6. SYSTEM CALIBRATION

Calibration is used to ensure that the estimation of the static weight produced by the weigh-in-motion (WIM) system is as close to the static weight as possible. A system is calibrated to offset the effects of site conditions such as pavement temperature, vehicle speed, and pavement conditions. These factors can influence the weight estimated by the system. Calibration may be done by comparing the estimation from the WIM system to the actual static weight of a number of different types of trucks. The American Society for Testing and Materials (ASTM) Standard Specification E 1318-94 concerning highway WIM systems lists the ASTM recommendations for the calibration procedure, which includes the acceptance and initial calibration processes (*1*). Table 6.1 shows the system calibration principles that should be considered.

Table 6.1
System Calibration Principles Checklist

	System Calibration Principles
6.1	**Follow a set initial calibration procedure.**
6.2	**Perform two-part calibration procedure; acceptance and testing.**
6.2.1	**Perform acceptance testing.**
6.2.1.1	Perform a system component operations check.
6.2.1.2	Perform an initial calibration.
6.2.1.3	Perform a 72-hour continuous operation check.
6.2.2	**Perform fine tuning or recalibration when the outcome of the quality assurance data analysis indicates recalibration is necessary.**
6.3	**Automatic recalibration**

6.1 CALIBRATION PROCEDURE

A calibration procedure should be established and followed to ensure that the WIM system performs properly during the site design life. This procedure includes the acceptance testing and recalibration (fine tuning) processes.

6.2 CALTRANS SUCCESSFUL PRACTICE: CALIBRATION PROCEDURE FOR BENDING PLATE WEIGH-IN-MOTION

Caltrans has established a calibration procedure for bending plate WIM systems during their 10-plus years of experience collecting WIM data (*12*). The procedure is divided into two parts, acceptance testing and fine tuning. The acceptance testing is done after installation and must be completed before the system is brought on-line. The fine tuning or recalibration is done throughout the design life of the site.

6.2.1 Acceptance Testing

The acceptance testing is done in three stages: the system component operation check, the initial calibration process, and the 72-hour continuous operation check. Once the acceptance testing is completed on the system, it can be brought on-line and data can be collected and used.

6.2.1.1 System Component Operation

The first stage is to ensure that the components of the WIM system are working properly. The roadway sensors should be sending signals to the on-site controller and the on-site controller should be converting those signals into useable data. This is done through observation at the on-site controller using the "real time" review capabilities of the system.

If the reported vehicles do not match the observed vehicles, or if some of the recorded data for speed and axle counts seem inconsistent, there may be a problem with a system component. Inconsistent readings can also be caused by irregular traffic conditions. If the inconsistent readings are caused by irregular traffic conditions, the types of error readings and the observed traffic conditions should be recorded in the "site database," as discussed in Section 7.

6.2.1.2 Initial Calibration

The initial calibration is performed after the component check is completed. Caltrans specifies that the WIM vendor is responsible for calibrating the WIM system and Caltrans is responsible for conducting the accuracy performance test. Caltrans works with the vendor during the initial calibration and uses the final test truck runs for the accuracy performance test. If problems occur during the final test runs, Caltrans executes the accuracy performance test with its own test truck.

> *6.1 Practical Calibration*
> "*It is neither practical nor effective to attempt static weighing of a large sample of random vehicles from the traffic stream to calibrate a WIM system.*" ... Caltrans

✎

The WIM vendor provides and uses only one test truck to calibrate the system. This differs from the ASTM Standard's minimum recommendation of 13 test vehicles. The test vehicle is normally a five-axle tractor-semi equipped with air suspension for both tandem axle groups, since this vehicle is the predominant truck used on the California's highway system. The test truck's axle groups are statically weighed and the axle spacings as well as the overall length are measured. These measurements as well as other information are recorded on a worksheet shown in Figure 6.1.

WIM CALIBRATION TEST VEHICLE

WIM SITE ____________________

CO-RTE-PM ____________________

CLASS/DESCRIPTION ____________________

PWR. UNIT LIC. ____________

TRLR. 1 LIC. ____________

TRLR. 2 LIC. ____________

AXLE SPACINGS :

1-2	________
2-3	________
3-4	________
4-5	________
5-6	________
	=============
OVERALL LENGTH	________

KINGPIN SETTING ____________

FRONT SETBACK ____________

REAR OVERHANG ____________

STEER AXLE WIDTH ____________

REAR AXLE WIDTH ____________

SUSPENSION TYPES

AXLE NO.	TYPE
______	______
______	______
______	______

STATIC WEIGHTS :

AXLE/AXLES	RUN 1 DATE ___/___/___	RUN 2 DATE ___/___/___
______	________	________
______	________	________
______	________	________
______	________	________
______	________	________
	=============	=============
GROSS WEIGHT	________	________

==

OWNER : ____________________ PHONE : ____________

DRIVER : ____________________

NOTES : ____________________

BY : ____________

DATE : ____________

Figure 6.1 Sample WIM Calibration Worksheet

The initial calibration procedure takes four steps; the last three utilize a test vehicle. The four steps are discussed in the following sections.

6.2.1.2.1 Step 1

The WIM weight, axle spacing, and overall vehicle length settings are roughly adjusted using typical trucks in the traffic stream. This step is done before the test truck is on-site.

6.2.1.2.2 Step 2

The test vehicle makes several runs in each lane equipped with WIM to check the weight and axle spacing factors. The initial weight factor settings need to be set prior to Step 3 so that the estimated weight is within five percent of the actual weight. The axle spacing factor should be corrected at this time since the axle spacing is used to validate the speed readings. Because WIM estimates may be speed dependent, speed accuracy is an important part of the calibration procedure.

6.2.1.2.3 Step 3

The test truck is driven over the WIM sensors in each lane a minimum of three times at 8 kph (5 mph) increments typically between 72 and 105 kph (45 and 65 mph). The range of speeds for which runs are made should include the range of speeds at which trucks in the traffic operate determined from the traffic characteristics. The gross weight percent error is calculated for each speed run, by dividing the difference between the actual and estimated weights by the actual weight. This information is plotted on a "Gross Weight Percent Error by Vehicle Speed" graph for each traffic lane. An example of this graph is shown in Figure 6.2, which was obtained from the conference precedings and was not converted to metric units. If the plots are inconsistent for any of the speeds, additional runs should be made. The graphs are used to record pavement effects on vehicle dynamics.

These graphs are analyzed to adjust the WIM weight factors. The weight factor can be adjusted for three different speed "points." The high and low speed "points" should be such that most of the trucks on the roadway fall in that range. The middle speed "point" is typically the midpoint but may be raised or lowered to provide for a best fit. The weight factors for different speeds are adjusted using the speed plots from the graphs.

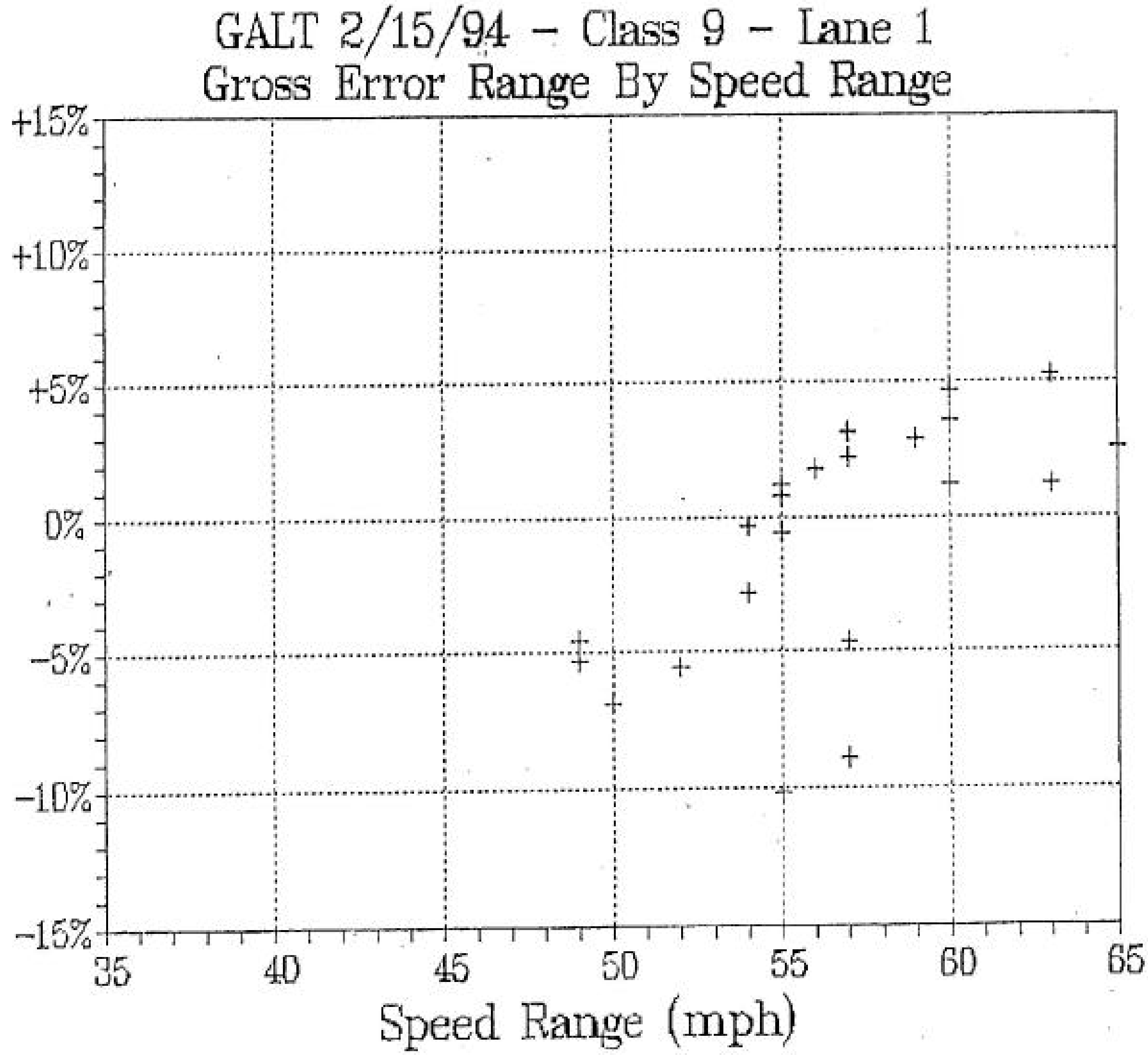

Figure 6.2 Sample Gross Weight Percent Error by Vehicle Speed Graph

6.2.1.2.4 Step 4

The test truck makes two additional runs at each speed after the weight factors have been adjusted. These runs are used to determine if the WIM system is operating at an accuracy level that meets Caltrans' functional requirements for weight, axle spacing, vehicle length, and vehicle speed. The values for the functional requirements are shown in Table 6.2. The initial and final test truck runs can also indicate a WIM system problem such as a defective weigh pad. If the requirements are not met or a problem is detected, Caltrans uses its own test truck to determine the problem, which can be in the WIM system or the pavement condition.

Table 6.2
Caltrans Functional Requirements

VARIABLE	MEAN	STANDARD DEVIATION
Vehicle Weight		
Single Axle	± 5 percent	8 percent
Tandem Axle	± 5 percent	6 percent
Gross Weight	± 5 percent	5 percent
Axle Spacing	± 150 mm (6 in)	300 mm (12 in)
Vehicle Length	± 300 mm (12 in)	460 mm (18 in)
Vehicle Speed	± 1.6 kph (1 mph)	3.2 kph (2 mph)

6.2.1.3 Seventy-Two-Hour Continuous Operation

During the third stage of the acceptance test the WIM system is monitored for a 72-hour period. The data produced during this period is reviewed using the First Level Data Review and the Second Level Data Review discussed in Section 7. Once it is determined that the system components are working on a continuous basis within the required specifications, the system is accepted and placed on-line.

6.2.2 Fine Tuning or Recalibration

Fine tuning or recalibrating takes place throughout the design life of a WIM site. The parameters are adjusted when problems are identified during the Quality Assurance Procedure discussed in Section 7.

✎ *6.2 Data Analysis*
"It is very important that the data analyst be knowledgeable of the site characteristics, the traffic characteristics, the trucks' operating characteristics, and the WIM System's vehicle passage processing in order to properly validate the data and "fine tune" the WIM system's calibration. As much documentation as possible should be accumulated during on-site system testing." ... Caltrans.

6.3 MINNESOTA DEPARTMENT OF TRANSPORTATION SUCCESSFUL PRACTICE: AUTOMATIC SYSTEM RECALIBRATION PROCEDURE

The Minnesota Department of Transportation (DOT) utilizes a computer program to automatically recalibrate their bending plate WIM systems (*13*). The recalibration program is based on the front axles of five-axle semis (FHWA Class 9). This program is stored on the hard drive of the roadside computer at each WIM site and can be turned on and off from an off-site computer using the utility commands. The recalibration process is used on each lane individually.

The initial calibration procedure used by the Minnesota DOT is a two step process. The first step is to calibrate the system using a five-axle semi as a test truck. The second part of the process is to operate the system for a week collecting data. The distribution of the gross vehicle weight (GVW) of five-axle semis collected during this period is examined. The emphasis of the examination is the placement of peaks for loaded and unloaded vehicles. If the peaks occur at reasonable locations, i.e. 33,500 - 35,300 kilograms (kg) (74,000 - 78,000 pounds) for loaded vehicles and 12,700 - 13,600 kg (28,000 - 30,000 pounds) for unloaded vehicles, the system is considered calibrated (*14*). The front axle weights (FAWs) collected during the second part of the process are used as the desired FAWs in the automatic recalibration process.

The program collects FAWs for three GVW groups. The average recorded FAWs are compared to given desired FAWs for each GVW group. The system recalibrates if the percentage of the difference between the average recorded FAWs and the desired FAWs is greater than a set percentage in at least two of the three GVW groups. The program collects FAWs for a predetermined number of Class 9 vehicles and number of hours. The number of Class 9 vehicles and hours are set in the program by the operating agency. Table 6.3 shows an example of the values used by this program. These values can be changed at any time. As seen in the example in Table 6.3, the program collects weights for at least 48 hours and 250 Class 9 vehicles. The allowable deviation between the recorded and desired FAWs is 3.50 percent.

Table 6.3
Example Automatic Recalibration Values

Gross Vehicle Weight [pounds (kg)]	Desired Front-Axle Weight [pounds (kg)]
< 32,000 (14,500)	8,500 (3,850)
32,000 - 70,000 (14,500-31,750)	9,300 (4,200)
> 70,000 (31,750)	10,400 (4,700)
Percent Deviation Allowed from Desired Weight	3.5 percent
Minimum Number of Hours to be Monitored	48
Minimum Number of Class 9 Vehicles Weighed	250

The system recalibrates itself by calculating a calibration correction factor. An example of the method used to calculate the calibration correction factor is shown in Table 6.4. This factor is computed averaging the correction percentages for each of the GVW groups. As shown in the example, the correction percentage for the GVW range of greater than 31,750 kg (70,000 pounds) is determined by multiplying the percent deviated from the desired FAWs, 4.8, and the adjustment factor, 90.0 percent, to obtain 4.32 percent. This figure is subtracted from 1.00 to obtain a correction factor, 0.957. The adjustment factor used in this equation is found on a Minnesota DOT adjustment factor table shown in Table 6.5. This table gives adjustment factors based on the number of trucks weighed in each GVW group.

Table 6.4
Example of Recalibration Procedure

Gross Vehicle Weight Range [pounds (kg)]	Desired Front Axle Weight [pounds (kg)]	Percent Deviation from Desired Front Axle Weight	Number of Vehicles Weighed	Adjustment Factor Percentage	Percent Deviated Times Adjustment Factor	Correction Factor 1 - (% Dev. * Adj. Fac.)
< 32,000 (14,500)	8,500 (3,850)	+ 4.7	59	90.0	4.23%	0.958
32,000 - 70,000 (14,500-31,750)	9,300 (4,200)	+ 4.3	112	95.0	4.09%	0.959
> 70,000 (31,750)	10,400 (4,700)	+ 4.8	79	90.0	4.32%	0.957
Calibration Correction Factor (Average of Correction Factors)						0.958

The calibration correction factor is multiplied by the sensor weight factor to obtain a new sensor weight factor. The sensor weight factor is the base calibration factor used by a WIM system. Once the recalibration is made, the program will begin recording data for the next recalibration procedure. This will continue until the recalibration option is turned off. The program keeps a record of the previous 10 recalibrations. An example of the recalibration results is shown in Table 6.6.

Table 6.5
Minnesota DOT Adjustment Factors

Number of 5-Axle Semis Weighed	Adjustment Factor Percentage	Number of 5-Axle Semis Weighed	Adjustment Factor Percentage
0	0.0	45 - 49	80.0
1	20.0	50 - 54	80.0
2	20.0	55 - 59	90.0
3	20.0	60 - 64	90.0
4	20.0	65 - 69	90.0
5 - 9	30.0	70 - 74	90.0
10 - 14	50.0	75 - 79	90.0
15 - 19	50.0	80 - 84	90.0
20 - 24	60.0	85 - 89	90.0
25 - 29	70.0	90 - 94	90.0
30 - 34	70.0	95 - 99	90.0
35 - 39	70.0	100	95.0
40 - 44	80.0	> 100	95.0

Table 6.6
Example of Recalibration Results

Lane	Date		Time
#1	Fri. Mar.29, 1991		16:00:00
Gross Vehicle Weight Range [pounds (kg)]	Number of Vehicles Weighed	Average Recorded Weight [pounds (kg)]	Percent Deviation from Desired Weight
< 32,000 (14,500)	59	8,900 (4,000)	+ 4.7
32,000 - 70,000 (14,500-31,750)	112	9,700 (4,400)	+ 4.3
> 70,000 (31,750)	79	10,900 (4,950)	+ 4.8
Calibration Factor: 0.959		Sensor Weight Factor: 15.22	