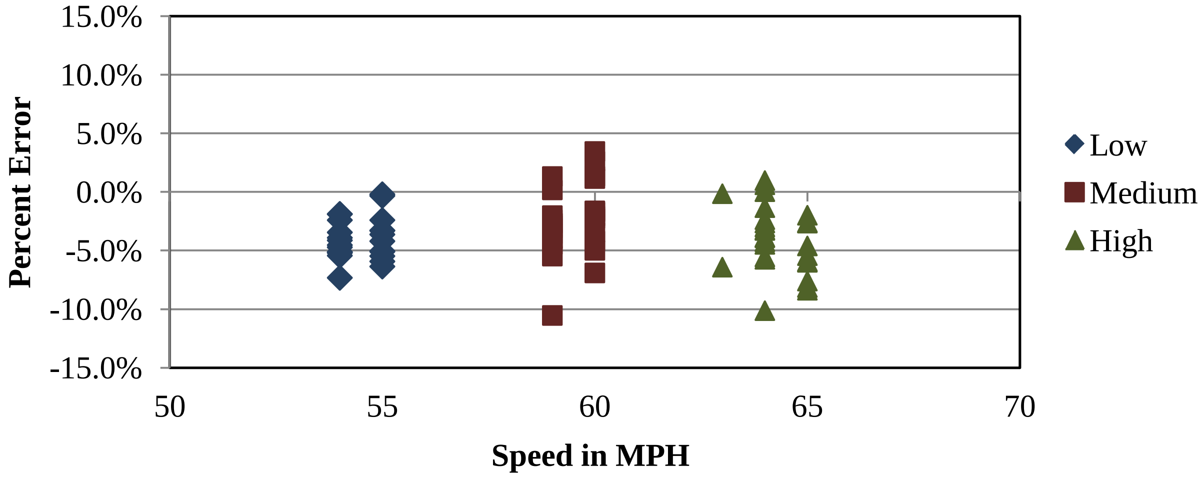



**Figure 5-3 – Pre-Validation Tandem Axle Weight Errors by Speed – 3-Apr-12**

#### 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 at all speeds. Distribution of errors is shown graphically in Figure 5-4.

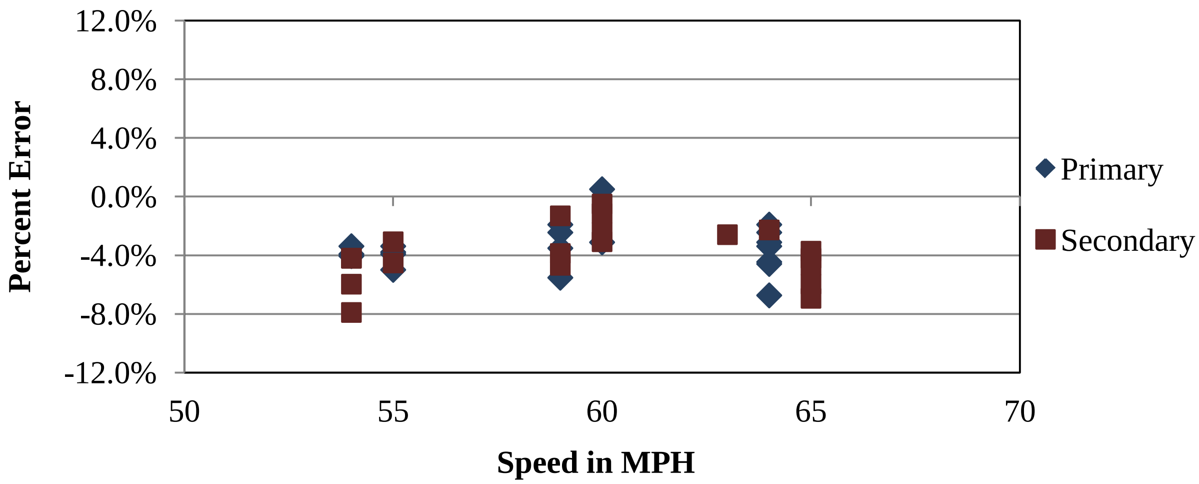



**Figure 5-4 – Pre-Validation GVW Errors by Truck and Speed – 3-Apr-12**

5.1.1.5 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 -0.1 feet to 0.0 feet. Distribution of errors is shown graphically in Figure 5-5.

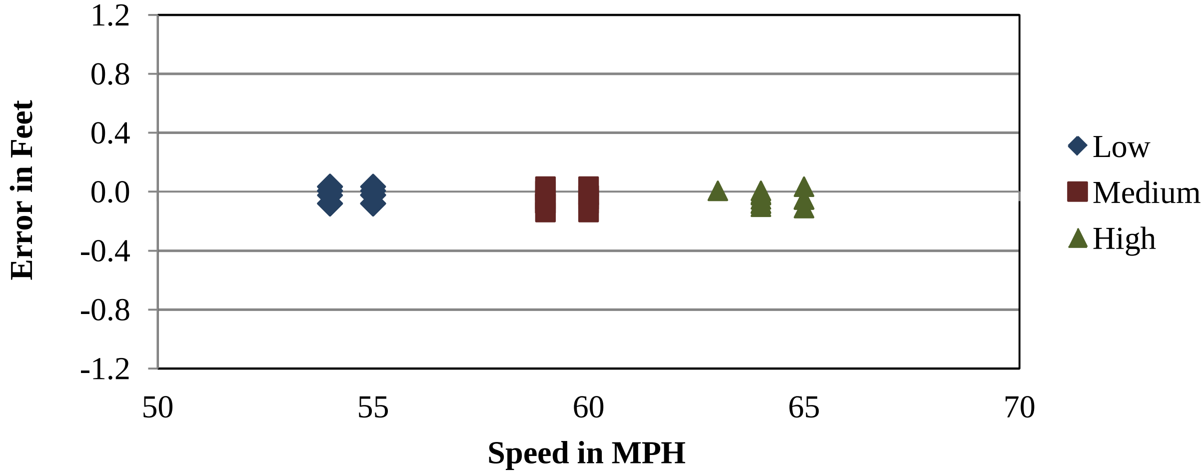



**Figure 5-5 – Pre-Validation Axle Length Errors by Speed – 3-Apr-12**

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 0.2 to 3.2 feet. Distribution of errors is shown graphically in Figure 5-6.

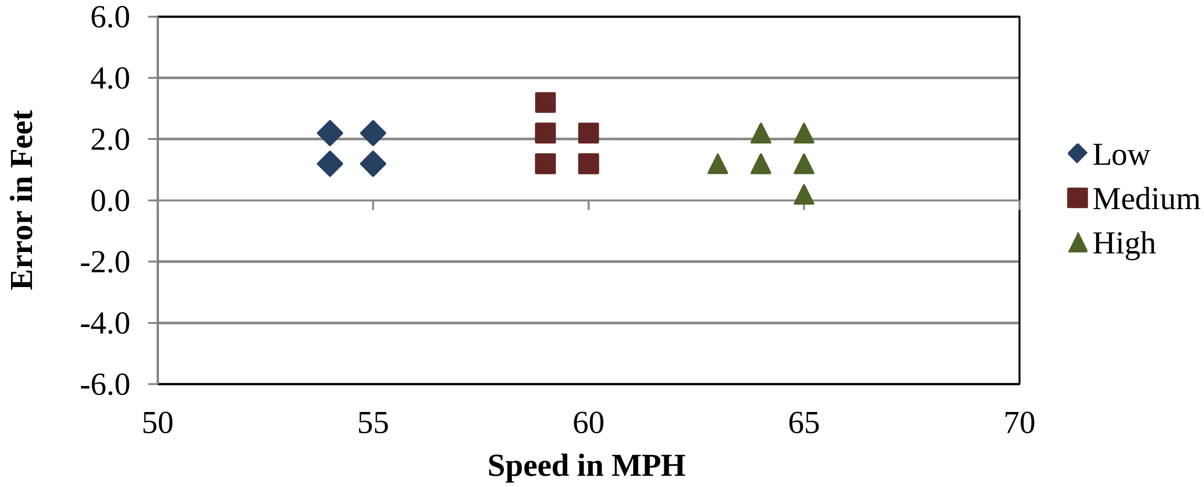



**Figure 5-6 – Pre-Validation Overall Length Error by Speed – 3-Apr-12**

### *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 29.6 degrees, from 56.0 to 85.6 degrees Fahrenheit. Since the desired 30 degree temperature range was nearly met, the pre-validation test runs are being reported under three temperature groups – low, medium and high, as shown in Table 5-4.

**Table 5-4 – Pre-Validation Results by Temperature – 3-Apr-12**

| Parameter | 95% Confidence Limit of Error | Low 56.0 to 70 degF | Medium 70.1 to 82.0 degF | High 82.1 to 85.6 degF |
|---|---|---|---|---|
| Steering Axles | ±20 percent | -5.6 ± 9.4% | -4.7 ± 6.6% | -4.8 ± 6.3% |
| Tandem Axles | ±15 percent | -4.0 ± 6.2% | -2.6 ± 6.9% | -4.3 ± 4.6% |
| GVW | ±10 percent | -4.1 ± 3.2% | -2.7 ± 4.6% | -4.2 ± 2.7% |
| Vehicle Length | ±3.0 percent (2.2 ft) | 1.5 ± 1.1 ft | 1.5 ± 1.4 ft | 1.8 ± 1.3 ft |
| Vehicle Speed | ± 1.0 mph | 0.4 ± 1.8 mph | 0.5 ± 1.4 mph | 0.6 ± 2.6 mph |
| Axle Length | ± 0.5 ft [150mm] | 0.0 ± 0.1 ft | 0.0 ± 0.1 ft | 0.0 ± 0.1 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 generally underestimates GVW across the range of temperatures observed in the field. The range in error is greater at medium temperatures compared to low and high temperatures.

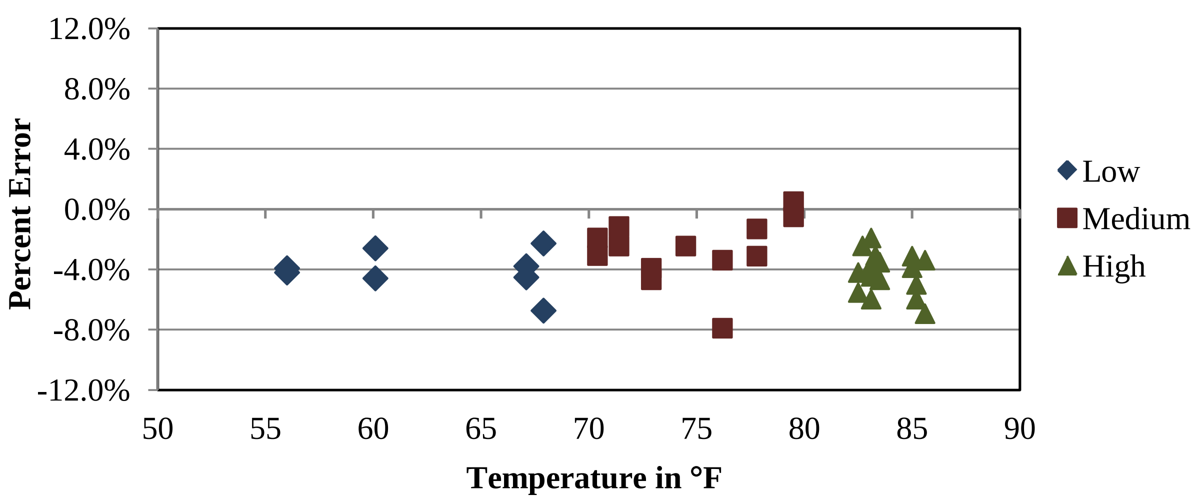



**Figure 5-7 – Pre-Validation GVW Errors by Temperature – 3-Apr-12**

5.1.2.2 Steering Axle Weight Errors by Temperature

Figure 5-8 illustrates that for steering axles, the WIM equipment underestimates weights at all temperatures. The range in error is similar for the three temperature groups.

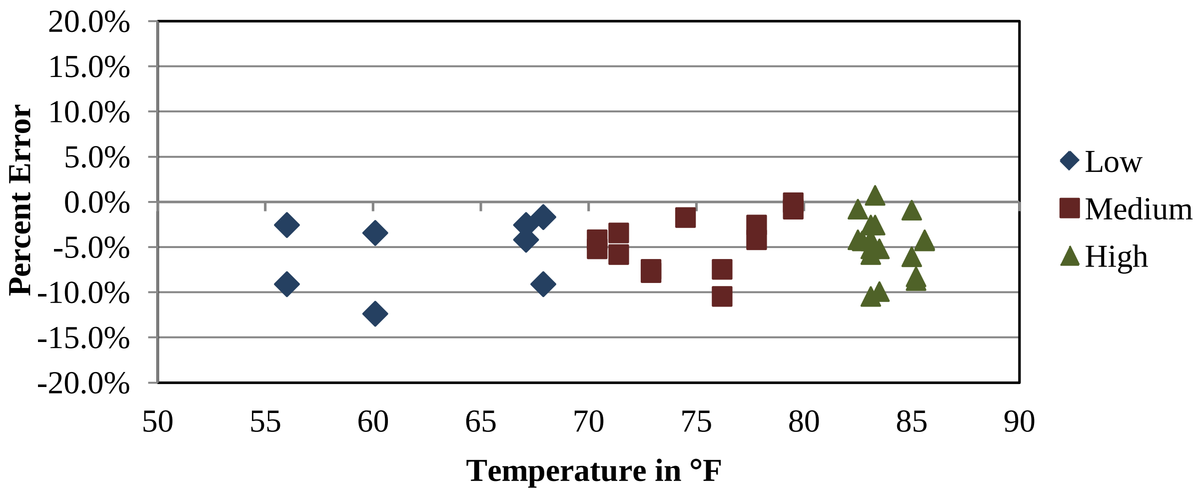



**Figure 5-8 – Pre-Validation Steering Axle Weight Errors by Temperature – 3-Apr-12**

5.1.2.3 Tandem Axle Weight Errors by Temperature

As shown in Figure 5-9, the WIM equipment generally underestimates tandem axle weights across the range of temperatures observed in the field. The range in tandem axle errors is consistent for the three temperature groups.

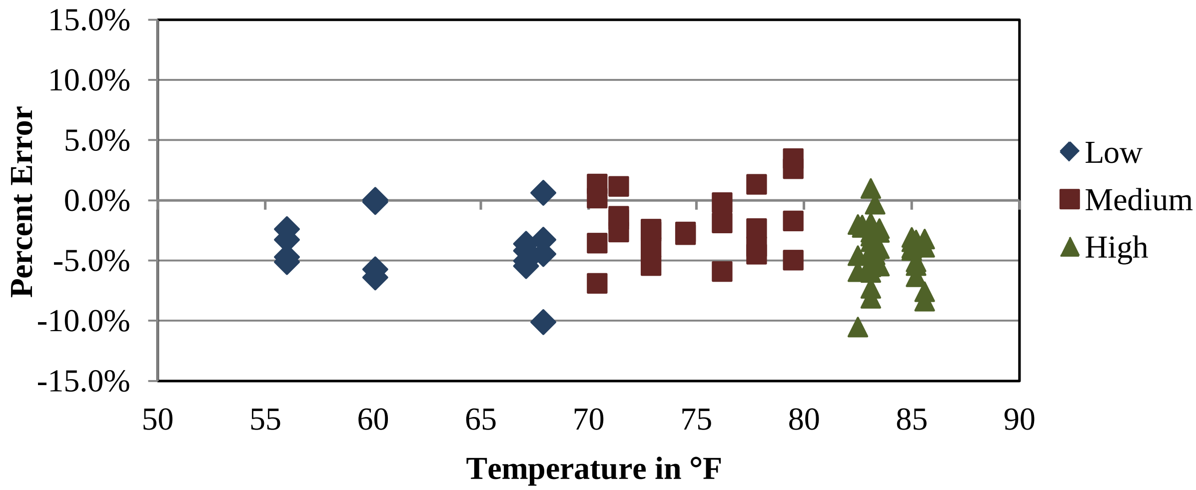



**Figure 5-9 – Pre-Validation Tandem Axle Weight Errors by Temperature – 3-Apr-12**

#### 5.1.2.4 GVW Errors by Temperature and Truck Type

When analyzed for each test truck, 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. For both trucks, the range of errors and bias are similar over the range of temperatures. Distribution of errors is shown graphically in Figure 5-10.

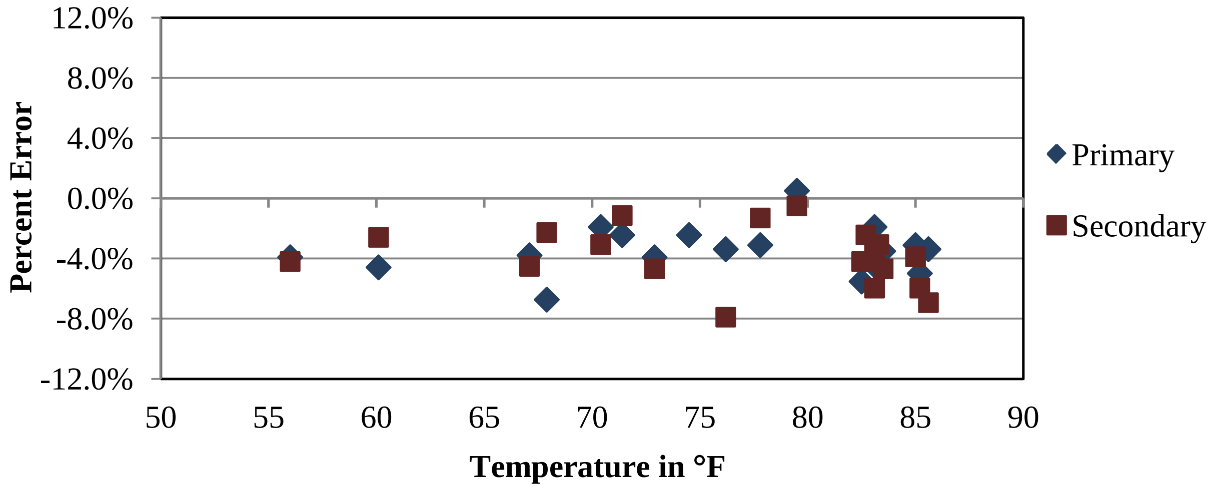



**Figure 5-10 – Pre-Validation GVW Error by Truck and Temperature – 3-Apr-12**

### *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 35 vehicles including 23 trucks (Class 4 through 13) was collected. The small sample was due to the low volume of trucks passing over the WIM scale. 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, three Class 3 vehicles were misclassified as Class 5 vehicles and one Class 5 vehicle was misclassified as a Class 8 vehicle by the equipment.

**Table 5-5 – Pre-Validation Misclassifications by Pair – 3-Apr-12**

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

As shown in the table, a total of 4 vehicles, including 0 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 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 11.4%, was due to three misclassifications of Class 3 vehicles as Class 5s and one misclassification of Class 5 vehicle as a Class 8. The causes for the misclassifications were not investigated in the field.

The combined results produced an undercount of three Class 3 vehicles and an overcount of two Class 5 vehicles and one Class 8 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 – 3-Apr-12**

| Class | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Observed Count | 12 | 1 | 9 | 0 | 0 | 0 | 12 | 1 | 0 | 0 | 0 |
| WIM Count | 9 | 1 | 11 | 0 | 0 | 1 | 12 | 1 | 0 | 0 | 0 |
| Observed Percent | 34.3 | 2.9 | 25.7 | 0.0 | 0.0 | 0.0 | 34.3 | 2.9 | 0.0 | 0.0 | 0.0 |
| WIM Percent | 22.9 | 2.9 | 31.4 | 0.0 | 0.0 | 2.9 | 34.3 | 2.9 | 0.0 | 0.0 | 0.0 |
| Misclassified Count | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Misclassified Percent | 33.3 | 0.0 | 11.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Unclassified Count | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Unclassified Percent | 12.5 | 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 – 3-Apr-12**

| Observed Class | Unclassified | Observed Class | Unclassified | Observed Class | Unclassified |
|---|---|---|---|---|---|
| 3 | 1 | 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 23 trucks, 2.9 percent 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.

For speed, the mean error for WIM equipment speed measurement was 0.7 mph; the range of errors was 2.0 mph.

## 5.2 Calibration

The WIM equipment required two 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 – 3-Apr-12**

| Speed Point | MPH | Left | | Right | |
|---|---|---|---|---|---|
| | | 1 | 3 | 2 | 4 |
| 64 | 40 | 3650 | 3650 | 3282 | 3282 |
| 80 | 50 | 3786 | 3786 | 3404 | 3404 |
| 96 | 60 | 3942 | 3942 | 3544 | 3544 |
| 112 | 70 | 3868 | 3868 | 3478 | 3478 |
| 125 | 78 | 3506 | 3506 | 3153 | 3153 |
| **Axle Distance (cm)** | | 365 | | | |
| **Dynamic Comp (%)** | | 100 | | | |
| **Loop Width (cm)** | | 183 | | | |

### 5.2.1 Calibration Iteration 1

#### 5.2.1.1 Equipment Adjustments

The pre-validation test truck runs produced an overall error in the GVW measurement of -3.7% and errors of -4.63%, -2.98%, and -4.93% at the 50, 60 and 70 mph speed points, respectively. To compensate for these errors, the following changes to the compensation factors were made:

**Table 5-9 – Calibration 1 Equipment Factor Changes – 4-Apr-12**

| Speed Points | Old Factors | | | | New Factors | | | |
|---|---|---|---|---|---|---|---|---|
| | Left | | Right | | Left | | Right | |
| | 1 | 3 | 2 | 4 | 1 | 3 | 2 | 4 |
| 64 | 3650 | 3650 | 3282 | 3282 | 3827 | 3827 | 3441 | 3441 |
| 80 | 3786 | 3786 | 3404 | 3404 | 3970 | 3970 | 3569 | 3569 |
| 96 | 3942 | 3942 | 3544 | 3544 | 4063 | 4063 | 3653 | 3653 |
| 112 | 3868 | 3868 | 3478 | 3478 | 4069 | 4069 | 3658 | 3658 |
| 125 | 3506 | 3506 | 3153 | 3153 | 3688 | 3688 | 3317 | 3317 |
| **Axle Distance (cm)** | 365 | | | | 365 | | | |
| **Dynamic Comp (%)** | 100 | | | | 101 | | | |
| **Loop Width (cm)** | 183 | | | | 233 | | | |

#### 5.2.1.2 Calibration 1 Results

The results of the 12 first calibration verification runs are provided in Table 5-10 and Figure 5-11. As can be seen in the table, the mean error of all weight estimates changed from negative to positive as a result of the first calibration iteration.

**Table 5-10 – Calibration 1 Results – 4-Apr-12**

| Parameter | 95% Confidence Limit of Error | Site Values | Pass/Fail |
|---|---|---|---|
| Steering Axles | ±20 percent | 4.6 ± 6.8% | Pass |
| Tandem Axles | ±15 percent | 1.9 ± 4.7% | Pass |
| GVW | ±10 percent | 2.4 ± 2.3% | Pass |
| Vehicle Length | ±3.0 percent (2.2 ft) | -0.1 ± 1.1 ft | Pass |
| Axle Length | ± 0.5 ft [150mm] | 0.0 ± 0.1 ft | Pass |

Figure 5-11 shows that the WIM equipment is estimating GVW with similar (high) accuracy at low and medium speeds, and with marginally higher error at the high speeds.

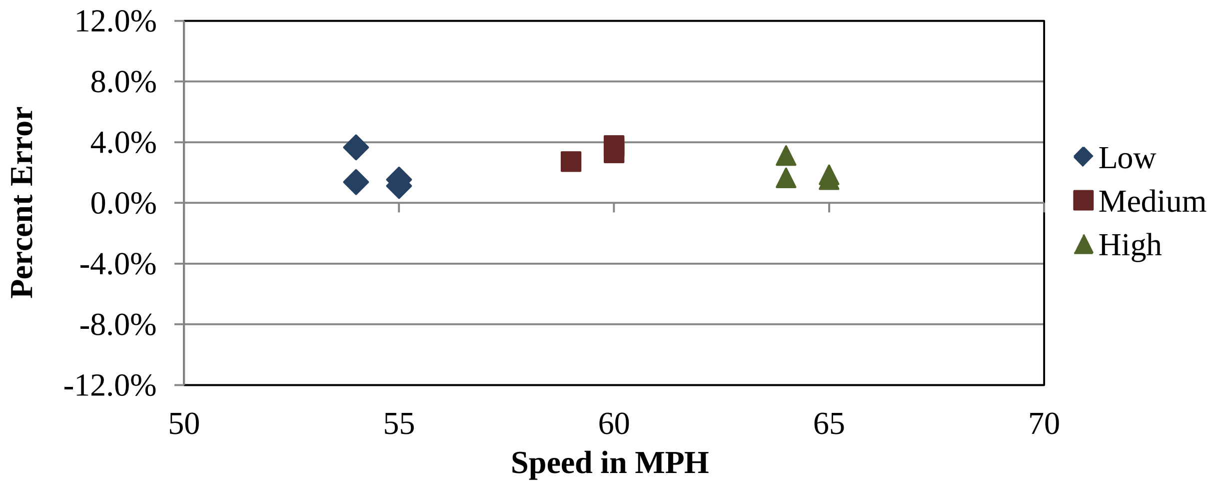



**Figure 5-11 – Calibration 1 GVW Error by Speed – 4-Apr-12**

Based on the results of the first calibration, where weight estimate bias was 2.4 percent, a second calibration was considered to be necessary to improve the accuracy of the WIM system.

### *5.2.2 Calibration Iteration 2*

#### 5.2.2.1 Equipment Adjustments

The first calibration test truck runs produced an overall error of 2.4% and errors of 2.16%, 2.26%, and 1.34% at the 50, 60 and 70 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 – 4-Apr-12**

| Speed Points | Old Factors | | | | New Factors | | | |
|---|---|---|---|---|---|---|---|---|
| | Left | | Right | | Left | | Right | |
| | 1 | 3 | 2 | 4 | 1 | 3 | 2 | 4 |
| 64 | 3827 | 3827 | 3441 | 3441 | 3746 | 3746 | 3369 | 3369 |
| 80 | 3970 | 3970 | 3569 | 3569 | 3886 | 3886 | 3494 | 3494 |
| 96 | 4063 | 4063 | 3653 | 3653 | 3973 | 3973 | 3572 | 3572 |
| 112 | 4069 | 4069 | 3658 | 3658 | 4015 | 4015 | 3610 | 3610 |
| 125 | 3688 | 3688 | 3317 | 3317 | 3639 | 3639 | 3273 | 3273 |
| **Axle Distance (cm)** | 365 | | | | 365 | | | |
| **Dynamic Comp (%)** | 101 | | | | 99 | | | |
| **Loop Width (cm)** | 233 | | | | 233 | | | |

#### 5.2.2.2 Calibration 2 Results

The results of the 12 second calibration verification runs are provided in Table 5-10 and Figure 5-11. As can be seen in the table, the mean error of all weight estimates was reduced as a result of the second calibration iteration.

**Table 5-12 – Calibration 2 Results – 4-Apr-12**

| **Parameter** | **95% Confidence Limit of Error** | **Site Values** | **Pass/Fail** |
|---|---|---|---|
| Steering Axles | ±20 percent | -1.2 ± 7.7% | Pass |
| Tandem Axles | ±15 percent | 1.4 ± 5.3% | Pass |
| GVW | ±10 percent | 0.2 ± 3.4% | Pass |
| Vehicle Length | ±3.0 percent (2.2 ft) | -0.2 ± 1.1 ft | Pass |
| Axle Length | ± 0.5 ft [150mm] | 0.0 ± 0.1 ft | Pass |

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

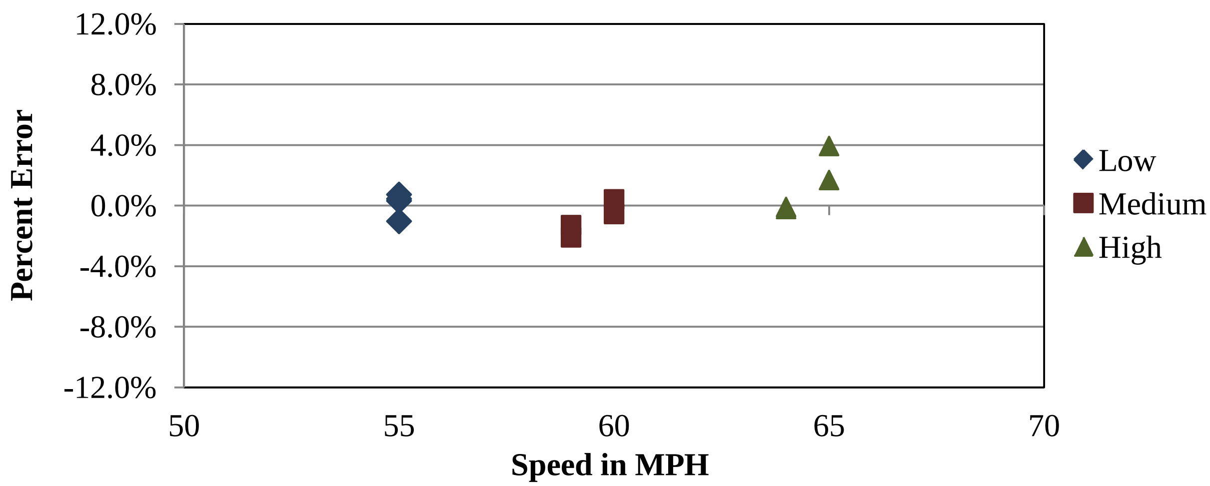



**Figure 5-12 – Calibration 2 GVW Error by Speed – 4-Apr-12**

Based on the results of the second calibration, where GVW estimate bias decreased to 0.2 percent, a third calibration was not considered to be necessary. 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 April 4, 2012, beginning at approximately 10:16 AM and continuing until 3:04 PM.

The two test trucks consisted of:

- A Class 9 truck, loaded with palleted beezwax, pellet fuel, and wood shavings, and equipped with air suspension on truck and trailer tandems and with standard tandem spacings on both the tractor and trailer.

- A Class 9 truck, loaded with palletized wood shavings, 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 post-validation and re-weighed at the conclusion of the post-validation. The average test truck weights and measurements are provided in Table 5-13.

**Table 5-13 – 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 | 74.6 | 12.1 | 16.5 | 15.8 | 15.1 | 15.1 | 17.2 | 4.3 | 34.5 | 4.0 | 60.0 | 71.8 |
| 2 | 62.2 | 11.4 | 14.1 | 14.1 | 11.0 | 11.6 | 17.1 | 4.3 | 35.5 | 4.0 | 60.9 | 71.8 |

Test truck speeds varied by 11 mph, from 54 to 65 mph. The measured post-validation pavement temperatures varied 32.5 degrees Fahrenheit, from 53.9 to 86.4. The sunny weather conditions provided the desired minimum 30 degree temperature range. Table 5-14 is a summary of post validation results.

**Table 5-14 – Post-Validation Overall Results – 4-Apr-12**

| Parameter | 95% Confidence Limit of Error | Site Values | Pass/Fail |
|---|---|---|---|
| Steering Axles | ±20 percent | -1.3 ± 5.7% | Pass |
| Tandem Axles | ±15 percent | 0.9 ± 4.6% | Pass |
| GVW | ±10 percent | -0.4 ± 3.0% | Pass |
| Vehicle Length | ±3.0 percent (2.2 ft) | 0.1 ± 1.1 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 0.4 ± 1.7 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 65 mph. The test runs were divided into three speed groups - low, medium and high speeds, as shown in Table 5-15.

**Table 5-15 – Post-Validation Results by Speed – 4-Apr-12**

| Parameter | 95% Confidence Limit of Error | Low | Medium | High |
|---|---|---|---|---|
| | | 54.0 to 57.7 mph | 57.8 to 61.4 mph | 61.5 to 65.0 mph |
| Steering Axles | ±20 percent | -0.6 ± 6.6% | -2.7 ± 4.7% | -0.6 ± 5.9% |
| Tandem Axles | ±15 percent | -1.3 ± 3.6% | -0.4 ± 4.7% | 0.7 ± 5.6% |
| GVW | ±10 percent | -1.0 ± 2.8% | -0.7 ± 2.5% | 0.6 ± 3.0% |
| Vehicle Length | ±3.0 percent (2.2 ft) | -0.1 ± 1.0 ft | 0.1 ± 1.1 ft | 0.2 ± 1.3 ft |
| Vehicle Speed | ± 1.0 mph | 1.0 ± 1.3 mph | -0.2 ± 1.7 mph | 0.2 ± 1.3 mph |
| Axle Length | ± 0.5 ft [150mm] | 0.0 ± 0.1 ft | 0.0 ± 0.1 ft | 0.0 ± 0.1 ft |

From the table, it can be seen that the WIM equipment generally estimates all weights with similar accuracy at all speeds. Variability in error for GVW and steering axles appears to be similar for all speed ranges, and increases with speed for tandem axles.

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 5-13, the equipment estimated GVW with similar accuracy at low and medium speeds. The bias transitions from slight underestimation at the low and medium speeds to slight overestimation at the higher speeds. The range in error is similar throughout the entire speed range.

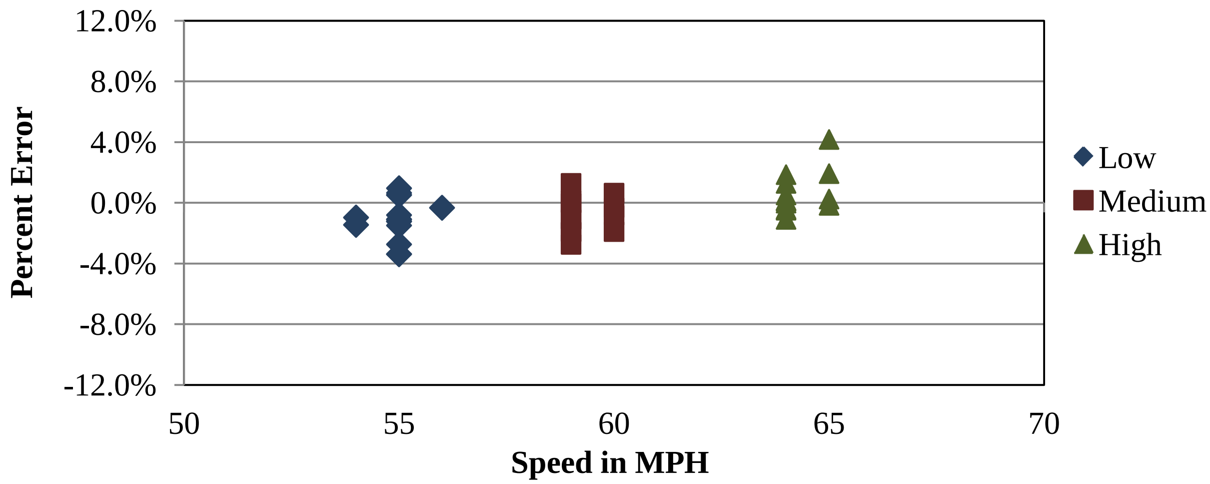



**Figure 5-13 – Post-Validation GVW Errors by Speed – 4-Apr-12**

5.3.1.2 Steering Axle Weight Errors by Speed

As shown in Figure 5-14, the equipment estimated steering axle weights with similar accuracy at all speeds. The range in error is similar throughout the entire speed range.

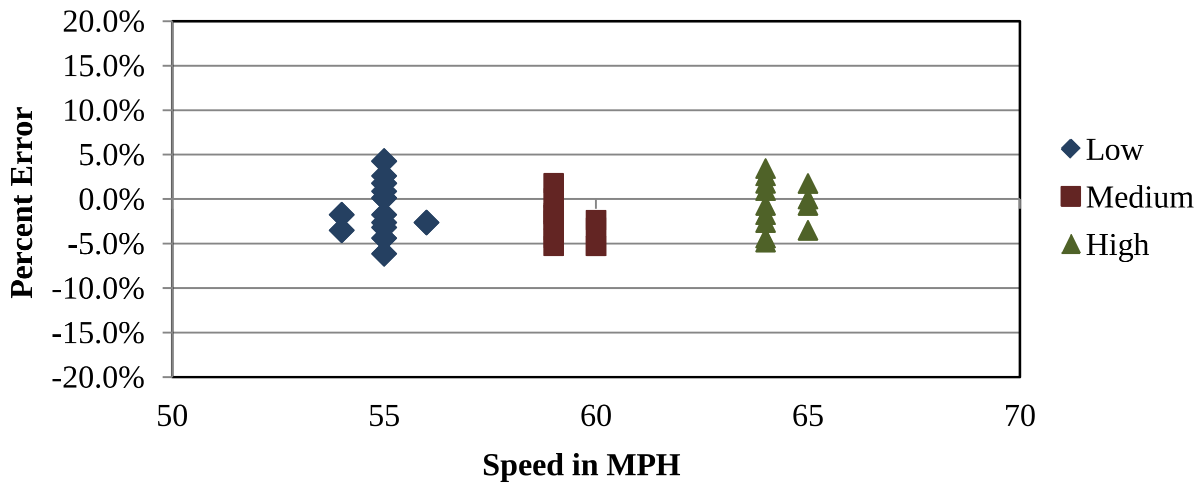



**Figure 5-14 – Post-Validation Steering Axle Weight Errors by Speed – 4-Apr-12**

5.3.1.3 Tandem Axle Weight Errors by Speed

As shown in Figure 5-15, the equipment estimated tandem axle weights with similar accuracy at all speeds. The range in error is similar throughout the entire speed range and bias changes slightly from small negative value to small positive value.

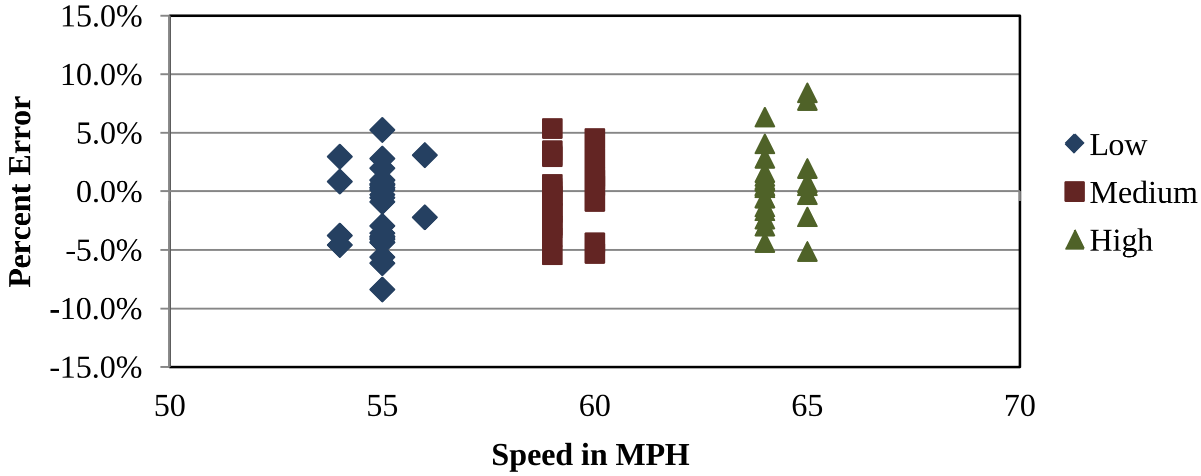



**Figure 5-15 – Post-Validation Tandem Axle Weight Errors by Speed – 4-Apr-12**

5.3.1.4 GVW Errors by Speed and Truck Type

It can be seen in Figure 5-16 that when the GVW errors are analyzed by truck type, the WIM equipment precision and bias is similar for both the heavily loaded (Primary) truck and the partially loaded (Secondary) truck. For both trucks, the bias changes from negative to positive with increase in speed.

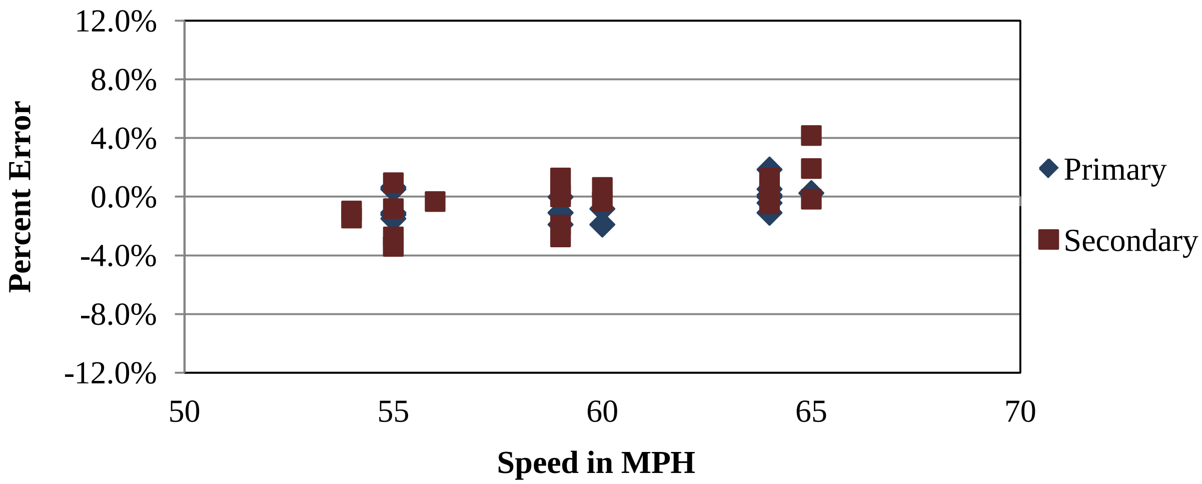



**Figure 5-16 – Post-Validation GVW Error by Truck and Speed – 4-Apr-12**

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 was from -0.1 feet to 0.1 feet. Distribution of errors is shown graphically in Figure 5-17.

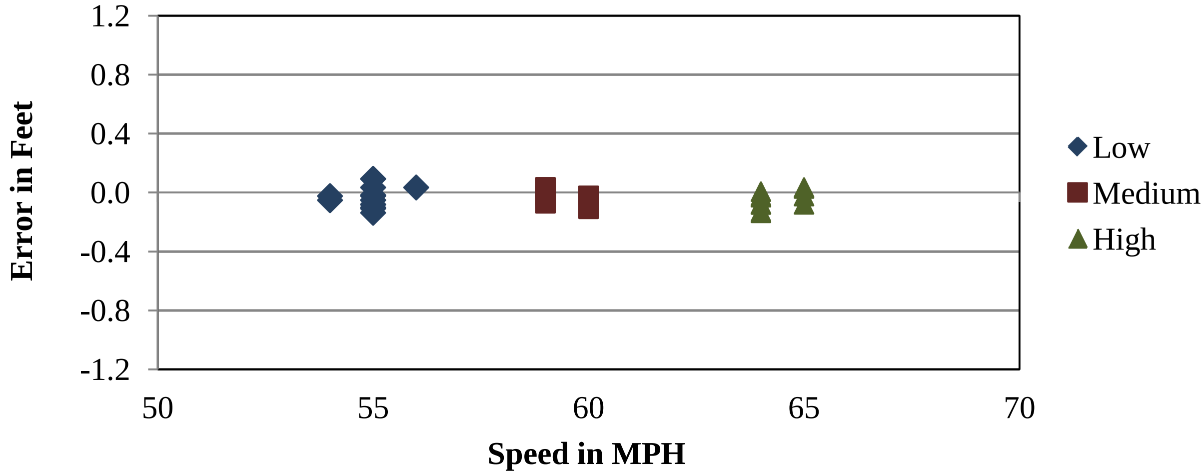



**Figure 5-17 – Post-Validation Axle Length Error by Speed – 4-Apr-12**

### 5.3.1.6 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 5-18.

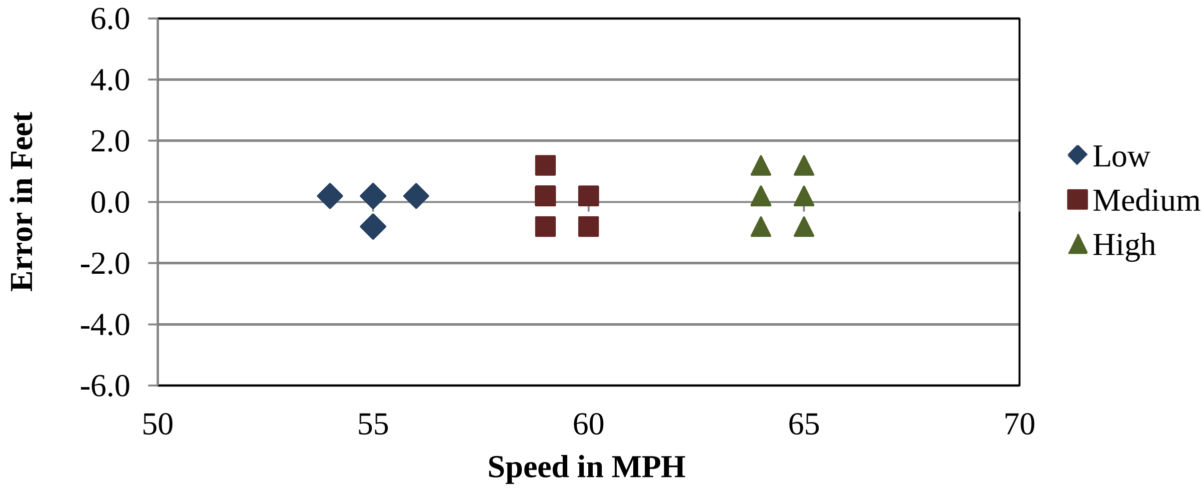



**Figure 5-18 – Post-Validation Overall Length Error by Speed – 4-Apr-12**

## *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 32.5 degrees, from 53.9 to 86.4 degrees

Fahrenheit. The post-validation test runs are reported under three temperature groups – low, medium and high, as shown in Table 5-16 below.

**Table 5-16 – Post-Validation Results by Temperature – 4-Apr-12**

| Parameter | 95% Confidence Limit of Error | Low<br>53.9 to 65 degF | Medium<br>65.1 to 82.0 degF | High<br>82.1 to 86.4 degF |
|---|---|---|---|---|
| Steering Axles | ±20 percent | -0.4 ± 7.8% | -1.1 ± 5.6% | -1.9 ± 5.0% |
| Tandem Axles | ±15 percent | 0.4 ± 5.3% | -0.4 ± 4.9% | -1.0 ± 4.2% |
| GVW | ±10 percent | 0.4 ± 3.4% | -0.4 ± 2.9% | -1.0 ± 2.7% |
| Vehicle Length | ±3.0 percent (2.2 ft) | -0.2 ± 1.1 ft | 0.3 ± 0.6 ft | 0.1 ± 1.2 ft |
| Vehicle Speed | ± 1.0 mph | 0.4 ± 1.7 mph | 0.6 ± 2.4 mph | 0.3 ± 1.4 mph |
| Axle Length | ± 0.5 ft [150mm] | 0.0 ± 0.1 ft | 0.0 ± 0.1 ft | 0.0 ± 0.1 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 5-19, 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 weight estimates at this site.

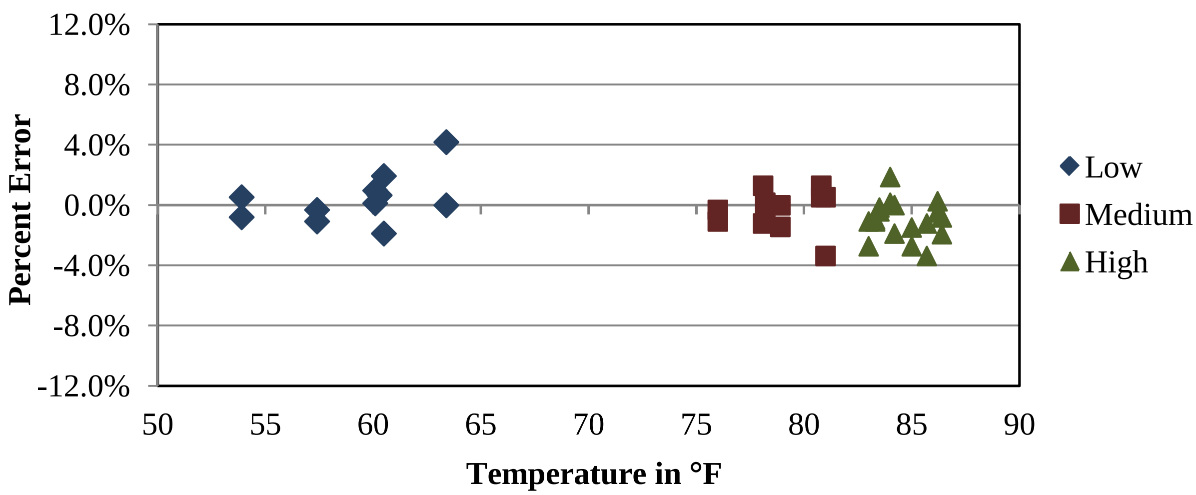



**Figure 5-19 – Post-Validation GVW Errors by Temperature – 4-Apr-12**

#### 5.3.2.2 Steering Axle Weight Errors by Temperature

Figure 5-20 demonstrates that for steering axles, the WIM equipment appears to estimate weights with similar accuracy 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.

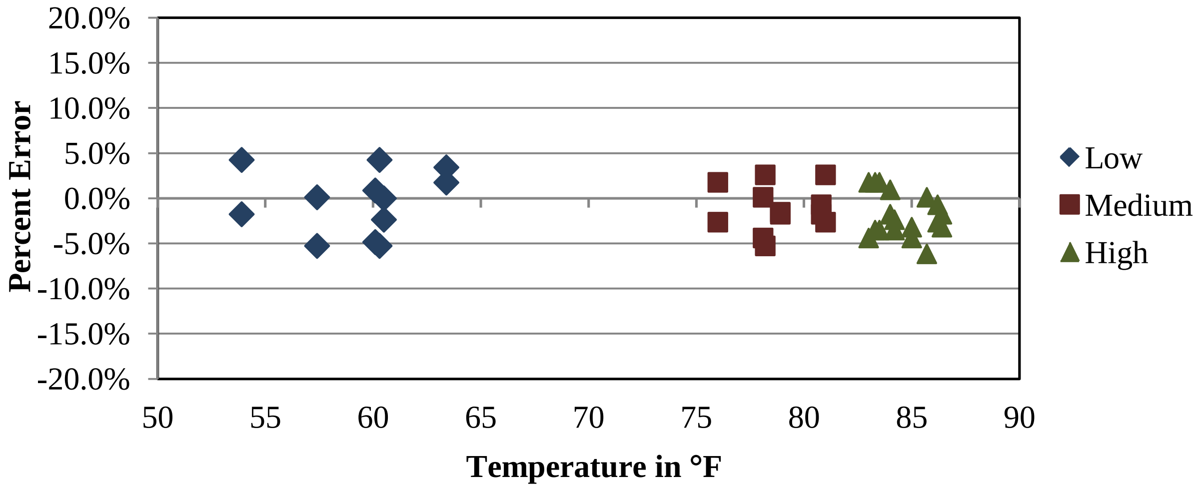



**Figure 5-20 – Post-Validation Steering Axle Weight Errors by Temperature – 4-Apr-12**

#### 5.3.2.3 Tandem Axle Weight Errors by Temperature

As shown in Figure 5-21, 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 lower at high temperatures compared to low and medium temperatures.

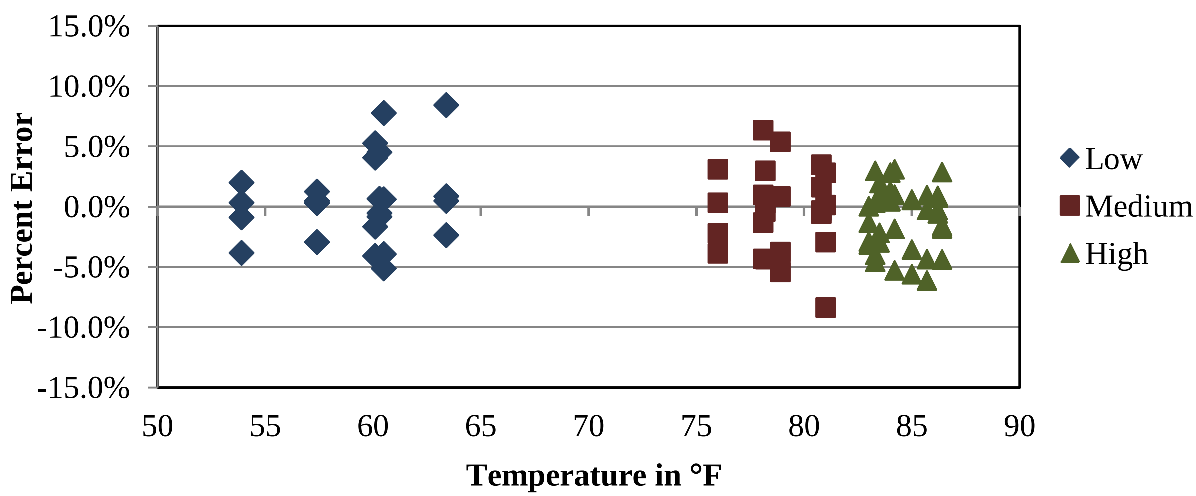



**Figure 5-21 – Post-Validation Tandem Axle Weight Errors by Temperature – 4-Apr-12**

#### 5.3.2.4 GVW Errors by Temperature and Truck Type

As shown in Figure 5-22, when analyzed by truck type, GVW measurement errors for both trucks are similar at all temperatures. For both trucks, the range of errors and bias are reasonably consistent over the range of temperatures.

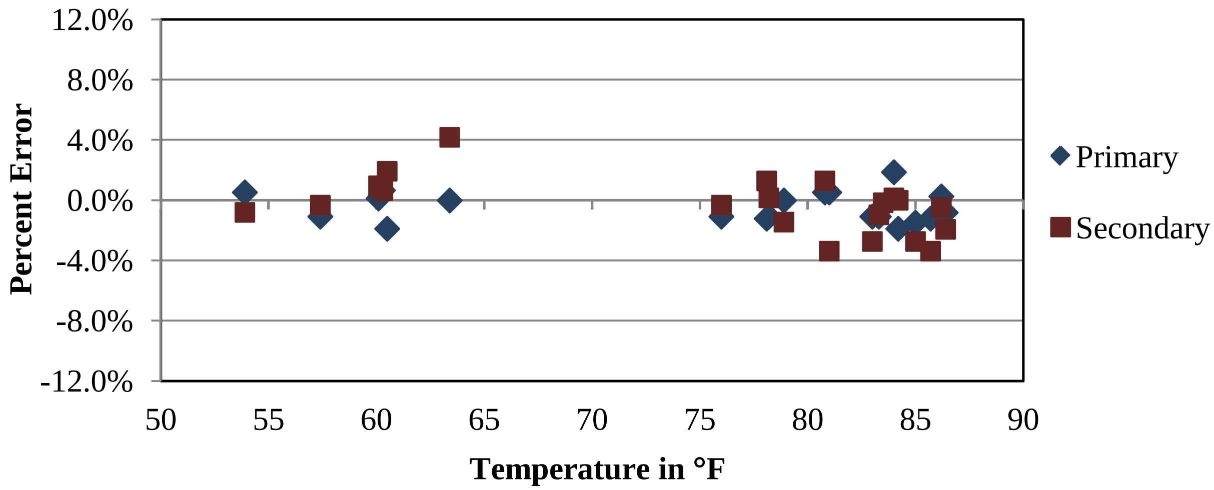



**Figure 5-22 – Post-Validation GVW Error by Truck and Temperature – 4-Apr-12**

### *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 35 vehicles including 31 trucks (Class 4 through 13) was collected. The small sample size was due to low truck volumes at the site. 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 5-17. The table illustrates the breakdown of vehicles observed and identified by the equipment for the manual classification study. As shown in Table 5-17, one Class 4 vehicle was misclassified as a Class 5 vehicle, four Class 5 vehicle were misclassified as Class 3 vehicles, and one Class 5 vehicle was misclassified as a Class 8 vehicle by the equipment.

**Table 5-17 – Post-Validation Misclassifications by Pair – 4-Apr-12**

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

As shown in the table, a total of 6 vehicles, including 0 heavy trucks (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 17.1 percent, was primarily due to the misclassification of lightweight vehicles in Class 3 through Class 5. The causes for the misclassifications were not investigated in the field.

The combined results of the misclassifications resulted in an undercount of a Class 4 vehicle and four Class 5 vehicles and an overcount of four Class 3 vehicles and one Class 8 vehicle as shown in Table 5-18. The misclassified percentage represents the percentage of the misclassified vehicles in the manual sample.

**Table 5-18 – Post-Validation Classification Study Results – 4-Apr-12**

| **Class** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Observed Count | 4 | 1 | 11 | 2 | 1 | 1 | 15 | 0 | 0 | 0 | 0 |
| WIM Count | 8 | 0 | 7 | 2 | 1 | 2 | 15 | 0 | 0 | 0 | 0 |
| Observed Percent | 11.4 | 2.9 | 31.4 | 5.7 | 2.9 | 2.9 | 42.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| WIM Percent | 22.9 | 0.0 | 20.0 | 5.7 | 2.9 | 5.7 | 42.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Misclassified Count | 0 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Misclassified Percent | 0.0 | 100.0 | 45.5 | 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 5-19.

**Table 5-19 – Post-Validation Unclassified Trucks by Pair – 4-Apr-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 31 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 0.5 mph; the range of errors was 2.9 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 5-20.

**Table 5-20 – Final Factors**

| Speed Point | MPH | Left | | Right | |
|---|---|---|---|---|---|
| | | 1 | 3 | 2 | 4 |
| 64 | 40 | 3746 | 3746 | 3369 | 3369 |
| 80 | 50 | 3886 | 3886 | 3494 | 3494 |
| 96 | 60 | 3973 | 3973 | 3572 | 3572 |
| 112 | 70 | 4015 | 4015 | 3610 | 3610 |
| 125 | 78 | 3639 | 3639 | 3273 | 3273 |
| **Axle Distance (cm)** | | 365 | | | |
| **Dynamic Comp (%)** | | 99 | | | |
| **Loop Width (cm)** | | 233 | | | |

# 6 Post-Visit Data Analysis

A post-visit data analysis is conducted to further evaluate the validation results 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 carried out to investigate the cause of each truck misclassification.

If indicated, a traffic data sample from the period immediately following the validation to the date of the report submission may be analyzed to further investigate anomalies in the traffic data that may have been identified the validation process, or any other changes that may influence WIM system accuracy.

## 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 54 to 65 mph.
- Pavement temperature. Pavement temperature ranged from 53.9 to 86.4 degrees Fahrenheit.

### 6.1.2 Results

For analysis of GVW weights, 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, given in Table 5-5, 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 | -7.4130 | 3.1199 | -2.3760 | 0.0229 |
| Speed | 0.1743 | 0.0488 | 3.5699 | 0.0010 |
| Temp | -0.0451 | 0.0174 | -2.5946 | 0.0136 |
| Truck | 0.2373 | 0.3779 | 0.6280 | 0.5340 |

For example, the probability value for speed given in Table 6-1 is 0.001. This means that there is about 0.1 percent chance that the value of regression coefficient for speed (0.1743) can occur by chance alone.

The relationship between speed and GVW measurement error is shown in Figure 6-1. The figure includes a trend line for the predicted percent error. Besides the visual assessment of the relationship, Figure 6-1 provides quantification and statistical assessment of the relationship.

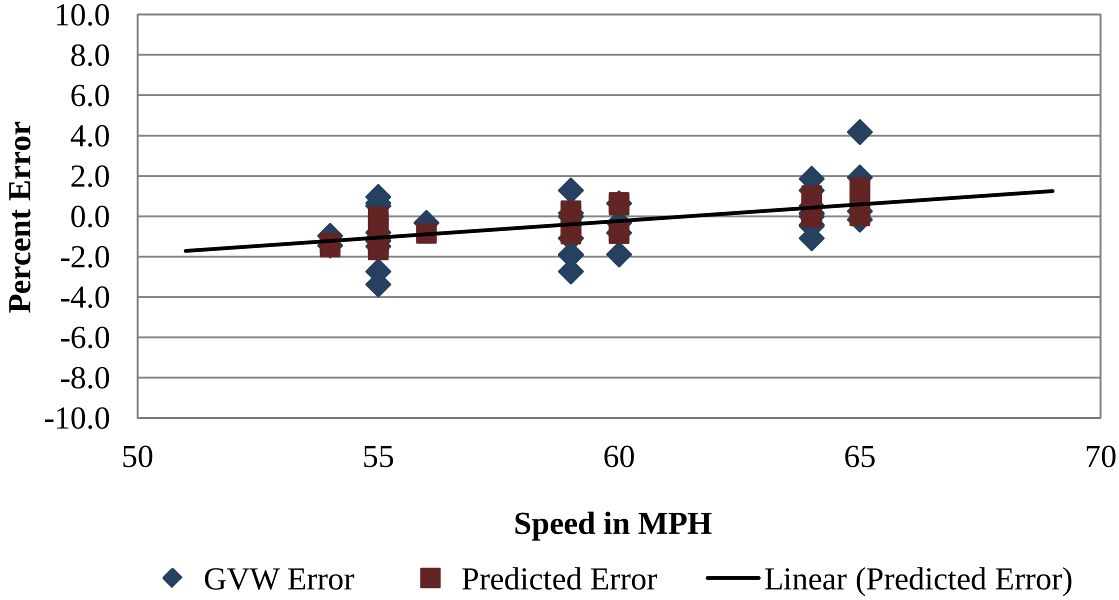



**Figure 6-1 – Influence of Speed on the Measurement Error of GVW**

The quantification of the relationship is provided by the value of the regression coefficient, in this case 0.1743 (in Table 6-1). This means, for example, that for a 10 mph increase in speed, the error is increased by about 1.7 percent (0.1743 x 10). The statistical assessment of the relationship is provided by the probability value of the regression coefficient (0.001) and which indicates that the relationship is statistically significant.

### *6.1.3 Summary Results*

Table 6-2 lists regression coefficients and their probability values for all combinations of factors and % 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 insignificant (the probability that the relationship can occur by chance alone was greater than 20 percent).

**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 | 0.1743 | 0.0010 | -0.0451 | 0.0136 | - | - |
| Steering axle | - | - | -0.0488 | 0.1567 | -3.0135 | 0.0002 |
| Tandem axle tractor | 0.1610 | 0.0734 | -0.0699 | 0.0308 | 1.3523 | 0.0530 |
| Tandem axle trailer | 0.2664 | 0.0027 | - | - | - | - |

### *6.1.4 Conclusions*

1. According to Table 6-2, speed had statistically significant effect on the measurement errors of GVW and tandem axles on trailers. The effect of speed on the measurement error of tandem axles on tractors was marginal.

2. Temperature had a statistically significant effect on the measurement errors of GVW and steering axles. Even thought the effect was statistically significant, the values of the regression coefficients close to zero indicate that this relationship has no practical significance.

3. Truck type had statistically significant effect on steering axle and tractor tandem axle errors. The regression coefficients for truck type in Table 6-2 represent the difference between the mean errors for the Primary and Secondary trucks. (Truck type is an indicator variable with values of 0 or 1.). The effect of truck type is further analyzed in Section 6.1.5.

4. Even though speed, temperature and truck type had statistically significant effect on measurement errors of some of the parameters, the practical significance of these effects on WIM system calibration tolerances was small and does not affect the validity of the validation.

### *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 addressed in this section is: What would be the calibration factors (calibration results) if only one truck (either Primary or Secondary) was used.

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. The figures, and associated statistical analysis, show that whereas the GVW measurement errors for the Secondary truck were influenced by truck speed and pavement temperature, the measurement errors for the Primary truck did not depend on speed or temperature. It is noted that the influence of pavement temperature is not directly used in the calibration process.

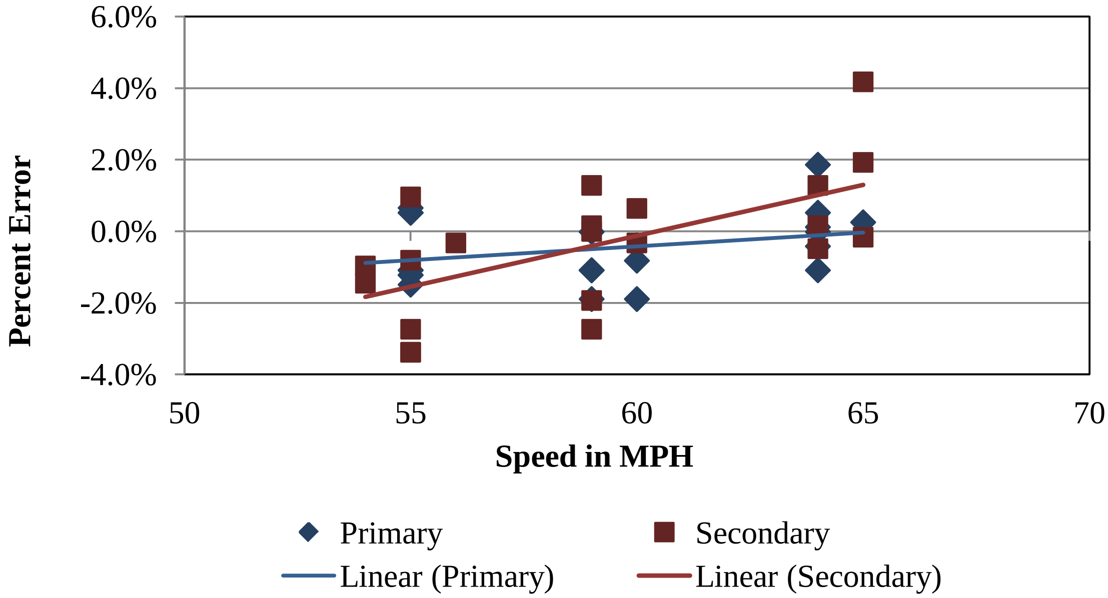



**Figure 6-2– Influence of Speed on the GVW Measurement Error of Primary and Secondary Trucks**

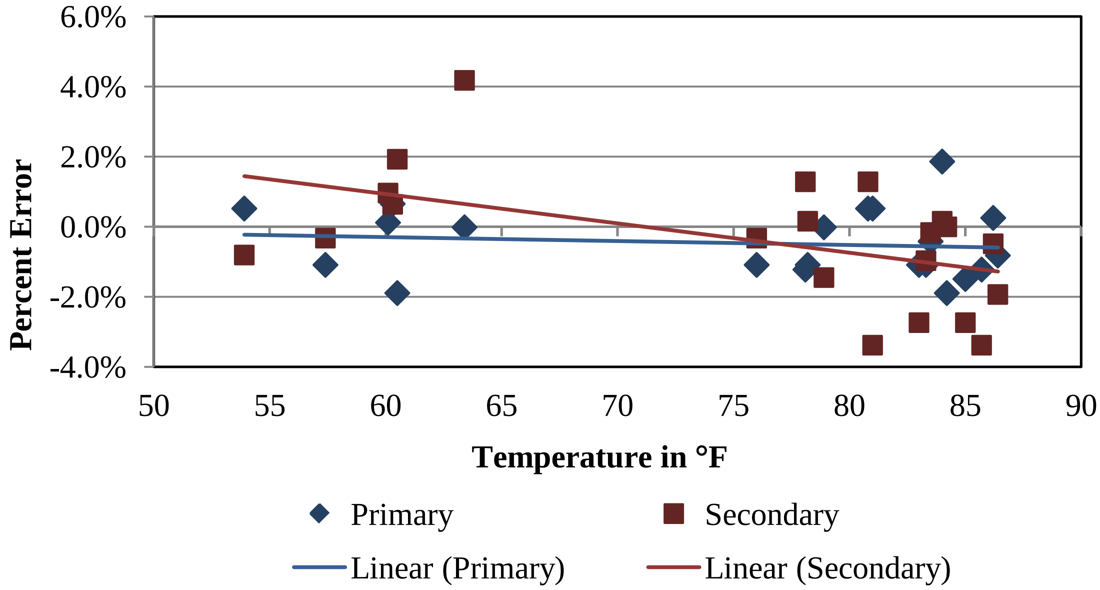



**Figure 6-3 – Influence of Temperature on the Measurement Error of Primary and Secondary Trucks**

The influence of speed on measurement errors for the Secondary truck was significant at the 1 percent level, and the value of the regression coefficient was 0.345. The corresponding numbers for temperature were 4 percent and -0.074. The effects of speed and temperature were not significant for the Primary truck.

The trend lines for the Primary and the Secondary Trucks shown in Figures 6-2 and 6-3 intersect close to zero percent error. In addition, data in Table 6-2 indicate that truck type had no significant effect on the average measurement errors of GVW.

The following observations and comments are based on Figures 6-2 and 6-3, and other associated data.

- The influence of speed on measurement errors for the Secondary truck was significant at the 1 percent level, and the value of the regression coefficient was 0.345. The corresponding numbers for temperature were 4 percent and -0.074. The effects of speed and temperature were not significant for the Primary truck.

- The trend lines for the Primary and the Secondary Trucks shown in Figures 6-2 and 6-3 intersect close to zero percent error.

- Data in Table 6-2 indicate that truck type had no significant effect on the average measurement errors of GVW. The mean measurement error (average error for all speeds) of the GVW for the Primary truck was -0.4 percent, whereas the corresponding number for the Secondary truck was -0.23 percent.

- It should be noted that the analysis presented in this section are based on the post-validation test truck data. It is probable that somewhat different results would be obtained using pre-validation test truck data, or using both pre-and-post-validation data.

- Experience shows that Primary and Secondary trucks always yield somewhat different results. Consequently, it is safe to assume that the use of a different set of Primary and Secondary trucks would produce somewhat different results from those produced by the current set. In other words, the calibration results are also influenced by the selection of calibration trucks.

Based on the above observations, it could be concluded that more detailed analysis of the influence of calibration trucks on the results would be beneficial in understanding the influence of different calibration trucks on the calibration results. The use of different trucks will always yield different results. It would be beneficial to evaluate practical significance of different results by quantifying the contribution of the individual test trucks to the calibration process.

## 6.2 Misclassification Analysis

A post-visit analysis was conducted on the truck misclassifications identified during the post-validation conducted in the field. For this site, a total of 6 vehicles, including 0 heavy truck (6 – 13) were misclassified by the equipment. The single truck misclassification that involved heavy vehicle classes was a Class 5 which was identified by the WIM system as a Class 8 vehicle. According to the Sheet 20, this vehicle was vehicle number 55937. The capture of the real-time record for vehicle 55937 is provided in Figure 6-2.

(55937) LANE #4 CLASS 8 GVW 33.7 kips LENGTH 46 ft
SPEED 60 mph MAX GVW 66.0 kips Wed Apr 4 2012 14:41:45 (2563)

| AXLE | SEPARATION (ft) | LEFT WT (kips) | RIGHT WT (kips) | TOTAL WT (kips) | ALLOWABLE (kips) |
|---|---|---|---|---|---|
| 1 S | | 3.4 | 3.4 | 6.8 | 20.0 |
| 2 S | 12.5 | 6.6 | 6.6 | 13.2 | 20.0 |
| 3 D | 21.3 | 3.5 | 3.0 | 6.5 | 17.0 |
| 4 D | 3.0 | 3.7 | 3.4 | 7.2 | 17.0 |

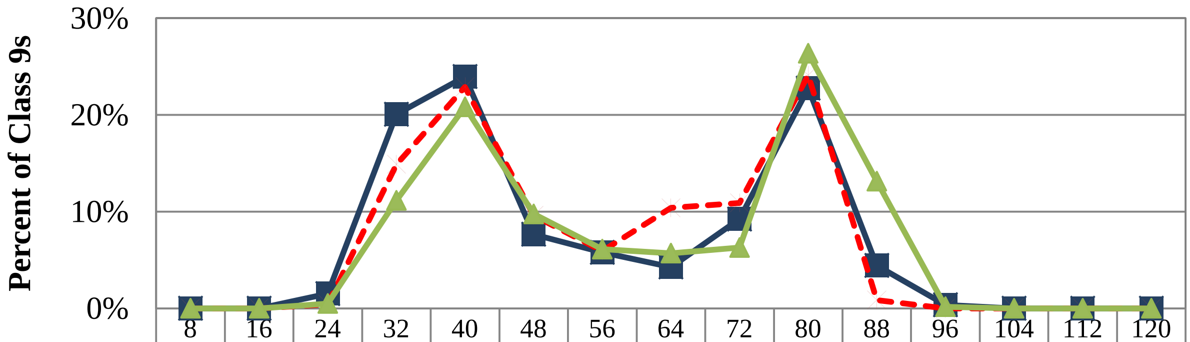
**Figure 6-4 – Vehicle Record 55937**

As Figure 6-4 illustrates, the misclassification involved a Class 5 vehicle towing a trailer. Setting minimum weight limit on trailer axles could prevent this misclassification in the future.

## 6.3 Traffic Data Analysis

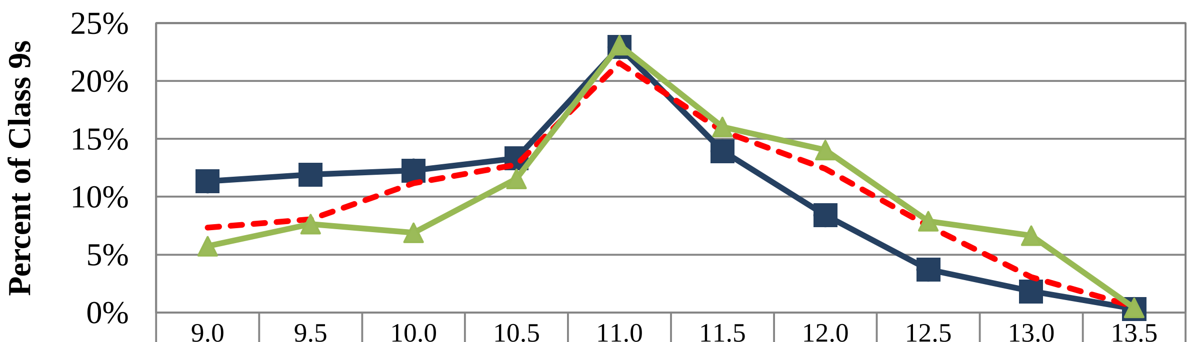
### *6.3.1 GVW and Steering Axle Weight Distributions*

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 April 15, 2012 and the Comparison Data Set of April 26, 2011 are similar, as illustrated in Figure 6-5 and Figure 6-6.




| | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 | 72 | 80 | 88 | 96 | 104 | 112 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data | 0.0% | 0.0% | 1.5% | 20.1% | 24.0% | 7.7% | 5.8% | 4.3% | 9.2% | 22.8% | 4.4% | 0.4% | 0.0% | 0.0% | 0.0% |
| CDS | 0.0% | 0.0% | 0.4% | 14.9% | 22.9% | 9.6% | 5.9% | 10.4% | 10.9% | 24.1% | 0.9% | 0.0% | 0.0% | 0.0% | 0.0% |
| Post | 0.0% | 0.0% | 0.5% | 11.2% | 20.8% | 9.8% | 6.1% | 5.7% | 6.3% | 26.4% | 13.1% | 0.2% | 0.0% | 0.0% | 0.0% |

**Figure 6-5 – 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 | 11.3% | 11.9% | 12.3% | 13.3% | 22.9% | 13.9% | 8.4% | 3.7% | 1.8% | 0.3% |
| CDS | 7.3% | 8.1% | 11.2% | 12.8% | 21.6% | 15.7% | 12.4% | 7.5% | 3.0% | 0.5% |
| Post | 5.7% | 7.6% | 6.9% | 11.6% | 23.1% | 16.0% | 14.0% | 7.9% | 6.7% | 0.4% |

**Figure 6-6 – Class 9 Steering Axle Weight Distribution**

#### *6.3.2 Imbalance*

The results of the validation test truck runs cannot be used to determine the presence of imbalanced weights due to the limited sample. Consequently, free flow truck traffic must be used.

A post-visit data analysis was conducted using an 11-day data sample that began the day following the date of the validation. The results of the post-visit imbalance analysis are presented in Table 6-4.

**Table 6-3 – Front Axle Weight Imbalance**

| Data Set | Date | Left | Right | Imbalance | PCT |
|---|---|---|---|---|---|
| Pre-Visit Sample | March 31, 2012 | 5.48 | 5.52 | Right | 0.9% |
| Post-Visit Sample | April 15, 2012 | 5.39 | 5.41 | Right | 0.4% |

As shown in the table, the right weights for the steering axle are, on average, 0.4 percent greater than the left side wheel weights. Therefore, it is not recommended that the calibration factors be adjusted.

#### *6.3.3 WIM System Factor Adjustments*

Since the average GVW and steering axle weights provided during the Post-Visit data analysis are reasonably similar to those provided by the Comparison Data Set from April 2011, and the steering axle sample does not demonstrate a significant imbalance, no further adjustments to the WIM system factors established during the validation performed on April 4, 2012 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 | |
| 13-Dec-06 | N/A | 0 | 0 | 0 | N/A | N/A | 0 | 0 | N/A | N/A | N/A | 0 |
| 14-Dec-06 | N/A | 0 | 0 | 0 | N/A | N/A | 0 | 0 | N/A | N/A | N/A | 0 |
| 28-Aug-07 | N/A | 100 | 0 | 0 | 0 | 50 | 0 | 0 | N/A | N/A | N/A | 0 |
| 29-Aug-07 | N/A | N/A | 0 | 0 | 0 | 0 | 0 | 0 | N/A | N/A | N/A | 0 |
| 11-Nov-08 | N/A | 100 | 25 | 25 | N/A | 100 | 0 | N/A | N/A | N/A | N/A | 0 |
| 12-Nov-08 | N/A | 0 | 0 | 0 | N/A | 0 | 0 | 0 | N/A | N/A | N/A | 0 |
| 26-Apr-11 | N/A | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 3-Apr-12 | 33 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.9 |
| 4-Apr-12 | 0 | 100 | 45 | 0 | 0 | 0 | 0 | 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 |
| 13-Dec-06 | -0.6 ± 6.3 | -5.2 ± 7.3 | 1.6 ± 5.4 |
| 14-Dec-06 | 3.0 ± 3.1 | -1.6 ± 6.8 | 4.6 ± 3.7 |
| 28-Aug-07 | -4.2 ± 5.8 | -4.8 ± 8.0 | -3.5 ± 9.2 |
| 29-Aug-07 | -2.6 ± 5.4 | -2.4 ± 9.2 | -2.3 ± 9.0 |
| 11-Nov-08 | -6.2 ± 4.7 | -6.6 ± 6.9 | -6.2 ± 5.2 |
| 12-Nov-08 | -0.2 ± 4.6 | -0.4 ± 7.9 | -0.2 ± 5.4 |
| 26-Apr-11 | -0.5 ± 2.7 | -1.2 ± 6.2 | -0.4 ± 4.0 |
| 3-Apr-12 | -3.7 ± 3.5 | -4.9 ± 6.4 | -1.4 ± 5.7 |
| 4-Apr-12 | -0.4 ± 3.0 | -1.3 ± 5.7 | 0.9 ± 4.6 |

The variability of the weight errors appears to have remained reasonably consistent since the site was first validated, with a slight increase for all weight measurement errors for the 2007 validation. From this information, it appears that the system demonstrates a tendency for the equipment to move toward an underestimation of all weights over time. 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

Minnesota, SPS-5
SHRP ID: 270500

Validation Date: April 4, 2012

**Photo 1 – Cabinet Exterior**

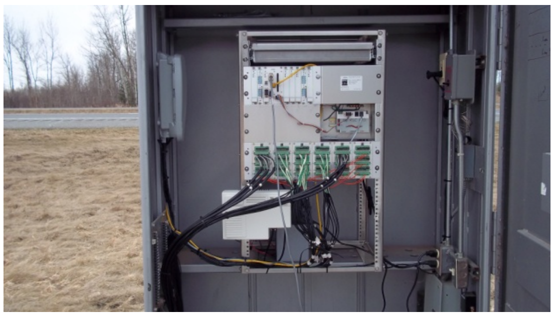


**Photo 2 – Cabinet Interior (Top)**

**Photo 3 – Cabinet Interior (Bottom)**

**Photo 4 – Leading Loop**

**Photo 5 – Leading WIM Sensor**

**Photo 6 – Trailing WIM Sensor**

**Photo 7 – Trailing Loop Sensor**

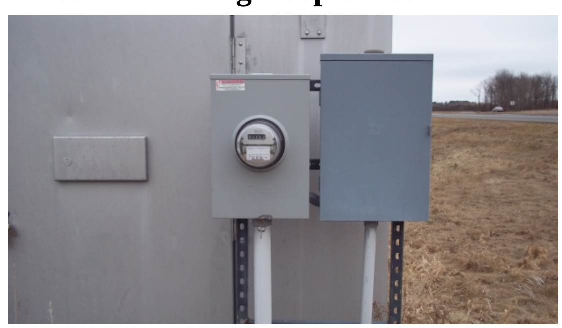


**Photo 8 – Power Service Box**


**Photo 9 – Telephone Service Box**

**Photo 10 – Downstream**

**Photo 11 – Upstream**

**Photo 12 – Truck 1**

**Photo 13 – Truck 1 Tractor**

**Photo 14 – Truck 1 Trailer and Load**

**Photo 15 – Truck 1 Suspension 1**

**Photo 16 – Truck 1 Suspension 2**

**Photo 17 – Truck 1 Suspension 3**

**Photo 18 – Truck 1 Suspension 4**

**Photo 19 – Truck 1 Suspension 5**

**Photo 20 – Truck 2**

**Photo 21 – Truck 2 Tractor**

**Photo 22 – Truck 2 Trailer and Load**

**Photo 23 – Truck 2 Suspension 1**

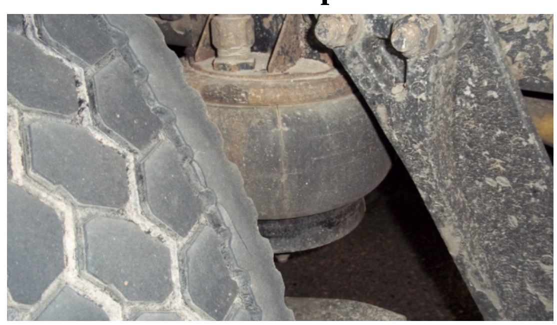


**Photo 24 – Truck 2 Suspension 2**

**Photo 25 – Truck 2 Suspension 3**

**Photo 26 – Truck 2 Suspension 5**

**Photo 27 – Truck 2 Suspension 4**

| Traffic Sheet 16<br>LTPP MONITORED TRAFFIC DATA<br>SITE CALIBRATION SUMMARY | STATE CODE: 27<br>SPS WIM ID: 270500<br>DATE (mm/dd/yyyy) 4/3/2012 |
|---|---|

## SITE CALIBRATION INFORMATION

1. **DATE OF CALIBRATION** {mm/dd/yy} 4/3/12

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 iSINC

## 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: | 9 | steel spring | standard |
| Truck 3: | | | |

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

Mean Difference Between -

| | Mean | | Standard Deviation |
|---|---|---|---|
| Dynamic and Static GVW: | -3.7% | Standard Deviation: | 1.7% |
| Dynamic and Static Single Axle: | -4.9% | Standard Deviation: | 3.2% |
| Dynamic and Static Double Axles: | -1.4% | Standard Deviation: | 2.8% |

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

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

| | | | Low | | High | Runs |
|---|---|---|---|---|---|---|
| a. | Low | - | 54.0 | to | 57.7 | 13 |
| b. | Medium | - | 57.8 | to | 61.4 | 13 |
| c. | High | - | 61.5 | to | 65.0 | 14 |
| d. | | - | | to | | |
| e. | | - | | to | | |

| Traffic Sheet 16 | STATE CODE: | 27 |
|---|---|---|
| LTPP MONITORED TRAFFIC DATA | SPS WIM ID: | 270500 |
| SITE CALIBRATION SUMMARY | DATE (mm/dd/yyyy) | 4/3/2012 |

**10. CALIBRATION FACTOR (AT EXPECTED FREE FLOW SPEED)** 3868 | 3478

**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:** Time

**14. MEAN DIFFERENCE IN VOLUMES BY VEHICLES CLASSIFICATION:**

| | | | | | |
|---|---|---|---|---|---|
| FHWA Class 9: | 0.0 | FHWA Class | 5 | - | 22.0 |
| FHWA Class 8: | Unk | FHWA Class | | - | |
| | | FHWA Class | | - | |
| | | FHWA Class | | - | |

Percent of "Unclassified" Vehicles: 2.9%

Validation Test Truck Run Set - Pre

**Person Leading Calibration Effort:**

**Contact Information:** Phone:

E-mail:

| Traffic Sheet 16 | STATE CODE: | 27 |
|---|---|---|
| LTPP MONITORED TRAFFIC DATA | SPS WIM ID: | 270500 |
| SITE CALIBRATION SUMMARY | DATE (mm/dd/yyyy) | 4/4/2012 |

## SITE CALIBRATION INFORMATION

**1. DATE OF CALIBRATION** {mm/dd/yy} 4/4/12

**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 iSINC

## 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: | 9 | steel spring | standard |
| Truck 3: | | | |

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

Mean Difference Between -

| | | | |
|---|---|---|---|
| Dynamic and Static GVW: | -0.4% | Standard Deviation: | 1.5% |
| Dynamic and Static Single Axle: | -1.3% | Standard Deviation: | 2.8% |
| Dynamic and Static Double Axles: | 0.9% | 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 | - | 54.0 | to | 57.7 | 16 |
| b. | Medium | - | 57.8 | to | 61.4 | 13 |
| c. | High | - | 61.5 | to | 65.0 | 13 |
| d. | | - | | to | | |
| e. | | - | | to | | |

| Traffic Sheet 16 | STATE CODE: | 27 |
|---|---|---|
| LTPP MONITORED TRAFFIC DATA | SPS WIM ID: | 270500 |
| SITE CALIBRATION SUMMARY | DATE (mm/dd/yyyy) | 4/4/2012 |

**10. CALIBRATION FACTOR (AT EXPECTED FREE FLOW SPEED)** 4015 | 3610

**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:** Time

**14. MEAN DIFFERENCE IN VOLUMES BY VEHICLES CLASSIFICATION:**

| | | | | | |
|---|---|---|---|---|---|
| FHWA Class 9: | 0.0 | FHWA Class | 5 | - | -36.0 |
| FHWA Class 8: | 100.0 | FHWA Class | | - | |
| | | FHWA Class | | - | |
| | | FHWA Class | | - | |

Percent of "Unclassified" Vehicles: 0.0%

Validation Test Truck Run Set - Post

**Person Leading Calibration Effort:**

**Contact Information:** Phone:

E-mail:

| **Traffic Sheet 20**<br>**LTPP MONITORED TRAFFIC DATA**<br>**SPEED AND CLASSIFICATION STUDIES** | STATE CODE: 27<br>SPS WIM ID: 270500<br>DATE (mm/dd/yyyy) 4/3/2012 |
|---|---|

Count - 35 Time = 3:05:20 Trucks (4-15) - 23 Class 3s - 12

| WIM speed | WIM class | WIM Record | Obs. Speed | Obs. Class | WIM speed | WIM class | WIM Record | Obs. Speed | Obs. Class |
|---|---|---|---|---|---|---|---|---|---|
| 64 | 9 | 49174 | 64 | 9 | **60** | **5** | **50076** | **60** | **3** |
| 67 | 5 | 49177 | 67 | 5 | 41 | 5 | 50095 | 41 | 5 |
| 63 | 3 | 49180 | 65 | 3 | 59 | 3 | 50100 | 58 | 3 |
| 59 | 3 | 49190 | 58 | 3 | 55 | 9 | 50102 | 54 | 9 |
| 65 | 10 | 49191 | 64 | 10 | 65 | 5 | 50141 | 64 | 5 |
| 66 | 9 | 49229 | 67 | 9 | 65 | 5 | 50142 | 64 | 5 |
| 62 | 3 | 49233 | 54 | 3 | 57 | 4 | 50159 | 55 | 4 |
| 59 | 9 | 49326 | 58 | 9 | 65 | 3 | 50171 | 65 | 3 |
| 64 | 9 | 49329 | 63 | 9 | 69 | 9 | 50172 | 70 | 9 |
| 60 | 5 | 49354 | 59 | 5 | 65 | 9 | 50174 | 64 | 9 |
| 68 | 9 | 49398 | 66 | 9 | | | | | |
| **64** | **15** | **49494** | **59** | **3** | | | | | |
| 64 | 3 | 49495 | 61 | 3 | | | | | |
| 65 | 9 | 49524 | 61 | 9 | | | | | |
| 64 | 3 | 49571 | 64 | 3 | | | | | |
| 65 | 9 | 49658 | 65 | 9 | | | | | |
| **64** | **5** | **49670** | **65** | **3** | | | | | |
| **60** | **8** | **49754** | **60** | **5** | | | | | |
| 71 | 5 | 49901 | 71 | 5 | | | | | |
| 67 | 5 | 49924 | 68 | 5 | | | | | |
| 64 | 9 | 49928 | 65 | 9 | | | | | |
| **58** | **5** | **49932** | **55** | **3** | | | | | |
| 59 | 3 | 49957 | 61 | 3 | | | | | |
| 60 | 5 | 49995 | 61 | 5 | | | | | |
| 62 | 9 | 50069 | 63 | 9 | | | | | |

Sheet 1 - 0 to 50 Start: 10:35:57 Stop: 13:41:17

Recorded By: kt Verified By: djw

Validation Test Truck Run Set - Pre

| Traffic Sheet 20<br>LTPP MONITORED TRAFFIC DATA<br>SPEED AND CLASSIFICATION STUDIES | STATE CODE: 27<br>SPS WIM ID: 270500<br>DATE (mm/dd/yyyy) 4/4/2012 |
|---|---|

Count - 35 Time = 2:59:41 Trucks (4-15) - 31 Class 3s - 4

| WIM speed | WIM class | WIM Record | Obs. Speed | Obs. Class | WIM speed | WIM class | WIM Record | Obs. Speed | Obs. Class |
|---|---|---|---|---|---|---|---|---|---|
| 67 | 5 | 55004 | 66 | 5 | 67 | 9 | 55930 | 68 | 9 |
| 64 | 7 | 55030 | 64 | 7 | **60** | **8** | **55937** | **66** | **5** |
| 66 | 9 | 55035 | 67 | 9 | 67 | 9 | 55991 | 62 | 9 |
| 66 | 3 | 55102 | 65 | 3 | 67 | 5 | 55996 | 67 | 5 |
| 70 | 6 | 55149 | 69 | 6 | 67 | 9 | 56063 | 61 | 9 |
| 67 | 3 | 55205 | 65 | 3 | 67 | 8 | 56069 | 67 | 8 |
| **62** | **3** | **55217** | **63** | **5** | 64 | 9 | 56075 | 63 | 9 |
| 64 | 5 | 55231 | 62 | 5 | **70** | **3** | **56076** | **71** | **5** |
| 58 | 3 | 55340 | 57 | 3 | 67 | 9 | 56092 | 67 | 9 |
| 58 | 5 | 55368 | 58 | 5 | 65 | 9 | 56150 | 65 | 9 |
| 63 | 9 | 55441 | 63 | 9 | | | | | |
| **57** | **5** | **55445** | **55** | **4** | | | | | |
| 67 | 6 | 55454 | 69 | 6 | | | | | |
| 65 | 9 | 55461 | 65 | 9 | | | | | |
| 64 | 9 | 55464 | 64 | 9 | | | | | |
| **64** | **3** | **55483** | **64** | **5** | | | | | |
| 53 | 3 | 55523 | 52 | 3 | | | | | |
| 67 | 9 | 55557 | 64 | 9 | | | | | |
| 62 | 9 | 55569 | 63 | 9 | | | | | |
| 56 | 9 | 55611 | 61 | 9 | | | | | |
| 68 | 5 | 55652 | 67 | 5 | | | | | |
| 68 | 5 | 55717 | 67 | 5 | | | | | |
| 64 | 9 | 55743 | 67 | 9 | | | | | |
| 64 | 9 | 55874 | 53 | 9 | | | | | |
| **65** | **3** | **55919** | **64** | **5** | | | | | |

Sheet 1 - 0 to 50 Start: 12:13:24 Stop: 15:13:05

Recorded By: kt Verified By: djw

Validation Test Truck Run Set - Post