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16. Abstract

The purpose of the State's Successful Practices Weigh-in-Motion Handbook is to provide practical advice for users of weigh-in-motion (WIM) technology, systems, sites, and states' "Successful Practices" using WIM systems. The states selected for each WIM system discussed in this Handbook are: California for bending plate, Missouri for piezoelectric sensors, and Oregon for load cell. The Handbook covers several areas including quality assurance, site maintenance, trouble-shooting, site characteristics, and WIM system description, installation, and calibration. Throughout the Handbook, several "Tricks of the Trade" are highlighted to reinforce some of the successful practices being used.

17. Key Words
Bending Plate
Calibration
Load Cell
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate

(Revised September 1993)

STATES' SUCCESSFUL PRACTICES WEIGH-IN-MOTION HANDBOOK

prepared for

FEDERAL HIGHWAY ADMINISTRATION

prepared by

Center for Transportation Research and Education
Iowa State University

with
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by
Arkansas State Highway and Transportation Department
California Department of Transportation
Minnesota Department of Transportation
Missouri Department of Transportation
Oregon Department of Transportation

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Table of Contents

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II. LIST OF FIGURES

III. LIST OF TABLES

IV. LIST OF "TRICKS OF THE TRADE"

✎ "Tricks of the Trade" are written in italics throughout the document. The pencil to the left is used to further emphasize their location. The "Tricks of the Trade" are numbered and titled for listing purposes.

1. PURPOSE OF THE HANDBOOK

The purpose of the *States' Successful Practices Weigh-in-Motion Handbook* is to provide an overview of weigh-in-motion (WIM) technology, systems, sites, and states' "Successful Practices" using WIM systems. WIM is described as "the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle" in the American Society for Testing and Materials (ASTM) Standard Specification E 1318-94 (*1*). States with successful WIM systems were selected using information from the Long Term Pavement Performance (LTPP) Program. The states selected for each WIM system discussed in this Handbook are: California for bending plate, Missouri for piezoelectric sensors, and Oregon for load cell. The discussion will not be limited to these three states, where applicable successful practices and procedures from other states will be introduced.

The purpose will be accomplished by discussing the principles behind WIM usage and documenting "Tricks of the Trade" for installation and operation of WIM systems. The principles of WIM usage are developed from the successful practices of states using the various WIM technologies. The "Tricks of the Trade" have been developed by state experts and vendors when working with WIM systems and sites. They deal with important aspects of accuracy, quality assurance, sites, installation, and calibration. The Handbook attempts to discuss successful practices that state experts have found over the years to work well.

States have found that the intended use of WIM data determines the approach the state should choose in developing the WIM data collection site and the resources required to maintain the site over the expected "site design life." The following general guiding principle checklist has been developed by state experts that are successfully meeting their end users' data requirements. The guiding principles are addressed in greater detail in the later sections of this handbook. The values in the Handbook are given in metric units when possible. The figures and tables that were obtained from outside sources were not converted to metric units.

Table 1.1
General Guiding Principles Checklist

	Guiding Principles
1.1	Decide on "site design life" and accuracy necessary to support the end user.
1.2	Budget the resources necessary to support the selected "site design life" and accuracy requirements.
1.3	Develop and maintain a thorough quality assurance program.
1.4	Purchase the WIM equipment with a warranty.
1.5	Manage the equipment installation.
1.6	Conduct preventative and corrective maintenance on the site.

1.1 ESTABLISH SYSTEM REQUIREMENTS

States have found that the intended use of the WIM data should determine the approach the state chooses in developing the WIM data collection “site design life.” The state should decide on the number of years that the WIM site will collect data. The established “site design life” and intended use of the data should influence decisions concerning the type of equipment, location and condition of the site, installation of equipment, and analyses performed on the collected data.

1.2 BUDGET FOR THE RESOURCES NECESSARY TO SUPPORT SITE DESIGN LIFE AND ACCURACY REQUIREMENTS

The intended use of the WIM data determines the resources required to maintain the site over the expected “site design life.” For a longer “site design life” additional financial and staff resources will be needed to maintain and replace the WIM equipment. The required financial and staff resources increase as the required accuracy level increases. Additional analysis and quality assurance is needed for higher levels of accuracy.

1.3 DEVELOP AND MAINTAIN A QUALITY ASSURANCE PROGRAM

An adequate quality assurance procedure should be developed and implemented to ensure that the gathered data are valid. The extent of this procedure should be based on the intended use of the data and the required accuracy level.

1.4 ESTABLISH WEIGH-IN-MOTION EQUIPMENT WARRANTY

The WIM equipment should have a warranty period that is specified by the state that should be reasonable in regards to the equipment and its intended use. For example, a five year warranty on weighpads may be deemed reasonable.

1.5 MANAGE SYSTEM INSTALLATION

The installation process should be monitored to ensure that the installation requirements are met. This process should be overseen by a state official and a vendor representative, ensuring that both the state’s and vendor’s requirements are met during the installation process.

1.6 CONDUCT PREVENTIVE AND CORRECTIVE MAINTENANCE

A thorough preventive and corrective maintenance program should be established for the site to help to ensure that the expected “site design life” is attained.

2. TRAFFIC MONITORING

States conduct traffic monitoring for many reasons, including (1) highway planning and design; and (2) motor vehicle enforcement. Weigh-in-Motion (WIM) is a major tool used to collect traffic data.

WIM equipment provides highway planners and designers with traffic volume and classification data by time of day and day of week. In addition, WIM equipment also provides planners and designers with equivalent single axle loadings (ESAL) that heavy vehicles place on pavements. Motor vehicle enforcement officers use heavy truck axle load data to plan enforcement activities. In summary, the uses of traffic and truck weight data include enforcement, pavement, bridge, and legislative and regulatory issues.

The intended use of WIM data should determine the approach the state chooses in developing the WIM data collection site and the resources required to maintain the site over the expected site design life. The following sections present specific successful practices, principles, and “Tricks of the Trade” that states have used to successfully meet an end user’s data, accuracy, quality, and site design life objectives.

3. WEIGH-IN-MOTION SYSTEM DISCUSSION

This section will discuss three types of weigh-in-motion (WIM) systems: bending plate, piezoelectric sensors, and load cell. Information will be presented for each of the WIM technologies. This information comes from either the states that use the systems or the vendors that provide the systems. Table 3.1 shows the WIM system principles that should be considered when selecting a system.

Table 3.1
WIM System Principles Checklist

	WIM System Principle
3.1	**Clearly define the required site design life and accuracy performance level.**
3.2	**Devote the necessary financial and technical resources to reaching the chosen site design life and performance level.**
3.3	**Consider the following aspects of WIM systems when making the selection.**
3.3.1	Sensor type
3.3.2	Site processor
3.3.3	Remote Communication Modem
3.3.4	Operating Software
3.3.5	Data Output format

The American Society for Testing and Materials (ASTM) "Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Method" (ASTM Designation: E 1318-94) classifies WIM systems as Type I, II, III, or IV according to their application and gives related performance and user requirements for each type of system (*1*). The Standard lists user requirements that should be met to ensure that the WIM system functions properly. The four systems have different speed ranges, data gathering capabilities, and intended applications. Table 3.2 shows the information for the four types of systems. Table 3.3 shows functional performance requirements for WIM systems.

Table 3.2
ASTM WIM System Classification

	CLASSIFICATION			
	TYPE I	**TYPE II**	**TYPE III**	**TYPE IV**
Speed Range	16 - 113 km/h (10 - 70 mph)	16 - 113 km/h (10 - 70 mph)	24 - 80 km/h (15 - 50 mph)	24 - 80 km/h (15 - 50 mph)
Application	traffic data collection	traffic data collection	weight enforcement station	weight enforcement station
Number of Lanes	up to four	up to four	up to two	up to two
Bending Plate	X	X	X	X
Piezoelectric Sensor	X	X		
Load Cell	X	X	X	X
Wheel Load	X		X	X
Axle Load	X	X	X	X
Axle-Group Load	X	X	X	X
Gross Vehicle Weight	X	X	X	X
Speed	X	X	X	X
Center-to-Center Axle Spacing	X	X	X	X
Vehicle Class	X	X		
Site Identification Code	X	X	X	X
Lane and Direction of Travel	X	X	X	
Date and Time of Passage	X	X	X	X
Sequential Vehicle Record Number	X	X	X	X
Wheelbase (front to rear axle)	X	X		
Equivalent Single-Axle Load	X	X		
Violation Code	X	X	X	X

Table 3.3
Functional Performance Requirements for WIM Systems

Function	Tolerance for 95% Probability of Conformity				
	Type I	Type II	Type III	Type IV	
				value ≥ kg (lb)*	± kg (lb)
Wheel Load	± 25%	n.a.	± 20%	2,300 (5,000)	100 (250)
Axle Load	± 20%	± 30%	± 15%	5,400 (12,000)	200 (500)
Axle-Group Load	± 15%	± 20%	± 10%	11,300 (25,000)	500 (1,200)
Gross Vehicle Weight	± 10%	± 15%	± 6%	27,200 (60,000)	1,100 (2,500)
Speed	± 2 km/h (1 mph)				
Axle Spacing	± 150 mm (0.5 ft)				

*Lower values are not normally a concern in enforcement

3.1 ESTABLISH SYSTEM REQUIREMENTS

The first step in choosing a WIM system is to clearly define the requirements expected from the system and the staff resources necessary to monitor and maintain the system. The "site design life" and the accuracy level are important requirements to consider when selecting WIM equipment. The cost of the system has been shown to directly relate to the overall performance obtained using that system, as shown in the following section.

3.2 ECONOMIC ANALYSIS

According to research by Taylor and Bergan, each WIM system provides a different level of accuracy at different system and maintenance costs (*2*). Table 3.4 shows the economic analysis produced by Taylor. The cost of the system includes the Estimated Initial Cost per Lane and Maintenance. The Performance of the systems is given as a percent error on gross vehicle weigh (GVW) estimation at highway speeds under ideal, ASTM site conditions. The Estimated Initial Cost per Lane includes the equipment and installation costs. The Estimated Average Cost per Lane is based on a 12-year life span and includes maintenance. The report did not specify the interest rate that was used in the calculations. According to Caltrans, maintenance can be subdivided into three areas: (1) power and communication, (2) structural, and (3) WIM system. The power and communication area includes the WIM power and phone lines. The structural area includes the roadway pavement and scale frames. A service contract with the vendor covers the maintenance for the WIM system.

Table 3.4
Cost Comparison of WIM Systems

WIM System	Performance (Percent error on GVW at highway speeds)	Estimated Initial Cost per Lane (Equipment and Installation)	Estimated Average Cost per Lane (12-year life span including maintenance)
Piezoelectric Sensor	+/- 10%	$ 9,500	$ 4,224
Bending Plate Scale	+/- 5%	$ 18,900	$ 4,990
Double Bending Plate Scale	+/- 3-5%	$ 35,700	$ 7,709
Deep Pit Load Cell	+/- 3%	$ 52,500	$ 7,296

Tables 3.5 and 3.6 show an example of a spreadsheet developed for LTPP to estimate the cost of purchasing, installing, operating, and maintaining WIM equipment (*3*). This example shows the cost of monitoring 100 established sites using both piezoelectric sensors and bending plate scales. The scales are installed on roadways made of both asphalt concrete pavement (ACP) and portland concrete cement (PCC) pavement. The spreadsheet allows for scale replacement, electronics replacement, pavement rehabilitation, calibration, and the necessary office and maintenance staff. The initial cost for this example is $612,000 which includes pavement rehabilitation and initial equipment purchases. The annual cost for this example $2,100,500 which includes pavement rehabilitation and other site maintenance, sensor replacement, electronics replacement, calibration costs, office costs, and travel and perdiem costs. The directions for use of this spreadsheet are given in Appendix 2. Table 3.6 is a summary of the example shown in Table 3.5.

Table 3.5
Example of Weigh-in-Motion Costs

ITEM	VALUE	ITEM	VALUE
Number of Sites			
Number of sites monitored	100		
Number needing new scales	12		
Number needing pavement rehab	10	Number of piezo	50
Percent of initial rehabs that are ACP	50%	Number of bending plate	50
Percent of sites that are ACP	50%		
Percent Bending Plates at existing sites	50%		
Pavement Rehabilitation Cost		**Initial Rehabilitation**	$300,000
ACP rehabilitation	$30,000		
PCC rehabilitation	$30,000		
Equipment Costs		**Initial Equipment Cost**	$312,000
Piezo WIM scale	$10,000	**Annual Sensor Replacement Cost**	$82,500
Piezo WIM scale installation	$10,000	**Annual Electromics Replacement**	$75,000
Piezo sensor cost	$1,500		
Number of piezo sensors per site	2		
Bending plate cost	$12,000		
Bending plate installation	$20,000		
Cost of replacement plates	$3,500		
Number of plates per site	2		
Office computer	$8,000		
Computers needed per site	0.12		
Cost of office software	$15,000		
Percent of new sites using bending plates	50%		

Table 3.5 (Continued)
Example of Weigh-in-Motion Costs

ITEM	VALUE	ITEM	VALUE
Site Maintenance		**Equipment Cost Rehab Sections**	$3,000
Percent of bending plates failing per year	15%	**Annual Pavement Rehab**	$225,000
Percent of piezos failing per year	20%	**Annual non-rehab Maintenance**	$250,000
Percent of ACP sites needing rehab per year	10%		
Percent of PCC sites needing rehab per year	5%		
Percent field electronics needing replacement	15%		
Cost of field electronics replacement	$5,000	**Annual Electronics Replacement**	$75,000
Calibration		**Annual Calibration Costs**	$1,100,000
Calibration trips per year	4		
Percent next to static scales	50%		
Cost per calibration (static scales)	$3,800	$475,000	
Cost per alt. calibration session	$5,000	$625,000	
Type of alternative method	two vehicles of known weight		
Percent with max. calibration trips per year	50%		
Staffing		**Office Costs**	$115,000
Office FTE needed per site	0.02	$2	
Telephones dollars per site	$350	$35,000	
Dollar cost of FTE per year	$40,000	$80,000	
Field FTE per year	4.63		
Dollar cost of field FTE	$50,000	$250,000	
Travel and per diem Costs		**Total Travel and per diem**	$250,000
Dollars per year	$500		

Table 3.6
Summary of Example Weigh-in-Motion Costs

Initial Costs		**Annual Costs**	
Pavement Rehabilitation	$300,000	Pavement Rehabilitation	$228,000
Initial Equipment Costs	$312,000	Other Site Maintenance	$250,000
Total Initial Cost	**$612,000**	Sensor Replacement	$82,500
		Electronics Replacement	$75,000
		Calibration Costs	$1,100,000
		Office Costs	$115,000
		Travel and Per Diem	$250,000
		Total Annual Costs	**$2,100,500**

3.3 BENDING PLATE

Bending Plate WIM systems utilize plates with strain gauges bonded to the underside. As a vehicle passes over the bending plate, the system records the strain measured by the strain gauge and calculates the dynamic load. The static load is estimated using the measured dynamic load and calibration parameters. The calibration parameters account for the influences factors, such as vehicle speed and pavement/suspension dynamics, have on estimating the static weight. This system is classified as an ASTM Type I, II, III, or IV system depending on the intended use of the device and the number of scales placed in the lane. Several vendors provide bending plate WIM systems.

3.3.1 Sensor

Bending Plate WIM systems consist of either one or two scales. The scale or pair of scales is placed in the travel lane perpendicular to the direction of travel. When two scales are used in a lane, one scale is placed in each wheelpath of the traffic lane so that the left and right wheels can be weighed individually. The pair of scales is placed in the lane either side-by-side or staggered by five meters (16 feet) Bending plate systems with one scale placed in either the left or right wheelpath are usually used in low volume lanes.

There are two types of bending plate systems, permanent and portable. The permanent system is discussed in the following section, including a diagram of a typical system layout. The portable system is not high-speed WIM, and therefore will not be discussed in this report.

Bending Plate WIM systems consist of at least one scale and two inductive loops. The scales are placed in the travel lane perpendicular to the direction of travel. The inductive loops are placed upstream and downstream from the scales. The upstream loop is used to detect vehicles and alert the system of an approaching vehicle. The vehicle speed, which is used to determine the axle spacing, can be determined by three methods: weighpad to inductive loop, weighpad to axle sensor, and weighpad to weighpad, if the weighpads are staggered. If an axle sensor is used to determine the vehicle speed, it is placed downstream of the weighpad. An example of the layout for a bending plate WIM system is shown in Figure 3.1.

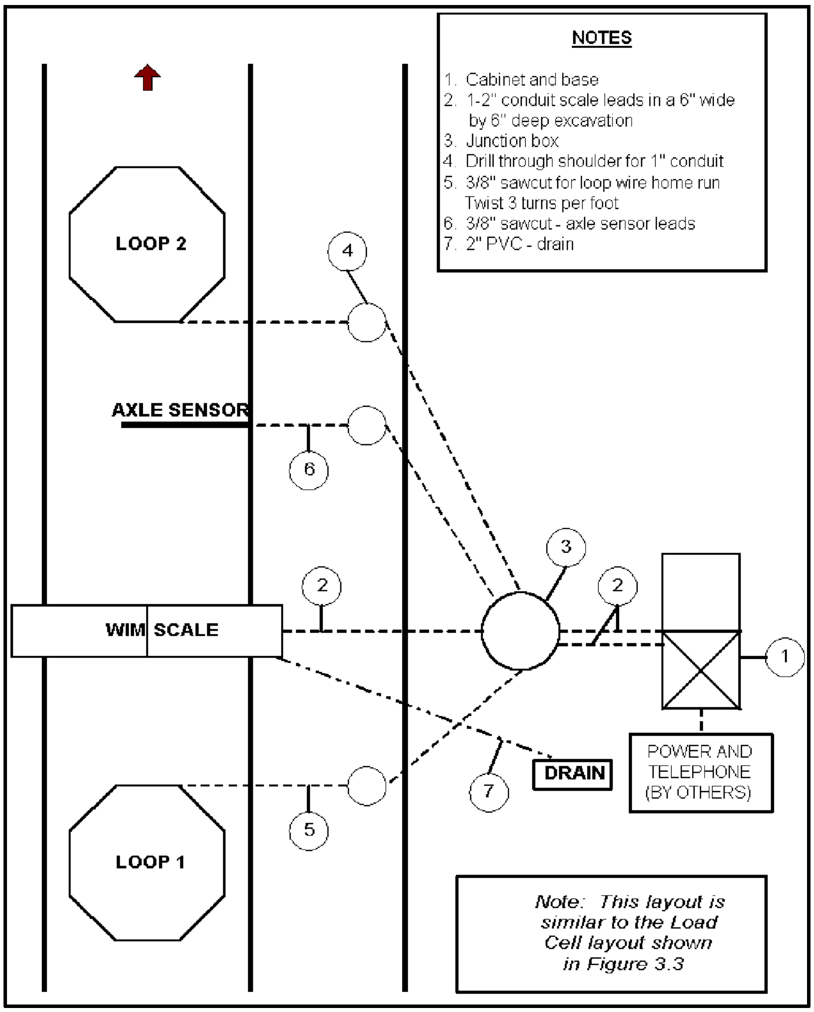

Figure 3.1 Example of Bending Plate System Layout

3.3.2 Site Processor

Processing units are used to sort and analyze the information obtained by the roadway sensors. A typical WIM system can process over 15,000 trucks a day and collect at least 30 days of continuous raw data for a four lane installation. The on-site processor can be provided by either the state or the vendor. Caltrans evaluated both options and determined that the vendor-provided processor is preferable as long as it is compatible with the state-provided in-house computer. The vendor-provided on-site processor eliminates the issue of compatibility between the sensors and the state-provided processor.

3.3.3 Remote Communication Modem

The modem used to collect data to monitor the system needs to be operable on a standard telephone line and capable of at least 1,200 bits per second (bps), but preferably at least 9,600 bps. The amount of data collected at the site and the frequence of downloading should be considered when selecting the telephone line and modem. In general, the download process will be quicker as the quality of the selected phone line and modem increases. The remote communication can be done using either telephone lines or cellular technology.

3.3.4 Operating Software

WIM software includes three separate software packages; on-site software, communications software, and in-house software. The typical on-site software interprets the signals from the WIM scale and generates the on-site files which include information such as:

1. Site Identification
2. Time and Date of Passage
3. Lane Number
4. Vehicle Sequence Number
5. Vehicle Speed and Classification
6. Weight of all Axles or Axle Groups
7. Code for Invalid Measurement
8. Optional Graphic Configuration
9. Equivalent Single Axle Loading (ESAL) value

The typical communications software allows for changes to be made to the on-site software setup including calibration factors from the in-house computer. The typical in-house software generates hard copy reports as well as ASCII files. The software allows reports to be generated on the collected raw vehicle record files. The typical communications and in-house software allow the user to perform the following tasks:

1. Real time vehicle viewing selectable by lane
2. Resetting of the system clock

3. Monitor system memory in terms of storage remaining
4. Setup and initiate the generation of summary reports on data previously collected by the system
5. View generated reports
6. Generate and view error reports including time down, system access, auto-calibration, and improperly completed records
7. Transfer selected raw data files or generated reports from the site system to the office host computer
8. Purge old data files from the system

3.3.5 Data Output Format

The typical in-house software is capable of generating output reports in the FHWA's Traffic Monitoring Guide Card Format. The in-house software is also capable of generating daily, weekly, monthly, or continuous summary reports in hourly increments based on vehicle speed, classification, ESAL, and weight summaries on a lane by lane or directional basis. The typical in-house software can also generate reports on errors, auto-calibration, site history, calibration history, and overweight vehicles.

3.4 PIEZOELECTRIC SENSORS

Piezoelectric WIM systems utilize piezo sensors to detect a change in voltage caused by pressure exerted on the sensor by an axle and measure the axle's weight. As a vehicle passes over the piezo sensor, the system records the electrical charge created by the sensor and calculates the dynamic load. The static load is estimated using the measured dynamic load and calibration parameters.

3.4.1 Sensor

Piezoelectric WIM systems consist of one or more sensors, which are placed across the traffic lane. Piezoelectric WIM systems are piezo sensors that may or may not be encapsulated in an epoxy-filled metal channel, usually aluminum. This system is classified as an ASTM Type I or II system depending on the intended use of the device and the number of sensors placed in the lane.

The typical system consists of at least one sensor and one inductive loop. The sensor(s) is placed in the travel lane perpendicular to the direction of travel. The inductive loops are placed upstream and downstream from the sensor. The upstream loop is used to detect vehicles and alert the system of an approaching vehicle. The downstream loop is used to determine speed and axle spacings based on timing. An example of the layout for a piezoelectric WIM system is shown in Figure 3.2.

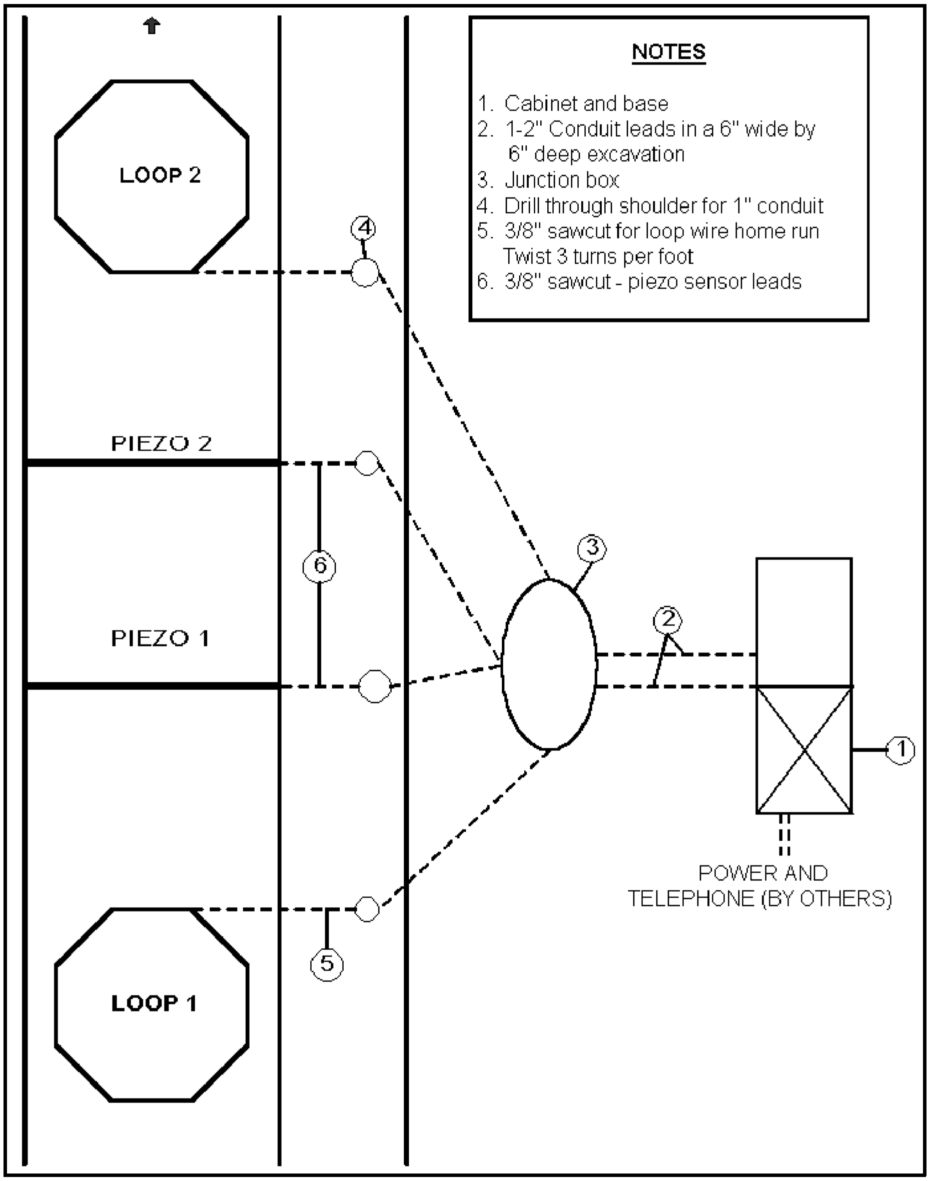

Figure 3.2 Example of Piezoelectric System Layout

3.4.2 Site Processor

Processing units are used to sort and analyze the information obtained by the roadway sensors. The on-site processor can be provided by either the state or the vendor. Caltrans evaluated both options and determined that the vendor-provided processor is preferable as long as it is compatible with the state-provided in-house computer. The vendor-provided on-site processor eliminates the issue of compatibility between the sensors and the state-provided processor.

3.4.3 Remote Communication Modem

The modem used to collect data to monitor the system needs to be operable on a standard telephone line and capable of at least 2,400 bps, but preferably at least 9,600 bps. The amount of data collected at the site and the frequence of downloading should be considered when selecting the telephone line and modem. In general, the download process will be quicker as the quality of the selected phone line and modem increases. The remote communication can be done using either telephone lines or cellular technology.

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WIM software includes three separate software packages; on-site software, communications software, and in-house software. The typical on-site software interprets the signals from the WIM scale and generates the on-site files which include information such as:

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8. Purge old data files from the system

3.4.5 Data Output Format

The typical in-house software is capable of generating output reports in the FHWA's Traffic Monitoring Guide Card Format. The in-house software is also capable of generating daily, weekly, monthly, or continuous summary reports in hourly increments based on vehicle speed, classification, ESAL, and weight summaries on a lane by lane or directional basis. The typical in-house software can also generate reports on errors, auto-calibration, site history, calibration history, and overweight vehicles. The auto-calibration report is an important report for piezoelectric WIM systems.

3.5 LOAD CELL

Load Cell WIM systems utilize a single load cell with two scales to detect an axle and weigh both the right and left side of the axle simultaneously. As a vehicle passes over the load cell, the system records the weights measured by each scale and sums them to obtain the axle weight.

3.5.1 Sensor

The typical Load Cell WIM systems consist of a single load cell placed across the traffic lane. The single load cell has two in-line scales that operate independently. Off-scale detectors are integrated into the scale assembly to sense any vehicles off the weighing surface. This system is classified as an ASTM Type I, II, III, or IV system depending on the site design.

The typical system consists of the load cell and at least one inductive loop and one axle sensor. The load cell is placed in the travel lane perpendicular to the direction of travel. The inductive loop is placed upstream of the load cell to detect vehicles and alert the system of an approaching vehicle. If a second inductive loop is used, it is placed downstream of the load cell to determine axle spacings, which is used to determine the vehicle speed. The axle sensor is placed downstream of the load cell to determine axle spacings and vehicle speed. An example of the layout for a load cell WIM system is shown in Figure 3.3 on the following page.

3.5.2 Site Processor

Processing units are used to sort and analyze the information obtained by the roadway sensors. The on-site processor can be provided by either the state or the vendor. Caltrans evaluated both options and determined that the vendor-provided processor is preferable as long as it is compatible with the state-provided in-house computer. The vendor-provided on-site processor eliminates the issue of compatibility between the sensors and the state-provided processor.

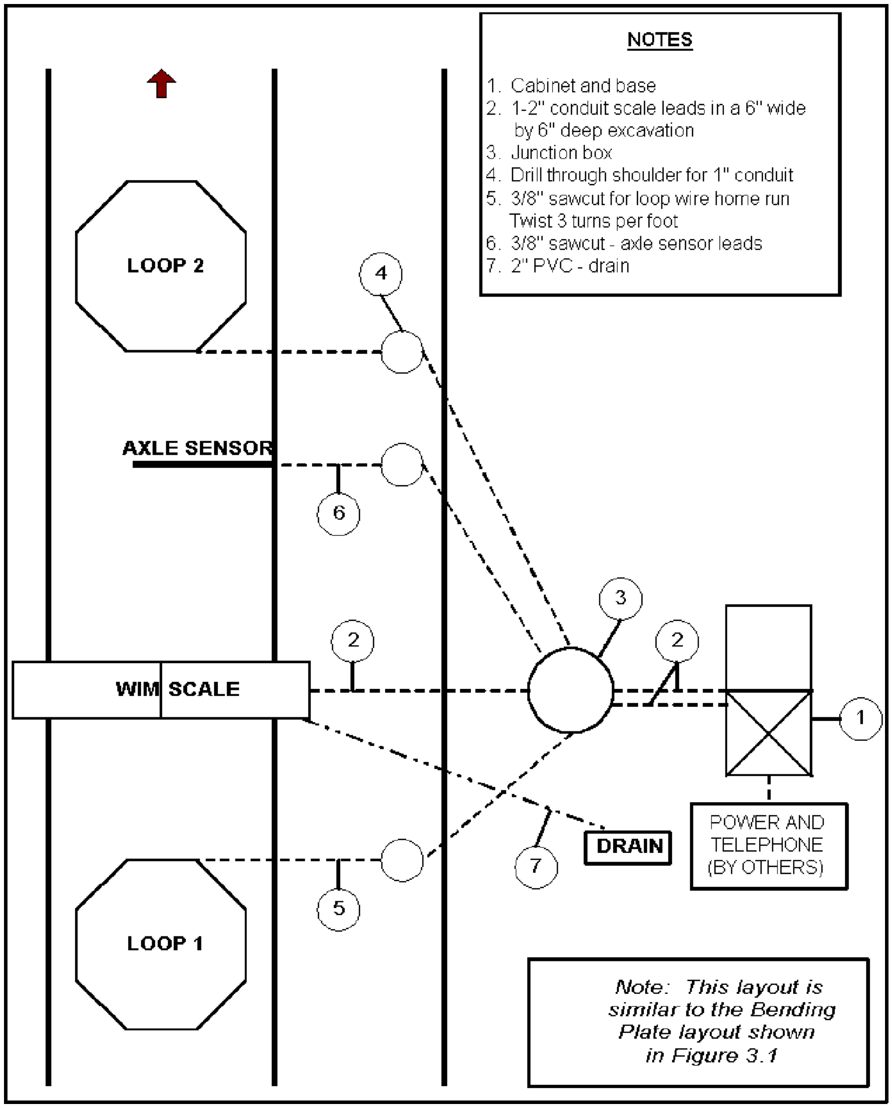


Figure 3.3 Example of Load Cell System Layout

3.5.3 Remote Communication Modem

The modem used to collect data to monitor the system needs to be operable on a standard telephone line and capable of at least 1,200 bps, but preferably at least 9,600 bps. The amount of data collected at the site and the frequence of downloading should be considered when selecting the telephone line and modem. In general, the download process will be quicker as the quality of the selected phone line and modem increases. The remote communication can be done using either telephone lines or cellular technology.

3.5.4 Operating Software

WIM software includes three separate software packages; on-site software, communications software, and in-house software. The typical on-site software interprets the signals from the WIM scale and generates the on-site files which include information such as:

1. Site Identification
2. Time and Date of Passage
3. Lane Number
4. Vehicle Sequence Number
5. Vehicle Speed and Classification
6. Weight of all Axles or Axle Groups
7. Code for Invalid Measurement
8. Optional Graphic Configuration
9. ESAL value

The typical communications software allows for changes to be made to the on-site software setup including calibration factors from the in-house computer. The typical in-house software generates hard copy reports as well as ASCII files. The software allows reports to be generated on the collected raw vehicle record files. The typical communications and in-house software allow the user to perform the following tasks:

1. Real time vehicle viewing selectable by lane
2. Resetting of the system clock
3. Monitor system memory in terms of storage remaining
4. Setup and initiate the generation of summary reports on data previously collected by the system
5. View generated reports
6. Generate and view error reports including time down, system access, auto-calibration, and improperly completed records
7. Transfer selected raw data files or generated reports from the site system to the office host computer
8. Purge old data files from the system

3.5.5 Data Output Format

The typical in-house software is capable of generating output reports in the FHWA's Traffic Monitoring Guide Card Format. The in-house software is also capable of generating daily, weekly, monthly, or continuous summary reports in hourly increments based on vehicle speed, classification, ESAL, and weight summaries on a lane by lane or directional basis. The typical in-house software can also generate reports on errors, auto-calibration, site history, calibration history, and overweight vehicles.

4. SITE DISCUSSION

According to the American Society for Testing and Materials (ASTM) standard entitled *Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Methods*(ASTM Designation E 1318-94), WIM users must provide and maintain an adequate operating environment for the system to perform properly (*1*). Several factors that influence the performance of a WIM system are in the geometric design and pavement condition of the roadway and the overall site location. These factors influence the dynamic behavior of the vehicle and thus influence the accuracy of the estimate of the static weight made by the WIM system (*4*). ASTM Standard, Section 6 has guidelines to be followed when evaluating a possible location for a WIM site. Table 4.1 shows the WIM site principles that should be considered when selecting a location for a WIM system.

✎ *4.1 WIM Site Selection*
"The quality of the WIM data is dependent upon the quality of the site selected."
... Caltrans.

Table 4.1
WIM Site Principles Checklist

	WIM Site Principles
4.1	**Select the site based on the required site design life and accuracy performance level.**
4.2	**Evaluate the geometric design of the location on the following qualities.**
4.2.1	Determine if the horizontal curvature is acceptable.
4.2.2	Determine if the roadway grade is acceptable.
4.2.3	Determine if the cross slope is acceptable.
4.2.4	Determine if the lane is wide enough and marked properly.
4.3	**Determine if the pavement is adequate or if the pavement should be replaced.**
4.4	**Evaluate the site location on the following qualities.**
4.4.1	Determine the availability of access to power and phone.
4.4.2	Determine if there is an adequate location for the controller cabinet.
4.4.3	Determine if the site provides adequate drainage.
4.4.4	Determine the traffic condition at the site.

4.1 SITE SELECTION

The site selected for a WIM system should be based on meeting the required "site design life" and accuracy necessary to support the user. In order to meet these requirements, the geometric design, pavement condition, and general characteristics of a potential site should be considered. Selecting an adequate site for the WIM location is a very important part of meeting the established WIM system requirements.

4.2 GEOMETRIC DESIGN

The geometric design of a roadway is an important factor that provides a foundation for using dynamic load measurements to estimate static loads accurately. This is due to the influence longitudinal and transverse offsets have on the behavior of a vehicle. The ASTM Standard sets guidelines for the horizontal curvature, the longitudinal gradient, the cross (lateral) slope, and the width of the paved roadway lane. The guidelines are set for each type (Type I, Type II, Type III, and Type IV) of WIM system installation (*1*). Table 4.2 shows the ASTM Standard geometric design requirements for each type of system.

Table 4.2
ASTM Standard (E 1318-94) Geometric Design Requirements

Characteristic	Type I	Type II	Type III	Type IV
Horizontal Curvature	radius ≥ 1740m 46m before/after	radius ≥ 1740m 46m before/after	radius ≥ 1740m 46m before/after	radius ≥ 1740m 46m before/after
Roadway Grade	≤ 2% 46m before/after	≤ 2% 46m before/after	≤ 2% 46m before/after	≤ 1% 91m before/after
Cross Slope (lateral)	≤ 2% 46m before/after	≤ 2% 46m before/after	≤ 2% 46m before/after	≤ 1% 46m before/after
Lane Width	3 to 4.5m 46m before/after	3 to 4.5m 46m before/after	3 to 4.5m 46m before/after	3 to 4.5m 46m before/after

4.2.1 Horizontal Curvature

The maximum allowable horizontal curvature for the roadway is identical for all four types of WIM system installations. The roadway has to have a horizontal radius of not less than 1740 meters (5,700 feet) for a distance of 46 meters (150 feet) before and after the WIM sensor. The radius is measured at the centerline of the lane in which the sensor is installed.

4.2.2 Roadway Grade

The maximum allowable roadway grade is the same for Type I, Type II, and Type III WIM systems. For these systems the roadway grade can not exceed two percent for a distance of 46 meters (150) feet before and after the sensor. For a Type IV system, the roadway grade can not exceed one percent for the 91 meter (300 foot) distance. No documentation was found for the minimum allowable amount of longitudinal waves in the roadway approaching the sensor.

4.2 Axle Weight Transfer and Roadway Grade

> *"The major data problem effected by installing a WIM system on a grade, say anything in excess of one percent, is the weight 'transfer' from the steer axle to the drive axle of the loaded trucks."* ... Caltrans.

✎

4.2.3 Cross Slope

The maximum allowable cross (lateral) slope of the road surface is the same for the first three types of WIM systems. For these systems the cross slope cannot exceed two percent for a distance of 46 meters (150 feet) before and after the sensor. The road surface 46 meters (150 feet) before and after a Type IV system cannot have a cross slope in excess of one percent.

4.2.4 Lane Width

A guideline for the width of the paved roadway lane is the same for the four types of systems. For 46 meters (150 feet) before and after the sensor the width needs to be between 3 and 4.5 meters (10 and 14 feet) depending on scale width. For Types III and IV the lane must be marked with a solid white line, 100 to 150 millimeters (4 to 6 inches) thick, running parallel to the lane. Additionally, one meter (three feet) of clear space must be provided on each side of the WIM sensor lane when the system is used on a ramp.

4.3 PAVEMENT CONDITION

The roadway pavement condition is important in the reduction of vehicle bounce. According to Deakin, "Vehicle bounce, resulting in variations in the vertical load imposed by a moving axle, increases with road roughness, leading to greater variations in the instantaneous axle loads (*5*)."

The guideline set forth in the ASTM Standard E 1318-94 states that for a distance of 46 meters (150 feet) before and after the sensor the roadway surface "shall be maintained in a condition such that a 150 millimeter (6 inch) diameter circular plate 3 millimeters (0.125 inches) thick cannot be passed beneath a 6 meter (20 foot) long straightedge (*1*)." The standard also states that a foundation must be provided and maintained to accommodate the sensors. The Oregon Department of Transportation uses a profilograph to measure the pavement roughness, shown in Figure 4.1 on the following page.

Photo courtesy of Oregon DOT

Figure 4.1 Use of Profilograph to Measure Road Roughness

Caltrans' successful practice requires that all WIM systems be installed in Portland cement concrete (PCC) pavement to provide roadway stability, durability, and smoothness throughout the 10 to 15 year expected equipment life. Caltrans guidelines establish that the PCC pavement should be the thickness shown on the construction plans or 300 millimeters (one foot), whichever is greater. If the WIM system is to be used on a roadway that is asphalt concrete (AC) pavement, the AC pavement must be replaced with PCC pavement for a minimum distance of 15 meters (50 feet) before and 7.5 meters (25 feet) after the sensor (*6*). The base structure at the sensor location follows the established parameters for that roadway. The Draft Long-Term Pavement Performance (LTPP) Program Specification sets a minimum pavement strength using a falling weight deflectometer (FWD) test. Using an applied load of 4,080 kilograms (9,000 pounds), the pavement deflection must be between 0.305 and 0.457 millimeters (0.012 and 0.018 inches) and the area of the deflection basin must be 17400 square millimeters (27 square inches) or greater. The Draft LTPP Standard notes that the pavement must be designed to operate near these strength levels throughout the year, even during periods when the pavement structure is weakened by high moisture content or thaw conditions (*7*).

4.3 Pavement Condition

"If the WIM equipment is not installed in pavement that is both stable and smooth, the estimates of static weight will not be very accurate." ... Caltrans.

4.4 SITE LOCATION

The location of a WIM site should be based on more than just the need for truck traffic data (*8*). The site needs to be located in an area with specific qualities including:

1. Availability of access to power and phone
2. Adequate location for controller cabinet
3. Adequate drainage
4. Traffic conditions

4.4.1 Availability of Access to Power and Phone

The site should have access to an AC power source and telephone utilities. Solar power and cellular phones can be used if utilities are not available. The power source and phone service used at a site is dependent upon the amount of truck data collected at the site. For more active sites Caltrans determined that wired phone service would be more cost effective than cellular (wireless) service.

4.4.2 Adequate Location for Controller Cabinet

The controller cabinet should be located so that it will function throughout the design life of the site. The cabinet needs to be in an area so that:

1. It will not be subjected to runoff during heavy rains or to standing or moving water from irrigation or drainage facilities
2. It can not be hit by a vehicle leaving the roadway, preferably behind a guardrail
3. It is accessible with a clear line of sight to the sensors
4. It can be serviced without endangering the technician(s)

Items three and four are important because technicians may need to spend time at the controller cabinet during system testing, calibration, and maintenance.

4.4.3 Adequate Drainage

Drainage should be adequate for the controller cabinet, junction boxes, and WIM sensors. The site should not be located in an area subjected to flooding. The water can be directed to the roadside’s outside slope or an existing drainage facility.

4.4.4 Traffic Conditions

WIM systems should be in an area of free traffic flow with good sight distances. The traffic conditions should be such that:

1. Stop and go traffic is minimized
2. Slow moving traffic is minimized
3. Lane changing is minimized
4. Passing on two lane roads is minimized

5. SYSTEM INSTALLATION

The American Society for Testing and Materials (ASTM) Standard (E 1318-94) requires that the weigh-in-motion (WIM) equipment be installed and maintained in accordance with the recommendations of the system vendors (*1*). This section will discuss techniques and additions that states with successful WIM systems implement during the installation process. The states with successful WIM systems were selected using information from the Long Term Pavement Performance (LTPP) program. The states selected for each WIM systems discussed in this report are California for bending plate, Missouri for piezoelectric sensors, and Oregon for load cell. The discussion will not be limited to these states; successful practices and procedures from other state transportation departments and the LTPP program will also be described. The discussion will cover only the installation procedures for the WIM scales and not the additional inductive loops and axle sensor.

5.1 Installation
"Proper installation is a key element in ensuring the WIM system will function within specifications throughout the site design life." ... Caltrans.

The Draft LTPP Specification lists several installation requirements which are in accordance with many of the vendor recommendations (*7*). The Draft LTPP requirements are:

1) Installation must be done in good weather, not wet, freezing, or hot conditions
2) The sensors must be flush with the road surface, no more than one millimeter separating the top of the sensor from the road surface
3) The equipment must be protected from water and dust
4) The equipment cabinet must protect the system electronics from temperature, dust, humidity, and insect and rodent infestation
5) The equipment must be protected from lightning and power surges
6) The equipment must be installed so that routine maintenance can occur without disruption of data collection

5.1 OBJECTIVES OF “SUCCESSFUL PRACTICES” INSTALLATIONS

The installation section of the WIM manual is intended to focus attention on techniques or additional steps that states with successful WIM systems implement during the vendor’s recommended installation process. For each WIM system discussed in this manual, an installation checklist of the required steps is included to show the installation process. The objective of the installation process is to provide a properly functioning WIM site for the established site design life. The WIM site design life should be established by the state. For example, if a state transportation department establishes an expected site design life of 10 to 15 years for bending plate WIM systems, the installation process should be established to provide a 10 to 15 year site design life. To ensure this objective is met, the general installation principles shown in Table 5.1 should be followed.

Table 5.1
Installation Principles Checklist

	Installation Principles
5.2	**Overall Process**
5.2.1	A Vendor representative should be on-site to ensure vendor requirements are met.
5.2.2	A State representative should be on-site to ensure state requirements are met.
5.2.3	Pre-construction meetings should be held before lane closure.
5.2.4	All necessary equipment, materials, and WIM components should be on-site before starting the job.
5.2.5	Complete site plans should be available on-site to ensure proper placement of equipment.
5.2.6	Installation team needs to make a good estimate of the time required to complete the work and lanes should be opened on schedule to accommodate traffic.
5.2.7	Junction box and roadside cabinet need to be placed away from water collection areas.
5.2.8	An accurate set of "as built" plans should be developed for future construction and maintenance work.

5.2 WEIGH-IN-MOTION SYSTEM INSTALLATION

During the installation process the principles listed in Table 5.1 need to be followed regardless of the type of WIM system being installed. A representative from both the equipment vendor and the state need to be present during the process to ensure that their requirements are met. A pre-construction meeting or meetings should be held to discuss the installation plan and review the equipment list. All of the necessary equipment, materials, WIM components, and site plans should be on-site and tested before the procedure is started. Checking the equipment and WIM components will save time and money not only during the installation process but also throughout the life of the site. The site must provide proper drainage away from the WIM components. The junction boxes and roadside cabinet must be placed away from water collection areas.

5.2 Sensor Test
"Identifying a 'bad' weighpad or sensor prior to installation will save time and money."...Caltrans.

5.3 BENDING PLATE INSTALLATION PROCESS

The detailed installation procedures for the bending plates and loops are well described in manuals provided by the vendors. This section will highlight areas of the installation process considered important to the successful practice managed by Caltrans. Table 5.2 shows the bending plate installation checklist to aid in the discussion.

5.3.1 Preparing the Road

Road preparation is the initial step in the installation process. In order to reduce the effects of pavement roughness, Caltrans' successful practice requires that the Portland cement concrete (PCC) pavement 46 meters (150 feet) before and 23 meters (75 feet) after the sensor location be ground in accordance with the provisions in Section 42-2, "Grinding," of the Caltrans Specification (*6*). Grinding specifications require that the distance between the roadway surface and the bottom edge of a straightedge be no more than 3 millimeters (0.01 feet). Asphalt concrete is replaced with PCC for a minimum distance of 15 meters (50 feet) prior to and 7.5 meters (25 feet) after the scale location. The asphalt concrete is ground 7.5 meters (25 feet) before and after the new pavement.

5.3.2 Excavating the Pit Area

The pit area should be marked on the pavement surface using the scale frame as a guide. In addition to cutting the outlines marked on the pavement, lines should be cut inside each outline in a checkerboard style to ease excavation. The concrete pavement must be wet during the cutting process. After the debris has been removed from the pit area, use a vacuum and air compressor to finish the cleaning process. The pit must be clean and dry for the epoxy to reach maximum adhesion, so the use of water to clean the pit area will delay installation.

5.3.3 Frame Installation

Supports are attached to the top of the scale frame to level the frame with the road surface and to make moving the frame easier. The frame is placed in the pit area and anchor holes are started using the frame as a templet. The frame is then removed and the anchor holes are drilled to the appropriate dimensions.

> *5.3 Frame Installation*
> *"At the time that the frame alignment has been finalized for the marking of anchor hole positions, paint the outline of the frame supports on the pavement surface to ensure frame/hole alignment for the epoxy pour."* ...Caltrans.

Table 5.2
Bending Plate Installation Checklist

Step	Installation Action Item
1	**Initial Test**
a	Resistance test performed before equipment is brought on-site.
2	**Preparing the Road**
a	Pavement prepared following the site specifications, including concrete replacement and grinding.
b	Saw cutting for in-pavement components done with care and according to specification.
c	Concrete removal from scale pit area was done with care to ensure proper pit width and depth.
d	Anchor holes were drilled wiith proper alingment, diameter, and depth.
e	Scale pit area was clean and dry before frame placement.
f	Proper drainage provided from pit area.
3	**Installing Scale Frames in the Scale Pit**
a	Installed the lead and drainage conduits so that the drainage conduit was lower.
b	Installed the conduits so that they are not obstructed.
c	Installed the pull rope in the lead conduit so that it is accessible and free from obstructions, snags, and excessive cable slack.
d	Sealed the lead and drainage conduits so that epoxy could not enter during epoxy placement.
e	Scale frames placed so that scales would be flush with road surface.
f	Epoxy components kept within the manufacturer’s recommended temperature range.
g	Each scale frame was properly grounded.
h	Epoxy placed with care to ensure that conduits and scale frames were stable.
4	**Installing Scale Pads in the Scale Frame**
a	Avoided pinching lead wires when placing scale pads.
b	Installed the scale pads flush with roadway surface.
c	Tightened and torqued bolts to vendor specification.
d	Sealed the system components to prevent possible damage due to moisture and dust.
5	**Final Test**
a	Performed resistance test to ensure lead cables were undamaged.

Install the shoulder conduits for cabling and drainage. The drainage conduit must be lower than the cabling conduit and be sloped a minimum of one percent to ensure water will flow away from the scales. It may also be necessary, depending upon the vendor installation method, to install a conduit where two frames meet in the roadway to facilitate drainage and the pulling of lead-in cables beneath the scale frames. If required by the WIM vendor, install a grounding rod in the shoulder junction box for connection to the scale frame through the cabling conduit.

Typically, mortar "dams" are constructed around the inside of the scale frames to contain the epoxy under the frames. The epoxy can be poured in one of two ways. Either place the frame into the pit area first and then pour the epoxy around the frame or pour the epoxy into the pit area to a pre-determined level and force the frame into the epoxy. In either case cover all holes in the scale frames with duct tape. This is done to prevent the epoxy from entering the frame holes when it is placed in the pit.

5.4 Conduit and Drain
"Ensure that the mortar dams are constructed such that the shoulder conduit and drain are completely encased in epoxy with no voids under the scale frame." ... Caltrans

5.5 Leveling
"When setting the scale frames into the pit, make sure that there is no debris between the bottom of the supports and the top of the pavement surface."... Caltrans.

Clean the pit area and the scale frames of any excess epoxy by scraping off any material on the scale frames. Finish the cleaning process with a vacuum and an air compressor.

5.3.4 Final Test

Once the scales are in place, they need to be tested to check for possible damage during installation. Resistance checks should be performed on the lead-in cables to check for damage and excitation. The resistence will increase as the length of the lead-in cable increases. The resistence will therefore increase at the roadside cabinet, depending on the distance to the cabinet. A fully installed bending plate scale is shown in Figure 5.1 on the following page. The painted outline of the frame supports can also be seen in this picture.

5.6 Lead Wires
"During the installation process don't pinch the lead wires.. Double check to make sure the lead wires are not cut or shorted." ... Caltrans

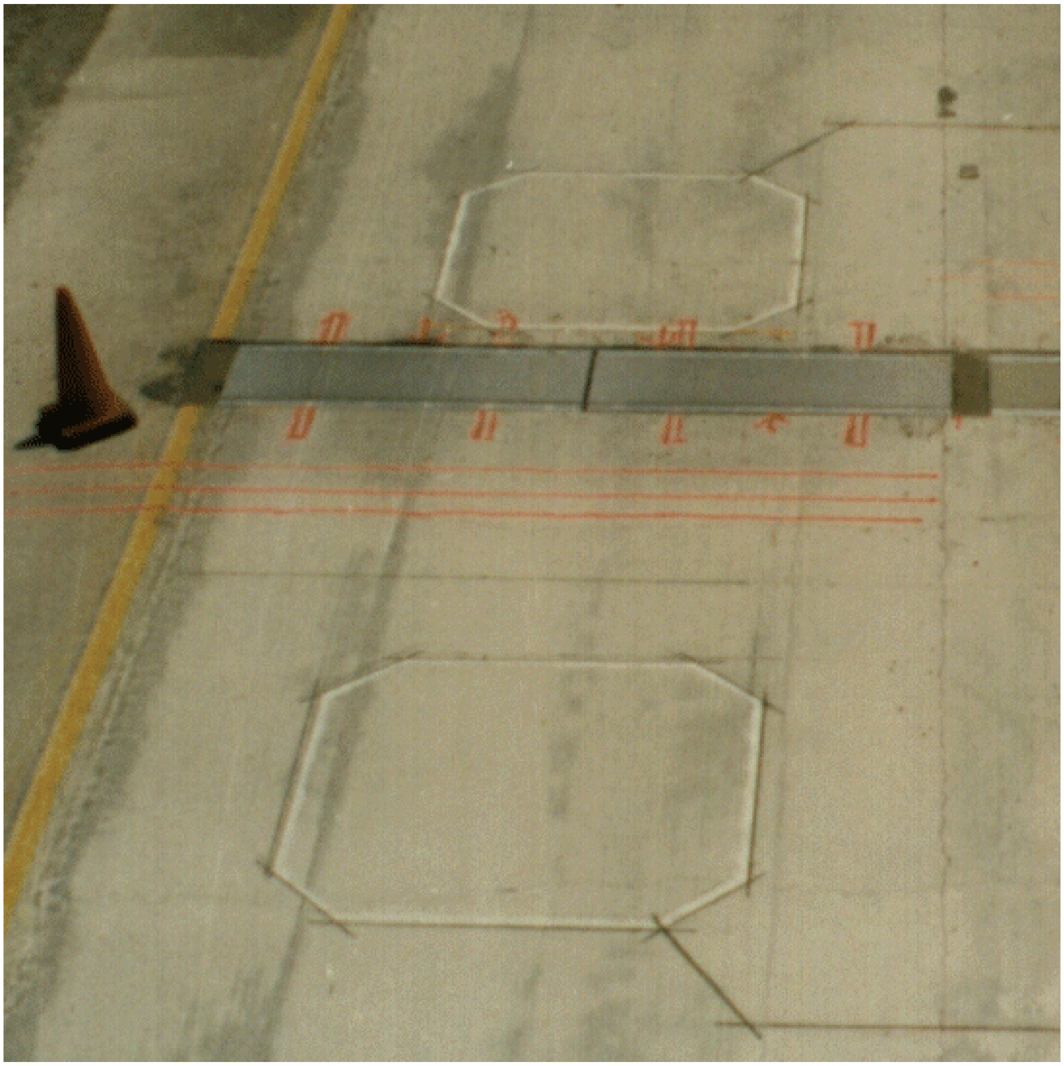


Figure 5.1 Installed Bending Plate Scale

5.4 PIEZOELECTRIC SENSOR INSTALLATION PROCESS

The detailed installation procedures for piezoelectric sensors and loops are well described in manuals provided by the vendors. This section will highlight areas of the installation process considered important to the successful practice managed by the Missouri Department of Transportation (DOT). Table 5.3 shows the installation checklist for piezoelectric sensor installation.

Table 5.3
Piezoelectric Sensor Installation Checklist

Step	Installation Action Item
1	**Initial Test**
a	Checked the sensor for dents or abrasions.
b	Tested the resistance using a multimeter.
c	Tested the voltage output for a voltage deflection by stepping on the sensor.
2	**Preparing the Road**
a	Pavement prepared according to site specifications, including concrete replacement and grinding.
b	Sensors placed in accordance with the site layout plan.
c	Saw cutting for in-pavement components was done with care and according to specifications.
d	Concrete removal from the slots was done with care to ensure proper hole width and depth.
e	Slots were clean and dry before sensor placement.
3	**Installing Sensor in the Main Slot**
a	Attached installation brackets to sensor.
b	Placed part of lead-in cable into lead-in slot and secure with caulking compound.
c	Filled main slot halfway with epoxy and carefully placed sensor in epoxy to avoid air pockets.
d	Placed weights on installation brackets to minimize sensor float.
e	Once the epoxy cured, removed the brackets and finished filling the main slot.
f	Placed the lead-in cable in the lead-in slot and secured it with loop sealant.
4	**Final Test**
a	Tested the resistance using a multimeter.
b	Tested the voltage output for a voltage deflection by driving a truck over the sensor.

5.4.1 Initial Test

Prior to installing the sensor in the roadway an initial test of the sensor should be made. This will ensure that the sensor is working properly so that time and money is not wasted installing a defective sensor.

5.4.2 Sensor Layout and Slot Cutting

Once the sensor locations are determined for the site, slotted aluminum templates for the sensors are placed on the roadway according to site layout plans. Florescent orange paint is then sprayed on the templates to mark where the pavement cuts will be made for the sensor slots. Figure 5.2 shows the florescent orange paint being sprayed onto positioned templates (*9*). Once the cuts have been made the slots need to be cleaned using a wire brush, a vacuum, and an air compresseor.

5.7 Slot Condition
"It is important to make sure that the slot is clean and dry to ensure that the epoxy attain maximum adhesion."....IRD

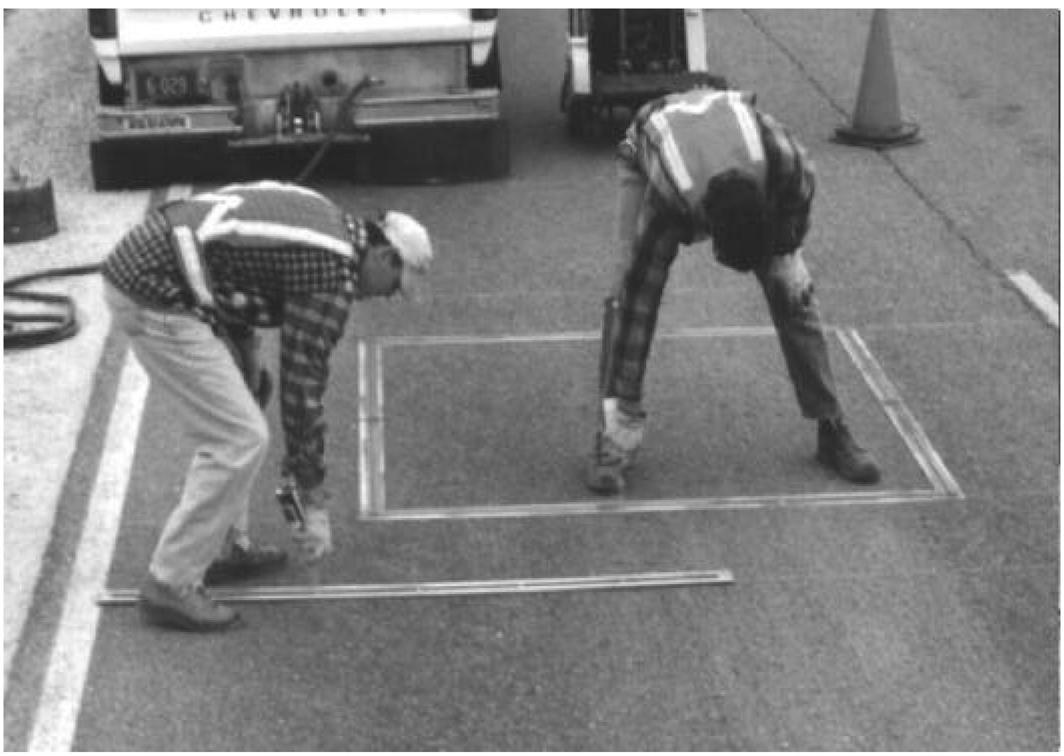


Figure 5.2 Positioning and Painting of Sensor Templates

5.4.3 Alternative Installation Procedure

The Arkansas State Highway and Transportation Department (AHTD) has been using piezoelectric sensors since 1990. AHTD has found that using mounting wires and concrete cylinders during installation have some inherent problems. The main problem is keeping the mounting wires tight during the installation process. This keeps the plates in the necessary positions and the sensor at the desired depth in the slot. Attaching the mounting wires to the sensor takes time. The problem associated with the use of concrete cylinders to hold the metal plates in place to avoid sensor float is the excess epoxy that collects on and around the cylinders and mounting plates. This increases the amount of time required to remove the cylinders and plates and finish the installation process. The modifications to the installation procedure that the AHTD Technical Service Section developed to reduce these problems are discussed below (*10*).

Instead of using a wire to attach the sensor to the metal plates, AHTD uses U-bolts formed from a 6.35 millimeters (0.25 inches) all-thread rod to attach the metal plates. The metal plates are attached to the sensor before transportation to the installation site. The U-bolts do not loosen during handling and eliminate the problems associated with loose wires.

Instead of using the concrete cylinders to anchor the sensor, the metal plates are bolted to the roadway. The metal plates are 50 millimeters by 406 millimeters (2.0 inches by 16.0 inches) with bolt holes on each end. After the slots are cut and cleaned the sensor is positioned and the bolt holes are marked on the pavement. The sensor is removed from the slot and the pilot holes are drilled into the pavement. After anchors are placed in the pilot holes, the sensor is placed in the slot and secured using lag screws. Additional plates can be bolted over the sensor if any portion of the sensor is too high with regard to the pavement surface. The epoxy is placed in the slot and allowed to cure. Once the epoxy has cured the plates are removed and the exposed portions of the bolts are cut and ground flush with the pavement surface.

5.8 Knowledge of Epoxy Properties

"The depth and width of the slot should vary with the type of epoxy used. Some epoxies cure faster in larger amounts and will need larger slots. An understanding of the epoxy used will improve the quality of the installation and save time." Arkansas State Highway and Transportation Department.

5.5 LOAD CELL INSTALLATION PROCESS

The detailed installation procedures for load cell scales are well described in manuals provided by the vendors. This section will highlight areas of the installation process considered important to the successful practice managed by the Oregon DOT. Table 5.4 shows the installation checklist for load cell scale installation.

5.5.1 Initial Test

Prior to installing the scales, resistance checks should be preformed on the scale and lead-in cables to check for cable damage, excitation, and proper attachments.

5.5.2 Preparing the Road

Road preparation is the initial step in the installation process. The Oregon DOT attempts to follow the ASTM Standard (E 1318-94) for pavement condition. In order to reduce the effects of pavement roughness, the Oregon DOT requires that the pavement 18 meters (60 feet) before and 12 meters (40 feet) after the sensor location should be ground in accordance with State specifications (*11*). In addition, the pavement 32 meters (100 feet) before the 18 meters of ground pavement should be milled in accordance with State specifications. If the load cell scale is installed in an asphalt concrete roadway, an 18 to 21 meter (60 to 70 foot) portland cement concrete slab is placed in the roadway before and after the scale location. The concrete is then ground to the State specifications. Pavement grinding is shown in Figure 5.3.

Figure 5.3 Pavement

Grinding
Table 5.4
Load Cell Scale Installation Checklist

Step	Installation Action Items
1	**Initial Test**
a	Performed resistance checks on the scales and lead-in cables.
b	Checked lead-in cables for possible damage and proper attachments.
2	**Preparing the Road**
a	Pavement prepared in accordance with the site specifications, including concrete replacement and grinding.
b	Saw cutting for in-pavement components done with care and according to specification.
c	Concrete removal from scale pit area was done with care to ensure proper hole width and depth.
d	Scale pit area was clean and dry before frame placement.
e	Proper drainage provided from pit area.
3	**Preparing the Pit to Receive the Scale Frames**
a	Rebar matting prepared in accordance with site specifications.
b	Dowels placed according to site specifications, only used for concrete roads.
4	**Preparing the Scale Frames**
a	J-bars installed in accordance with the site specifications.
b	Jackscrews installed in accordance with the site specifications.
c	Leveling legs installed in accordance with the site specifications.
5	**Installing Scale Frames into the Scale Pit**
a	Inserted scale frames so that J-bars fit in rebar matting and connected scale frames.
b	Cabling conduit connected between the scale areas.
c	Drainage conduit installed lower than cabling conduit and at a minimum of one percent slope.
d	Covered all bearing pads and conduit openings so that concrete would not enter during placement.
e	Grounded the scale frames.
f	Leveled the scale frames with the road surface and adjusted for lateral twisting.
g	Secured the scale frame with the jackscrews.
h	Poured concrete into scale pit area through the frame up to the bottom of the frame and vibrated concrete.
i	Poured concrete between frame and pit edge up to the road surface, but do not vibrate.
j	Finished concrete in accordance to site specifications and allowed 18- to 24-hour curing time.

Table 5.4 (Continued)
Load Cell Scale Installation Checklist

Step	Installation Action Items
6	**Cleaning up the Frame Installation**
a	Cleaned the scale pit area and scale frame of any spilled concrete.
b	Uncovered bearing pads and conduit openings.
c	Grinded drainage conduit flush with bottom of scale frames.
7	**Preparing the Single Load Cell Scale Pads**
a	Carefully removed the temporary shipping plates, load cell hatch, load cell and protective plate from the scales.
b	Removed the threaded shipping plugs from the pre-load spring holes.
c	Greased all o-rings and bearing pads with a multi-purpose, non-corrosive grease.
8	**Installing the Single Load Cell Scale Pads into the Frame**
a	Carefully lowered the scale pad into the frame in a level position.
b	Properly positioned the scale pads with the rounded corners out.
c	Secured the scales with bolts tightened and torqued to vendor specifications.
d	Avoided pinching wires when installing the scale pads and load cells.
e	Poured antifreeze into the load cell cavity.
f	Inserted the load cell into the load cell cavity.
g	Greased the top o-ring.
h	Replaced and secured the load cell hatch cover and tightened and torqued it to vendor specification.
9	**Testing the Operation of the Load Cell**
a	Connected the load cell to a 10-volt DC source for testing.
b	Measured the output and added 2 to 3 mV to obtain a target reading for pre-load springs.
c	Tightened the pre-load springs in accordance with vendor specifications to target reading.
d	Installed sealing plugs on pre-load springs.
e	Installed frost plugs on all bolt holes.
10	**Final Test**
a	Checked the output voltage of the load cell for compliance with site specifications.
b	Resistance checks made on the off-scale sensors and lead-in cables.

5.5.3 Installing the Load Cell Scale

The Oregon DOT contracts the WIM site preparation and equipment installation to a prime contractor. An Oregon DOT inspector is on site to ensure that the state's specifications are met (*11*). A fully installed load cell scale is shown in Figure 5.4. Since this load cell is located on a ramp that can be closed to traffic, the roadside cabinet is not as protected as it would be on a traffic lane.

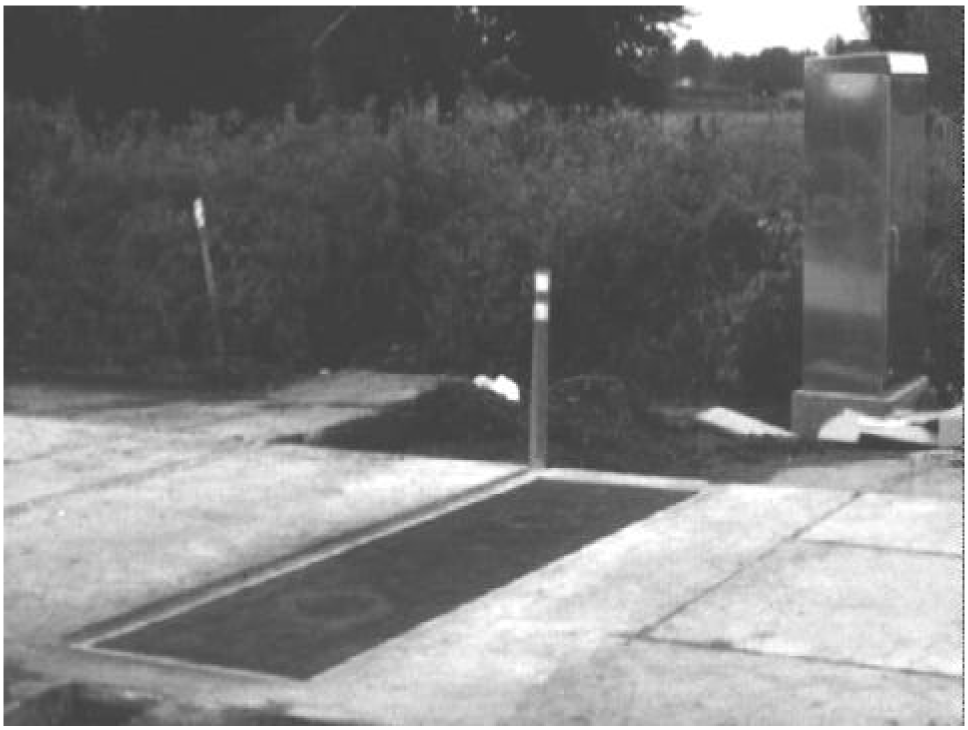


Figure 5.4 Installed Load Cell Scale

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.

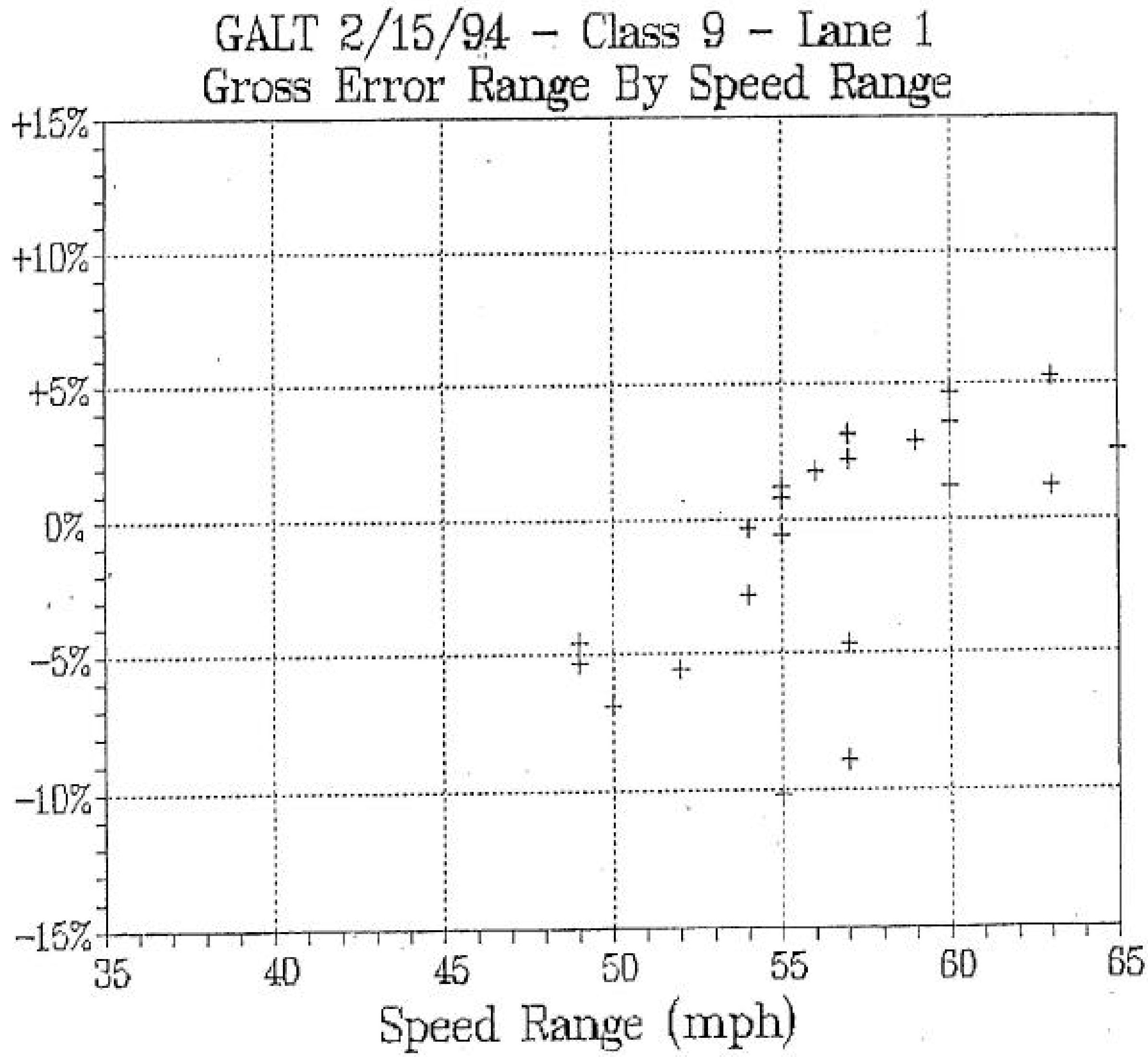


Figure 6.2 Sample Gross Weight Percent Error by Vehicle Speed Graph

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	

7. WEIGH-IN-MOTION ACCURACY AND QUALITY ASSURANCE RELATED TO PROBLEMS OCCURING AT THE WIM SITE

Although weigh-in-motion (WIM) systems can provide massive amounts of valuable data in a relatively efficient manner, the data must be checked for accuracy. This accuracy check is a WIM user's quality assurance (QA) program. A QA program adds confidence to the validity of the WIM data and alerts the data analyst to problems occurring at the WIM site. The purpose of a QA procedure is to help WIM users check data for accuracy and precision. A QA procedure conducted regularly will point out problems at the WIM site and help maintain the system throughout the site design life. The need for quality assurance prompted the development of software programs that could be used to validate data and point to problems occurring at the WIM site. These programs include the Long Term Pavement Performance (LTPP) QA software, the Vehicle TRavel Information System (VTRIS) and individual state software.

7.1 LONG TERM PAVEMENT PERFORMANCE PROCEDURE

This section is a brief description of the LTPP QA program. State agencies can use these same tests to help identify potential errors in any WIM data, whether or not it is intended for submission to the LTPP program, as long as those data are in a record format the LTPP QA Software can read (*7*). The LTPP QA Software automates these checks through a series of Statistical Analysis Software (SAS) programs. The SAS programs produce a number of output reports and graphs that require interpretation. Essentially, the LTPP software summarizes a data set in a series of simple graphs that can be used to identify "unusual occurrences" in the submitted traffic data. These "unusual occurrences" are examined to determine whether they are actually invalid data or rather the result of unusual traffic patterns or site malfunctions.

All graphs produced by the LTPP software are lane- and direction-specific. The software creates graphs for all lanes and directions for which data are submitted. The software automatically performs the following analyses and comparisons:

1. Gross Vehicle Weight Analysis
2. 7-Card Versus 4-Card Volume Comparison
3. 4- and 7-Card Vehicle Class Distribution Comparison
4. Cluster Analysis

7.2 VEHICLE TRAVEL INFORMATION SYSTEM SOFTWARE

The VTRIS software replaces the Truck Weight Software and uses the standards, formats, and methods specified by the Traffic Monitoring Guide (TMG), 1995 edition (*15*). VTRIS is a recommended, but not required, method to submit data to the Federal Highway Administration (FHWA) in a uniform format. The software validates, summarizes, and generates reports on vehicle travel characteristics by lane and by direction in the TMG format.

The VTRIS software develops and maintains a permanent database of the WIM data. The data are validated by VTRIS before inclusion into the VTRIS maintained database. The validation process can be adjusted for each station's site characteristics and user defined parameters for axle spacings and axle weights. Errors detected by the software can be viewed to determine the type of error and whether or not to include the record in the database. The software also converts the WIM data to metric units, thus complying with the FHWA Metric Conversion Plan.

7.3 CALTRANS SUCCESSFUL PRACTICE: QUALITY ASSURANCE PROGRAM

While the LTPP and VTRIS quality assurance software are available to states upon request, individual states may prefer to develop their own QA program that better fits their specifications. These states can work either independently or with a vendor to produce a QA process and reports. The advantages of a state's personalized QA process lie in the ability of the state to meet its specific requirements.

The QA procedure developed by the California Department of Transportation (Caltrans) is discussed in the manual as a "successful practice" due in part to the 10-plus years experience they have using WIM data (*16*). During those learning years the state developed and used a QA procedure for validating data from the WIM systems they have installed. Although their procedure bears several similarities to the procedure used for the LTPP program, it is distinctly different in many respects. Therefore, it is a good example of an individual state's QA procedure formed separately from the LTPP program. Table 7.1 on the following page is a checklist of the quality assurance principles.

7.1 Knowledge
"To properly diagnose, interpret, and validate data from a WIM System, the analyst must have knowledge of 1) the site's physical characteristics, 2) traffic and truck behavior, and 3) the WIM System's vehicle passage processing." ... Caltrans.

The Caltrans QA process applies to bending plate systems and consists of four parts. Part 1 is called the "Knowledge of Site Characteristics" Review. Part 2 is called "Real Time" Review. Part 3 is called the First Level Data Review. Part 4 is called the Second Level Data Review.

The actual Data Validation process itself is preceded by two separate, non-validation processes, the "Knowledge of Site Characteristics" Review and the "Real Time" Review, which supplement the data validation procedure. The "Knowledge of Site Characteristics" Review generates a "site database" based on the physical and traffic characteristics of the site. The "site database" is used and updated throughout the QA procedure to help explain any data anomalies that may occur. The "Real Time" Review performs a spot check of the site's performance. Four flowcharts, including descriptions of the main process events, are provided to aid in the discussion of the QA process developed and used by Caltrans.

Table 7.1
Quality Assurance Principles Checklist

	Quality Assurance Principles
7.3	**Develop and maintain a thorough and scheduled data analysis program.**
7.3	**Fix any site problems the data analysis program reveals.**
7.3.1	**Develop, maintain, and record a permanent "site database."**
7.3.1.2	Record the site's physical characteristics.
7.3.1.3	Record the traffic and truck behavior.
7.3.1.4	Record the WIM system's vehicle processing.
7.3.2	**Conduct a "Real Time" Review.**
7.3.2.1	Review of "snapshot" of the site's performance via telemetry.
7.3.2.2	Review the files for proper date, time, and sizes.
7.3.2.5	Review the "real time" data for proper axle weights and spacings.
7.3.2.6	Identify and repair any system component problems.
7.3.2.7	Identify and adjust any calibration parameter problems.
7.3.3	**Conduct a First Level Data Review - Summary Report.**
7.3.3.2	Identify any loop or loop processing problems.
7.3.3.2	Identify any erratic weighpad behavior causing "ghost axles" or missed axles.
7.3.3.3	Identify any time periods in which the WIM system is not reporting data.
7.3.4	**Conduct a First Level Data Review - Individual Truck Report.**
7.3.4.2	Identify any system equipment malfunctions.
7.3.4.2	Identify any atypical traffic patterns.
7.3.4.2	Identify any atypical truck operating characteristics.
7.3.5	**Conduct a Second Level Data Review.**
7.3.5.2	Identify and correct any problems with the calibration parameters.
7.3.5.3	Identify and correct any problems with the weighpads.

The Caltrans Data Validation process consists of two levels of review. The First Level Data Review is intended to identify:

1. The extent of loop or loop processing problems
2. Any erratic weighpad behavior causing “ghost axles” or missed axles
3. Missing data from a particular lane(s) and the suspected causes

The First Level Data Review includes two steps. Step 1 consists of reviewing the First Level Data Review - Summary Report presenting daily classification and speed summary data. Step 2 consists of reviewing the First Level Data Review - Individual Truck Report presenting individual truck records. The contents and general formats of the reports provided by the vendor’s application software are as required by Caltrans’ specifications.

The Second Level Data Review is intended to identify and correct any site calibration problems, including:

1. Wheel weights
2. Axle Spacings (affected by speed)
3. Vehicle overall lengths

The Second Level Data Review consists of reviewing reports generated by Caltrans’ WIM system analysis program utilizing known relationships of Class 9 and Class 11 trucks and comparing the report data with the known truck operating characteristics for each WIM site.

One of the modifications Caltrans implemented in the FHWA vehicle classification system is the addition of two vehicle classifications. This change brings the total number of vehicle classifications to 15 instead of the 13 classifications recognized by FHWA. The changes to the vehicle classifications are described as follows:

1. Class 9 is a five-axle tractor-semi trailer
2. Class 14 is a five-axle truck trailer
3. Class 15 is for vehicles not meeting the axle configurations and/or weights set for classifications 1 through 14 and vehicles unclassified due to system error

The California 15 Class Scheme is converted to the FHWA 13 Class Scheme when the data are submitted to FHWA. The California classification scheme for Classes 3 through 15 only is shown in Table 7.2 for english units and Table 7.2 (a) for metric units. Class 1, motorcycles, and Class 2, passenger cars, are not included in the table since these classes are not relevant to the manual.

The Caltrans QA procedure discussed in this section is for WIM data in general. Slight modifications may need to be made to the QA procedure depending on the type of system installed and the reports generated by each vendor.

Table 7.2 California Classification Scheme (English)

Class	Vehicle Description	No. Axles	Axle Space Between Axle Numbers (feet)								Weight (kips)	
			1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	MIN	MAX
3	Other (Limo, Van, RV)	2	10-14.5								1.00	7.99
3	Other w/ 1 axle trailer	3	10-14.5	6.0-25							1.00	11.99
3	Other w/ 2 AT	4	10-14.5	6.0-25	1-11.99						1.00	11.99
3	Other w/ 3 AT	5	10-14.5	6.0-25	1-3.49	1-3.49					1.00	11.99
4	Bus (2-3 axles)	2 - 3	23.1-40	3.5-6.0							12.00	>
5	2 axles with duals	2	8.80-23.								8.00	>
6	3 axle	3	6.10-23	3.5-6.0							12.00	>
7	4 axle	4	6.10-23	3.5-6.0	3.5-13.0						12.00	>
8	2S1, 2L	3	6.10-23	11-40							12.00	>
8	3S1, 3L	4	6.10-23	3.5-6.0	6.1-44.0						12.00	>
8	2S2	4	6.10-23	11-44	3.5-11.99						12.00	>
9	3S2, LOG, 32PUP	5	6.10-26	3.5-6.0	6.1-46.0	3.5-10					12.00	>
10	3S3, 33	6	6.10-26	3.5-6.0	6.1-46.0	0.1-11	0.1-11.0				12.00	>
11	2S12	5	6.10-26	11.1-26	6.10-20	11.1-26					12.00	>
12	3S12	6	6.1-26.0	3.50-6	11.1-26	6.1-24	11.1-26				12.00	>
13	2S23, 2S22, 3S13	7	6.1-45.0	3.5-45	3.5-45.0	3.5-45	3.5-45	3.5-45			12.00	>
13	3S23	8	6.1-45.0	3.5-45	3.5-45.0	3.5-45	3.5-45	3.5-45	3.5-45		12.00	>
13	Permit	9	6.10-45	3.5-45	3.5-45.0	3.5-45	3.5-45	3.5-45	3.5-45	3.5-45	12.00	>
14	32	5	6.1-23.0	3.5-6.0	6.1-23.0	11-27					12.00	>
15	Unclassified and Errors - Vehicles not meeting axle configurations set for Classifications 1 thru 14 and "error" vehicles											

Table 7.2 (a) California Classification Scheme (metric)

Class	Vehicle Description	No. Axles	Axle Space Betweem Axle Numbers (meters)								Weight (kg)	
			1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	MIN	MAX
3	Other (Limo, Van, RV)	2	3.0-4.4								450	3620
3	Other w/ 1 axle trailer	3	3.0-4.4	1.8-7.6							450	5450
3	Other w/ 2 AT	4	3.0-4.4	1.8-7.6	0.3-3.7						450	5450
3	Other w/ 3 AT	5	3.0-4.4	1.8-7.6	0.3-1.1	0.3-1.1					450	5450
4	Bus (2-3 axles)	2 - 3	7.0-12.2	1.1-1.8							5450	>
5	2 axles with duals	2	2.7-7.0								3630	>
6	3 axle	3	1.9-7.0	1.1-1.8							5450	>
7	4 axle	4	1.9-7.0	1.1-1.8	1.1-4.0						5450	>
8	2S1, 2L	3	1.9-7.0	3.4-12.2							5450	>
8	3S1, 3L	4	1.9-7.0	1.1-1.8	1.9-13.4						5450	>
8	2S2	4	1.9-7.0	3.4-13.4	1.1-3.7						5450	>
9	3S2, LOG, 32PUP	5	1.9-7.9	1.1-1.8	1.9-14.0	1.1-3.0					5450	>
10	3S3, 33	6	1.9-7.9	1.1-1.8	1.9-14.0	0.03-3.4	0.03-3.4				5450	>
11	2S12	5	1.9-7.9	3.4-7.9	1.9-6.1	3.4-7.9					5450	>
12	3S12	6	1.9-7.9	1.1-1.8	3.4-7.9	1.9-7.3	3.4-7.9				5450	>
13	2S23, 2S22, 3S13	7	1.9-13.7	1.1-13.7	1.1-13.7	1.1-13.7	1.1-13.7	1.1-13.7			5450	>
13	3S23	8	1.9-13.7	1.1-13.7	1.1-13.7	1.1-13.7	1.1-13.7	1.1-13.7	1.1-13.7		5450	>
13	Permit	9	1.9-13.7	1.1-13.7	1.1-13.7	1.1-13.7	1.1-13.7	1.1-13.7	1.1-13.7	1.1-13.7	5450	>
14	32	5	1.9-7	1.1-1.8	1.9-7.0	3.4-8.2					5450	>
15	Unclassified and Errors - Vehicles not meeting axle configurations set for Classifications 1 thru 14 and "error" vehicles											

7.3.1 “Knowledge of Site Characteristics” Review

For each WIM site, there is an initial stage of preparation that begins at the time of installation, referred to as the Knowledge of Site Characteristics, described by the flowchart in Figure 7.1. The physical and truck traffic characteristics of the WIM site are observed and recorded by the Caltrans site review person during installation, on-site calibration, and acceptance testing of the WIM equipment. This information is placed in a “site database” to be used during the validation and analysis of downloaded data to help explain any data abnormalities. The “site database” is updated as additional information is identified.

7.3.1.1 Purpose

The Knowledge of Site Characteristics is used to develop a “site database” which is used during the validation and analysis of downloaded data to help explain any data abnormalities.

7.3.1.2 Process 1

The success of the Caltrans QA technique is strongly founded upon a base of knowledge about the WIM site's characteristics. The physical and truck traffic characteristics noted during this review include the following:

1. Physical characteristics of a site
    a. Pavement condition and profile
    b. Grade
    c. Traffic flow restrictions
    d. Weather, including wind
2. Truck traffic characteristics of a site
    a. Empty vs. loaded trends
    b. Seasonal variations
    c. Enforcement effects
    d. Unique vehicles
    e. Traffic operating characteristics

7.3.1.3 Process 2

These characteristics are placed in a “site database” to be used during the data validation and analysis process. The “site database” helps in the development of a “site profile” which the reviewer can use to explain data abnormalities. While there are no pre-printed forms for the “site database,” it exists as a file of notes, log sheets and pictures to aid the reviewer.

7.3.1.4 Process 3

Throughout the life of a site the “site database” should be reviewed, updated, and expanded whenever atypical traffic or physical site characteristics become apparent.

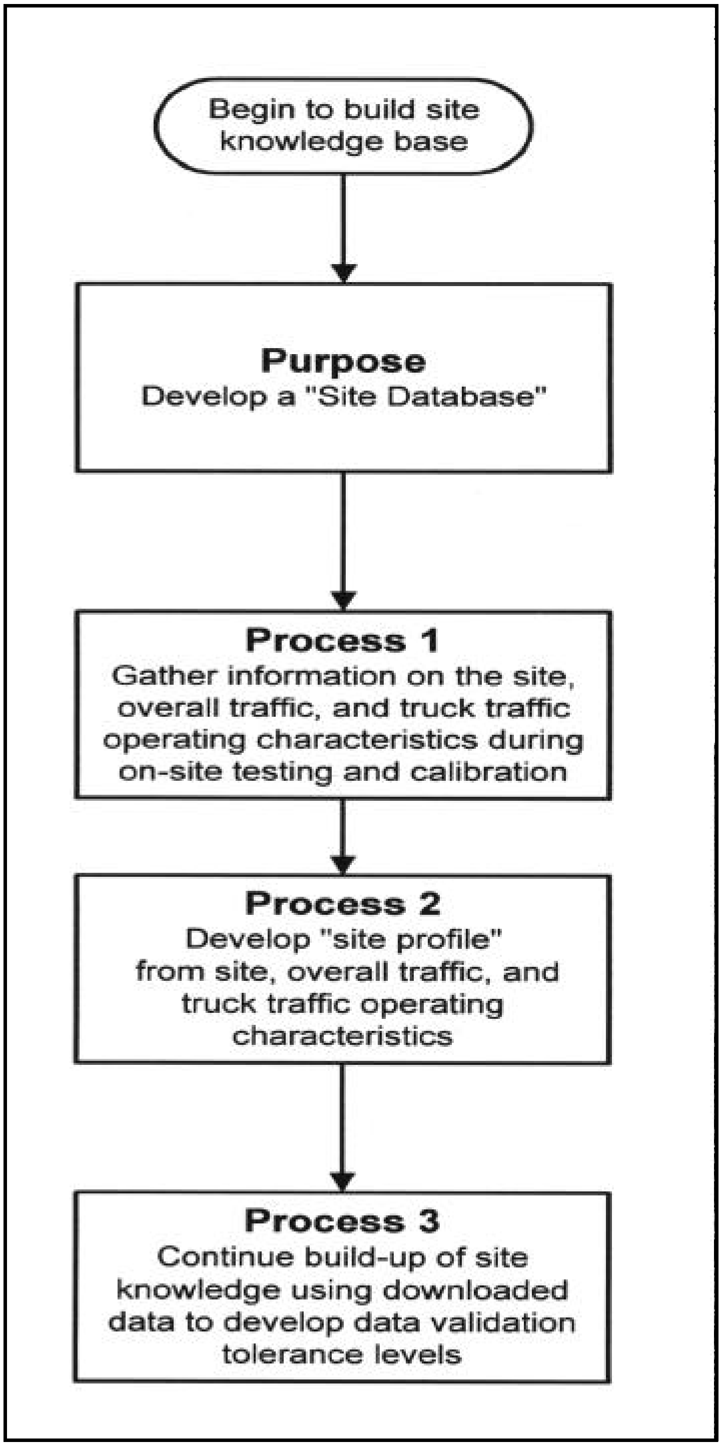


Figure 7.1 "Knowledge of Site Characteristics" Review Flowchart

7.3.2 "Real Time" Review

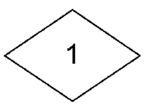
In addition to the two levels of data validation, Caltrans also accesses each site by modem and performs a quick spot check of each site's operation at least twice per month. This process is referred to as a "Real Time" Review and is shown in Figure 7.2. This "Real Time" Review is not actually a validation of data, but it can give an early indication of system problems and identify unusable data.

7.3.2.1 Purpose

The WIM system is monitored in "real time" via telemetry to get a "snapshot" of the site's performance condition indicators, at that time. This method is also used to review the status of data files accumulated since the last file download.

7.3.2.2 Step 1

The files stored at the site are checked first for proper time, date, and sizes; "real time" traffic is then monitored for proper axle spacing. An example of the data displayed in the "Real Time" review is shown in Figure 7.3. This figure was taken directly from one of Caltrans' WIM sites and therefore was not converted to metric. The file sizes vary greatly by site dependent upon traffic characteristics and the number of lanes.



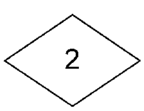
Determine if the time, date, or file sizes are incorrect.

7.3.2.3 Step 2

Check the data files' time and date stamps and sizes so to locate the day and time the site failed.

7.3.2.4 Step 3

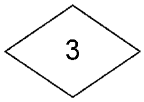
If necessary, correct the system's time and date.



Determine if the axle weights and spacings are correct.

7.3.2.5 Step 4

If the "real time" axle weights or spacings are found to be questionable, the system components (i.e.: loop signals, weigh pad signals, etc.) are checked. Problems with the system components may lead to actual physical repairs.



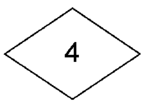
Determine if the system components are functioning properly.

7.3.2.6 Step 5

If the system components are not functioning properly, identify the equipment problem(s) and initiate corrective maintenance.

7.3.2.7 Step 6

If the "real time" axle weights or spacings are found to be questionable, the calibration parameters are also checked. A problem with calibration may lead to adjustments of the calibration parameters within the system software. These calibration parameters can be for axle weights, axle spacings, and vehicle overall length.



Determine if the calibration parameters are properly set.

7.3.2.8 Step 7

If the calibration parameters are not properly set, make the necessary adjustments.

7.3.2.9 Step 8

If any problem is found throughout the "Real Time" Review, the questionable data are identified for future analysis and appropriateness of use.

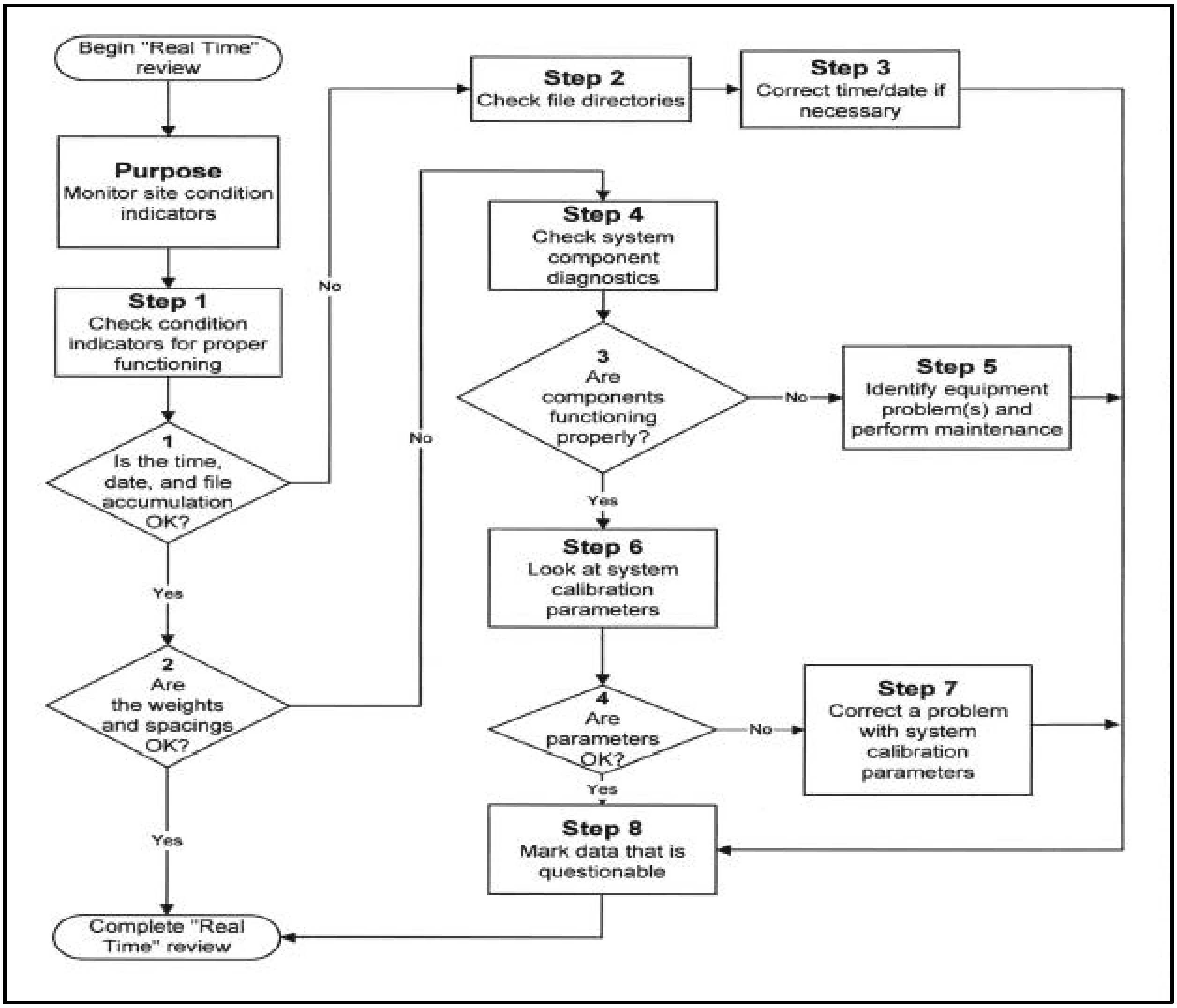


Figure 7.2 "Real Time" Review Flowchart

```
(1759) LANE SB#4  TYPE 15  GVW 4.5 kips  LENGTH 15 ft
18-K ESAL 0.000  SPEED 27 mph  MAX GVW 0.0 kips  Tue Oct 08 13:31:17.94 1996

      5.2
 o-----------o
2.1         2.4


(1762) LANE SB#3  TYPE 10  GVW 35.4 kips  LENGTH 70 ft
18-K ESAL 0.139  SPEED 54 mph  MAX GVW 80.0 kips  Tue Oct 08 13:31:18.10 1996

  4.1  4.2       28.0      4.2   16.2
 o----o----o---------------o----o---------o
3.4  5.0  3.4             6.8  6.9      9.9


(1764) LANE SB#3  TYPE 9  GVW 30.4 kips  LENGTH 39 ft
18-K ESAL 0.124  SPEED 55 mph  MAX GVW 80.0 kips  Tue Oct 08 13:31:19.48 1996

  4.1   12.7  4.3   12.8
 o----o------o----o-------o
4.9  3.5    6.3  5.9     9.8
```

Note: The axles are read from the right to the left, units are shown as they are in the field

Figure 7.3 "Real Time" Review Example

7.3.3 First Level Data Review - Summary Report

The procedure for the First Level Data Review - Summary is shown as a flowchart in Figure 7.4. In general, the first level is intended to identify any system equipment malfunctions, missing data, atypical traffic patterns, and atypical truck operating characteristics, by examining the reports shown in Figures 7.5 - 7.9. Included in the figures are examples of the results obtained from analyzing each report. The figures were obtained from Caltrans and were not converted to metric units. The information established for each site in the "site database" provides a foundation for this review.

Caltrans' First Level Data Review - Summary is accomplished by examining reports that are generated using the WIM vendor's application software. The contents and general format of these reports are in accordance with the Caltrans' specifications.

About 14 days of WIM data per month per site are downloaded to a host PC by modem. This is usually enough data to support planning and pavement design analysis, unless a special study or situation arises. The QA procedure is performed on at least seven days of data per month.

7.3.3.1 Purpose

The first process is to review information on the distribution of vehicle classifications by hour of day and the distribution of speeds by vehicle classification. This process is intended to identify:

1. The extent of loop or loop processing problems
2. Any erratic weighpad behavior causing "ghost axles" or missed axles

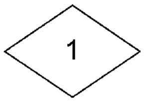
The second process is to review daily vehicle counts by hour of day by lane to identify any time periods in which the WIM system is not reporting data. This process also identifies the suspected causes of the lack of data. Both processes are done during this data review.

7.3.3.2 Process 1

Figure 7.5 is an example of the classification summary report. Specific counts that should be examined on this report are:

1. Class 1. Abnormally high Class 1 (motorcycle) counts are generally the result of erroneous low speeds and shortened axle spacings caused by loop errors.
2. Class 13. An obvious increase in Class 13 vehicles usually shows a problem of ghost axles being read by the weighpad.
3. Class 15. Unclassified vehicle counts greater than 0.5 percent are generally caused by loop errors.

Another explanation for an abnormally high Class 1 count would be if the loop drops out between the truck and the trailer, which might happen for logging trucks. This would cause the truck to be classified as a Class 5, three-axle truck and the trailer to be classified as a Class 1, motorcycle. One of the counts that should be examined that is not included in this example is the Class 8 counts. Class 8 counts may be abnormally high by missing or dropping one of the drive or trailor tandem axles. This can occur if the axle sensors do not stabilize in sufficient time to receive the second axle of a tandem.



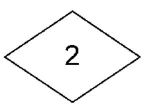
Determine if the counts for Class 1, Class 13, or Class 15 are too high.

7.3.3.2.1 Step 1

If any of the classification counts are questionable, they then should be checked on a lane-by-lane basis. An example of this report is shown in Figure 7.6. Studying this report may quickly associate any problems with a specific lane.

7.3.3.2.2 Step 2

The speed distribution report, shown in Figure 7.7, should be reviewed when the Class 1 or Class 15 counts are too high. High and low speed errors are usually caused by loop malfunctions, which can affect the axle spacing used to classify vehicles.



Determine if the high counts occur all day or sporadically.

A further review of the classification report for specific lanes can give insight to the source of problems that might cause bad data. If the errors are present sporadically, the problem is probably a poor splice or terminal connection that is affected by moisture or temperature. If the errors are present continuously throughout the day, the problem is probably a malfunctioning loop board or bad connection. In both instances the equipment needs to be visually inspected and repaired. Figure 7.8 is an example of sporadic error readings.

7.3.3.2.3 Step 3

If there appears to be a high Class 13 count, the WIM system may be reporting “ghost” axles. A weighpad diagnostic needs to be performed to determine if the weighpad is functioning properly.

7.3.3.3 Process 2

After the classification and speed summary reports are examined for unusual counts of specific classes, a review of the vehicle counts by lane, shown in Figure 7.9, is done. The vehicle counts report is used to reveal time periods in which the WIM system is not reporting data for a particular lane.

3 Determine if there are any times of the day when data are not recorded.

4 Determine if the data are missing from all lanes or from a single lane.

If the data are missing from all lanes it is probably due to a system failure such as a power outage. If the missing data are from a single lane it could be due to a lane closure for maintenance or a loop malfunction.

5 Determine if the vehicle counts in the adjacent lanes are higher than normal.

By looking at the lane distributions in the report, it can usually be determined if the lack of traffic data is simply due to traffic being shifted to an adjacent lane, as opposed to a system failure. If the vehicle counts in the adjacent lanes are higher than normal then the data are probably missing due to a lane closure for maintenance or construction. If the vehicle counts in the adjacent lanes are not higher, the missing data are probably due to a loop malfunction.

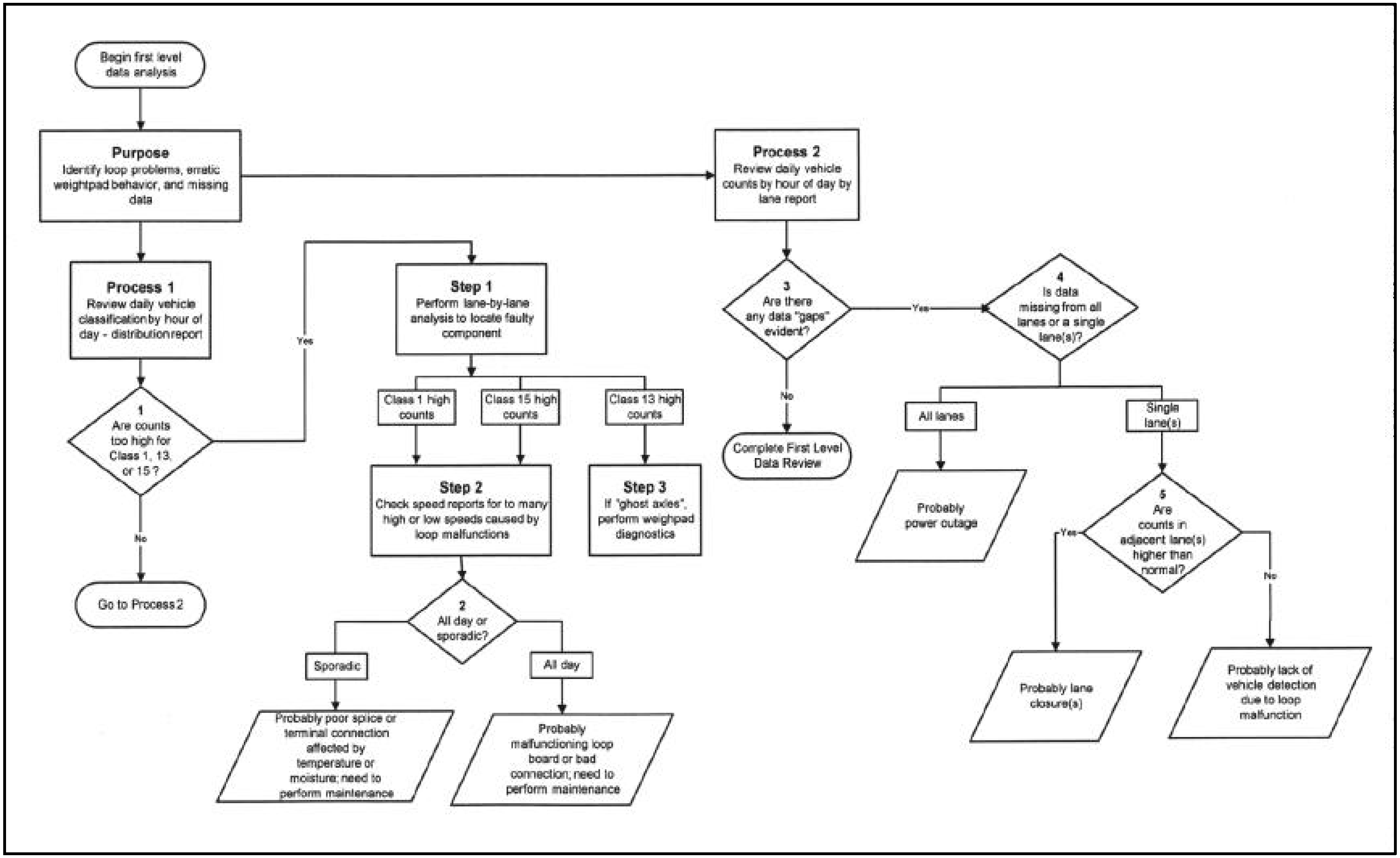


Figure 7.4 First Level Data Review - Summary Report Flowchart

Example Data Review:

- The percentage of Class 15 vehicles (1.0 percent) is too high (> 0.5%) for this site and indicates that one or more lanes are experiencing minor loop problems.

- The class 13 count is acceptable and indicates that there are no "ghost axle" problems.

- The Class 1 count is acceptable and indicates that loop problems are not "shortening" axle spacings

- The Class 15 hourly distribution indicates that the "error" vehicles are distributed throughout the day and, as such, are probably not due to changes in temperature or moisture.

Figure 7.5
Distribution of Vehicle Classification by Hour of Day

DISTRIBUTION OF VEHICLE CLASSIFICATIONS BY HOUR OF DAY

SITE NO : 001
DATE : 08/10/94

Location : LODI- 005. 43.7
County : SJ
State-ID : CA

LaneId : 1 2 3 4
Direction : N N S S

Report covers all lanes

HOURLY SUMMARY

VEHICLE COUNTS

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
0-1	0	300	33	3	11	1	0	6	121	5	82	5	0	1	6	577
1-2	0	181	36	1	10	1	0	16	91	1	81	6	0	1	3	428
2-3	0	144	18	1	6	0	0	7	97	0	71	3	0	2	1	350
3-4	0	125	22	0	9	0	0	14	106	3	69	3	0	2	5	364
4-5	0	320	71	0	21	3	0	19	128	3	75	4	1	2	4	651
5-6	1	640	170	1	36	2	0	23	159	2	83	6	0	5	7	1135
QTR TOTALS	0	1710	350	6	93	13	0	85	702	14	461	30	1	13	26	3506
6-7	0	1162	202	4	60	14	0	36	186	2	130	10	1	9	6	1882
7-8	0	1783	306	3	84	12	0	39	210	3	133	12	1	9	22	2617
8-9	0	1532	265	6	89	12	0	32	319	0	158	11	0	13	25	2368
9-10	0	1572	274	5	101	16	0	42	263	1	147	13	2	14	23	2473
10-11	0	1518	306	2	89	15	0	56	275	3	180	19	1	17	20	2501
11-12	0	1594	289	1	84	19	0	45	300	5	157	13	0	16	26	2549
QTR TOTALS	0	9161	1702	21	507	88	0	250	1453	14	901	78	5	78	122	14380
12-13	0	1525	300	0	74	14	0	37	307	8	174	7	0	14	34	2494
13-14	0	1626	314	1	95	17	0	68	330	4	173	12	2	11	39	2684
14-15	0	1681	313	1	95	17	0	39	317	7	165	10	0	19	38	2682
15-16	0	1995	390	0	104	13	0	65	289	5	140	9	2	8	34	3054
16-17	1	2074	399	3	109	17	0	44	296	6	151	2	0	17	37	3156
17-18	0	2161	319	0	84	13	0	46	265	7	123	12	1	15	26	3072
QTR TOTALS	1	11062	2035	5	561	91	0	291	1804	37	906	52	5	84	208	17142
18-19	0	1638	234	3	64	18	0	18	274	6	131	14	0	8	23	2431
19-20	0	1191	177	3	51	13	0	24	200	3	103	19	0	3	13	1802
20-21	0	936	152	3	27	8	0	24	207	4	117	5	0	4	17	1504
21-22	0	767	111	1	28	7	0	17	172	1	110	13	1	7	8	1241
22-23	0	665	96	2	17	4	0	16	158	2	125	12	0	0	6	1103
23-24	0	475	64	2	13	4	0	7	126	2	110	4	0	4	7	816
QTR TOTALS	0	5570	834	14	198	54	0	105	1137	18	696	67	1	36	76	8897

DAILY SUMMARY

VEHICLE COUNTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
TOTAL	2	27603	4921	46	1359	246	0	732	5096	83	2964	227	12	241	432	43924
PERCENT	0.0	62.8	11.2	0.1	3.1	0.6	0.0	1.7	11.6	0.2	6.7	0.5	0.0	0.5	1.0	100.0

No major loop problem

No "ghost axle" problems

A little high for this site

Example Data Review:

- The circled numbers indicate that almost half of the Class 15 "errors" are in lane 1, whereas almost all of the speed "errors" are in lanes 2 and 3.

DISTRIBUTION OF CLASSIFICATION AND SPEED COUNTS BY LANE

SITE NO : 001
DATE : 08/10/94

Location : 10DI - 005. 43.7
County : SJ
State ID : CA

Lane(s) : 1 2 3 4
Direction : N N S S

LANE NUMBER

	1		2		3		4		5		6		ALL LANES	
	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%
CLASS														
1	0	0.0	0	0.0	2	0.0	0	0.0	0	0.0	0	0.0	2	0.0
2	5592	47.3	8464	79.4	8196	81.8	5351	46.9	0	0	0	0	27603	62.8
3	1141	9.6	1419	13.3	1119	11.2	1242	10.9	0	0	0	0	4921	11.2
4	12	0.1	8	0.1	6	0.1	20	0.2	0	0.0	0	0.0	46	0.1
5	472	4.0	184	1.7	174	1.7	529	4.6	0	0.0	0	0.0	1359	3.1
6	103	0.9	17	0.2	14	0.1	112	1.0	0	0.0	0	0.0	246	0.6
7	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
8	343	2.9	34	0.3	35	0.3	320	2.8	0	0.0	0	0.0	732	1.7
9	2400	20.3	273	2.6	245	2.4	2178	19.1	0	0.0	0	0.0	5096	11.6
10	45	0.4	5	0.0	2	0.0	31	0.3	0	0.0	0	0.0	83	0.2
11	1306	11.0	157	1.5	127	1.3	1374	12.0	0	0.0	0	0.0	2964	6.7
12	117	1.0	9	0.1	11	0.1	90	0.8	0	0.0	0	0.0	227	0.5
13	6	0.1	0	0.0	1	0.0	5	0.0	0	0.0	0	0.0	12	0.0
14	~~93~~	~~0.8~~	17	0.2	10	0.1	81	0.7	0	0.0	0	0.0	~~201~~	~~0.5~~
15	198	1.7	68	0.6	78	0.8	88	0.8	0	0.0	0	0.0	432	1.0
TOTAL	11828	100.0	10655	100.0	10020	100.0	11421	100.0	0	100.0	0	100.0	43924	100.0
SPEED (MPH)														
1-5	0	0.0	0	0.0	5	0.0	0	0.0	0	0.0	0	0.0	5	0.0
6-10	0	0.0	0	0.0	3	0.0	0	0.0	0	0.0	0	0.0	3	0.0
11-15	0	0.0	0	0.0	1	0.0	0	0.0	0	0.0	0	0.0	1	0.0
16-20	0	0.0	0	0.0	3	0.0	0	0.0	0	0.0	0	0.0	3	0.0
21-25	0	0.0	0	0.0	1	0.0	0	0.0	0	0.0	0	0.0	1	0.0
26-30	1	0.0	0	0.0	1	0.0	0	0.0	0	0.0	0	0.0	2	0.0
31-35	3	0.0	0	0.0	1	0.0	0	0.0	0	0.0	0	0.0	4	0.0
36-40	3	0.0	4	0.0	1	0.0	1	0.0	0	0.0	0	0.0	9	0.0
41-45	29	0.2	6	0.1	0	0.0	15	0.1	0	0.0	0	0.0	50	0.1
46-50	188	1.6	6	0.1	6	0.1	143	1.3	0	0.0	0	0.0	343	0.8
51-55	1741	14.7	53	0.5	83	0.9	1508	13.2	0	0.0	0	0.0	3391	7.7
56-60	5239	44.3	980	9.2	778	7.8	3598	31.5	0	0.0	0	0.0	10595	24.1
61-65	3407	28.8	2248	21.1	3939	39.3	4025	35.2	0	0.0	0	0.0	13619	31.0
66-70	895	7.6	5382	50.5	3394	33.9	1836	16.1	0	0.0	0	0.0	11507	26.2
71-75	250	2.1	1503	14.1	1363	13.6	225	2.0	0	0.0	0	0.0	3341	7.6
76-80	45	0.4	286	2.7	256	2.6	52	0.5	0	0.0	0	0.0	639	1.5
81-85	11	0.1	44	0.4	50	0.5	7	0.1	0	0.0	0	0.0	112	0.3
86-90	2	0.0	39	0.4	14	0.1	4	0.0	0	0.0	0	0.0	59	0.1
91-95	2	0.0	~~8~~	~~0.1~~	~~8~~	~~0.1~~	0	0.0	0	0.0	0	0.0	~~18~~	~~0.0~~
96-100	~~1~~	~~0.0~~	11	0.1	15	0.1	~~1~~	~~0.0~~	0	0.0	0	0.0	28	0.1
> 100	11	0.1	85	0.8	92	0.9	6	0.1	0	0.0	0	0.0	194	0.4
TOTAL	11828	100.0	10655	100.0	10020	100.0	11421	100.0	0	100.0	0	100.0	43924	100.0
AVG SPEED	59		67		66		63		0		0		63	

Figure 7.6
Distribution of Classification and Speed Counts by Lane

Example Data Review:

- The table represents all lanes.

- The speed distribution pattern in this report makes it apparent that most of the vehicles exceeding 95 MPH are "error" vehicles. Less than half of these errors, however, have resulted in axle spacings such that the vehicles are "unclassified."

Figure 7.7
Distribution of Speed by Vehicle Classification

DISTRIBUTION OF SPEED BY VEHICLE CLASSIFICATION

SITE NO : 001 Location : LODI - 005. 43.7 [illegible] : 1 2 3 4
DATE : [illegible] County : SJ State-ID : CA Direction : N N S S

VEHICLE COUNTS

SPEED (MpH)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
1-5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5
6-10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	3
11-15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16-20	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	3
21-25	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
26-30	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
31-35	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2	4
36-40	0	6	0	0	0	0	0	0	2	0	1	0	0	0	0	9
41-45	0	17	8	0	9	2	0	1	2	0	8	0	0	0	3	50
46-50	0	82	37	0	41	7	0	10	50	0	90	2	1	2	21	343
51-55	0	723	248	0	182	53	0	172	1076	21	713	70	6	36	91	3391
56-60	0	3837	880	6	473	108	0	377	2877	59	1610	114	3	136	135	10595
61-65	0	9888	1652	26	437	67	0	153	971	3	497	39	2	34	50	13819
66-70	0	9628	1487	14	171	7	0	17	113	0	48	1	0	3	21	11507
71-75	0	2828	458	0	39	2	0	2	3	0	0	1	0	0	6	3341
76-80	0	539	92	0	5	0	0	0	0	0	0	0	0	0	3	639
81-85	0	91	19	0	0	0	0	0	0	0	0	0	0	0	2	112
86-90	0	36	18	0	0	0	0	0	0	0	0	0		0	5	59
91-95	0	[illegible]	[illegible]	0	1	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]
96-100	0	11	10	0	0	0	0	0	0	0	0	0	0	0	7	28
>100	0	104	7	0	0	0	0	0	0	0	0	0	0	0	83	194
TOTALS	2	27603	4921	46	1359	246	0	752	5096	83	2964	227	12	201	432	43924
AVG. SPEED	13	65	65	64	60	58	0	58	58	57	57	57	56	58	67	63

DAILY SPEED SUMMARY

TOTAL VEHICLES	43924	TOTAL VEHICLES > 55 Mph —	3112	% OF VEHICLES > 55 Mph —	91.3
AVERAGE SPEED	63.4	TOTAL VEHICLES > 60 Mph —	3517	% OF VEHICLES > 60 Mph —	67.2
MEDIAN SPEED	63.0	TOTAL VEHICLES > 65 Mph —	5898	% OF VEHICLES > 65 Mph —	36.2
85th PERCENTILE	68.0	TOTAL VEHICLES > 70 Mph —	1391	% OF VEHICLES > 70 Mph —	10.0

Circled vehicles are, for the most part, "error" vehicles.

Example Data Review:

- This report is the same as the report in Figure 7.5, but only for lane 1.

- By reviewing report, it is apparent that between the hours 1500 and 1700 either a loop or the processing of loop inputs was malfunctioning. Since counts for all the classifications are erroneous for this time period, the data for this lane would be usable only for vehicle counts purposes.

Figure 7.8
Distribution of Vehicle Classifications
By Hour of Day

DISTRIBUTION OF VEHICLE CLASSIFICATIONS BY HOUR OF DAY

SITE NO : 001
DATE : 01101892

Location : LODI - 005 43.7
County : SJ
State ID : CA

Lane(s) : 1
Direction : N

Lane 1 only

HOURLY SUMMARY — VEHICLE COUNTS

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
0-1	0	81	11	0	3	2	0	0	14	1	7	2	0	0	0	121
1-2	0	87	8	0	1	0	0	3	9	0	8	2	0	0	0	118
2-3	0	61	11	0	1	0	0	1	4	0	6	0	0	0	2	86
3-4	0	29	2	1	2	0	0	0	8	0	5	2	0	0	0	49
4-5	0	46	4	0	0	1	0	0	15	0	2	0	0	0	0	68
5-6	0	66	8	0	2	0	0	0	7	1	8	2	0	3	1	98
QTR TOTALS	0	370	44	1	9	3	0	4	57	2	36	8	0	3	3	540
6-7	0	87	19	1	2	0	0	1	12	0	5	4	0	0	0	131
7-8	0	99	18	1	4	4	0	1	25	0	5	4	0	0	0	161
8-9	0	129	17	0	5	4	0	3	16	1	2	0	0	0	4	181
9-10	0	218	28	1	3	2	0	4	32	0	1	5	0	0	4	298
10-11	0	294	46	0	5	3	0	1	25	0	4	0	0	2	3	383
11-12	0	368	36	1	8	2	0	6	33	0	3	4	0	2	1	464
QTR TOTALS	0	1196	164	4	27	15	0	16	143	1	20	17	0	4	12	1618
12-13	0	441	49	0	10	1	0	8	28	1	3	3	0	1	3	546
13-14	0	400	46	0	6	0	0	11	37	1	2	1	0	1	8	513
14-15	0	469	55	0	9	1	0	8	16	1	1	0	0	0	10	570
15-16	97	309	22	0	10	0	0	3	9	1	3	1	0	0	182	637
16-17	136	167	1	0	0	0	0	0	0	0	0	0	0	0	373	677
17-18	2	465	53	1	15	0	0	7	16	0	5	0	0	0	13	577
QTR TOTALS	235	2251	226	1	50	2	0	37	104	4	14	5	0	2	589	3520
18-19	0	373	48	0	7	3	0	6	22	0	2	1	0	0	3	465
19-20	0	368	46	0	10	0	0	1	15	0	5	1	0	0	1	447
20-21	0	338	35	0	11	3	0	3	15	0	1	0	0	0	1	407
21-22	0	251	24	0	8	0	0	2	18	0	1	0	0	0	1	305
22-23	0	191	15	0	2	0	0	2	21	0	7	0	0	0	1	239
23-24	0	150	9	0	4	2	0	1	15	0	8	1	0	0	0	190
QTR TOTALS	0	1671	177	0	42	8	0	15	106	0	24	3	0	0	7	2053

DAILY SUMMARY — VEHICLE COUNTS

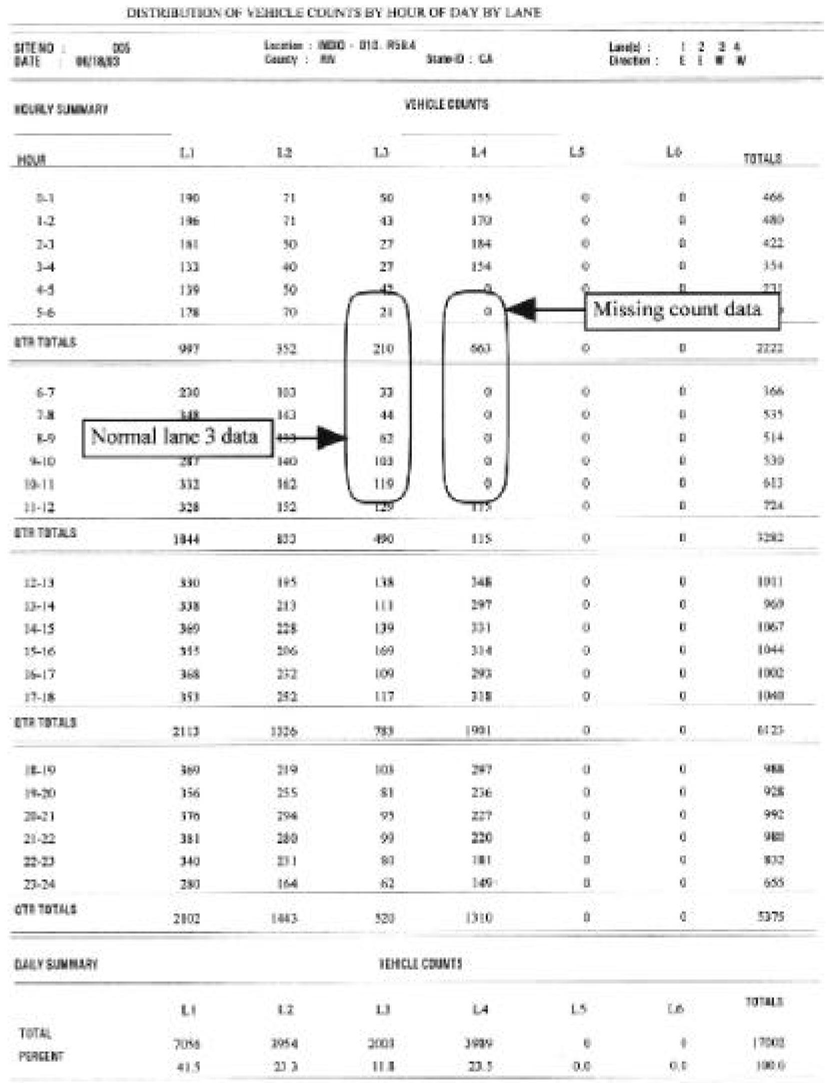
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
TOTAL	235	5847	611	6	128	28	0	72	410	7	94	33	0	9	611	7731
PERCENT	3.0	71.0	7.9	0.1	1.7	0.4	0.0	0.9	5.3	0.1	1.2	0.4	0.0	0.1	7.9	100.0

1500 - 1700 major loop problem!

Example Data Review:

- Data is missing from Lane 4: all other lanes appear to have normal data.

- In reviewing the Lane 3 and Lane 4 distibutions it is apparent that the "0" counts in Lane 4 are not due to traffic shifts to Lane 3. Therefore, the lack of data could be due to a loop malfunction.



DISTRIBUTION OF VEHICLE COUNTS BY HOUR OF DAY BY LANE

SITE NO : 005
DATE : 06/18/03

Location : INDIO - 010 - R58.4
County : RIV
State-ID : CA

Lane(s) : 1 2 3 4
Direction : E E W W

HOURLY SUMMARY — VEHICLE COUNTS

HOUR	L1	L2	L3	L4	L5	L6	TOTALS
0-1	190	71	50	155	0	0	466
1-2	186	71	43	170	0	0	480
2-3	161	50	27	184	0	0	422
3-4	133	40	27	154	0	0	354
4-5	139	50	42	0	0	0	231
5-6	178	70	21	0	0	0	[illegible]
QTR TOTALS	997	352	210	663	0	0	2222
6-7	230	103	33	0	0	0	366
7-8	348	143	44	0	0	0	535
8-9	[illegible]	333	62	0	0	0	514
9-10	287	140	103	0	0	0	530
10-11	332	162	119	0	0	0	613
11-12	328	152	129	115	0	0	724
QTR TOTALS	1844	833	490	115	0	0	3282
12-13	330	195	138	348	0	0	1011
13-14	338	213	111	297	0	0	969
14-15	369	228	139	331	0	0	1067
15-16	355	206	169	314	0	0	1044
16-17	368	232	109	293	0	0	1002
17-18	353	252	117	318	0	0	1040
QTR TOTALS	2113	1326	783	1901	0	0	6123
18-19	369	219	103	297	0	0	988
19-20	356	255	81	236	0	0	928
20-21	376	294	95	227	0	0	992
21-22	381	280	99	220	0	0	980
22-23	340	231	80	181	0	0	832
23-24	280	164	62	149	0	0	655
QTR TOTALS	2102	1443	520	1310	0	0	5375

DAILY SUMMARY — VEHICLE COUNTS

	L1	L2	L3	L4	L5	L6	TOTALS
TOTAL	7056	3954	2003	3989	0	0	17002
PERCENT	41.5	23.3	11.8	23.5	0.0	0.0	100.0

Figure 7.9
Distribution of Vehicle Counts by Hour of Day by Lane

7.3.4 First Level Data Review - Individual Truck Report

The procedure for the First Level Data Review - Individual Truck Report is shown in Figure 7.10. In general, this procedure is intended to identify any system equipment malfunctions, missing data, atypical traffic patterns, or atypical truck operating characteristics by examining the reports shown in Figure 7.11 and 7.12. Included in the figures are examples of the results obtained from analyzing each report. The information established for each site in the “site database” provides a foundation for this review.

7.3.4.1 Purpose

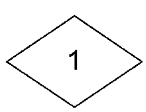
The next data review is conducted on the distribution of weight violations and invalid measurements report, displayed in Figure 7.11. This report covers truck information for all lanes. The truck record data should also be checked on a lane-by-lane basis, as displayed in Figure 7.12. The review of these reports is intended to identify:

1. Any classification problems due to a loop or loop processing malfunction
2. A bad weighpad
3. Any obvious calibration problem
4. Truck operation patterns

Any vehicle with a steering axle exceeding 3500 pounds (Classes 4-15) is included in these individual vehicle records.

7.3.4.2 Process

The First Level Data Review - Individual Truck Reports is completed by reviewing the distribution of weight violations and invalid measurements report (Figure 7.11) and the distribution of truck data by lane report (Figure 7.12). In general, these “truck” reports should be studied for a high number of unclassified (Class 15) counts, invalid measurement counts, and percent of overweight vehicles.



Determine if a high number of Class 15 counts are recorded.

For most California WIM sites, an unclassified count not exceeding four percent is acceptable. It is important to note that the unclassified count will generally increase on weekends when many of the more “typical” trucks, conforming to the Vehicle Classification Table in Table 7.2, are not running and a higher number of recreational vehicles (“Heavy” Class 3) are on the road.

2

Determine if there is a high number of invalid measurements.

When the difference between the left and right wheel weights of an axle exceed 40 percent, the measurement for that vehicle is classified as invalid. An imbalance that large may be caused by the following:

1. A truck changing lanes or not driving in the middle of the lane
2. Bouncing, usually by empty trailers
3. Empty van trailers in heavy cross winds
4. An extremely bad weighpad calibration factor
5. A malfunctioning weighpad

3

Determine if the truck traffic characteristics from the “site database” explains the high number of invalid counts.

Caltrans has performed extensive data analyses to determine at which WIM sites bouncing and cross winds cause a high percentage of invalid measurements and to what extent the two factors affect the invalid measurements. Once again the “site database” is useful in determining the cause for the invalid measurements. Caltrans also requires that the WIM on-site software be programmable from the host PC to modify the algorithm that determines invalid measurements. If the extent of invalid measurements is still suspicious after reviewing the site characteristics, a check should be made on the weighpad calibration parameters and, if necessary, the weighpads.

4

Determine if there is a high percentage of overweight vehicles.

The percent of overweight vehicles may be used as a check of system calibration. However, the percentage of overweights can vary greatly, depending upon the WIM site, the time of year, and the truck traffic characteristics. If the “site database” does not explain the high percentage of overweight trucks a check should be made of the weighpad calibration parameters. Also, the actual percentage of overweight trucks, if the trucks were weighed statically, may be approximately half the WIM-reported overweights. Some reasons for this are as follows:

1. Many trucks travel very close to their maximum legal weight; the slightest overage read of the static weight by the WIM system will result in a violation count.
2. Although a well-calibrated WIM system may produce good average gross weights, plus or minus three percent of the actual average gross weight, a violation count due to a slightly high reading will be recorded.

3. There is generally some weight transfer from the steer axle to the drive axle for most of the heavier trucks, particularly if there is any uphill grade, which could be recorded as a violation due to heavier drive axles.
4. The weight violation look-up tables do not account for certain exceptions, particularly for the steering axle.

It is important to review the total counts and distributions by class shown in the weight violations and invalid measurements report (Figure 7.11). Doing so will provide additional information about the site characteristics, specifically seasonal variations in truck traffic due to agricultural and industrial shipping.

As the analyses of the reports covered under the First Level Data Review - Summary Report (Figures 7.5 - 7.9) and - Individual Truck Report (Figures 7.11 - 7.12) are performed, certain key elements are entered into log sheets along with any annotations deemed necessary. Figure 7.13 is an example of a log sheet prepared during the analysis of the classification and speed summary reports (Figure 7.6). These log sheets serve three basic purposes:

1. They show what data are available and what data have been validated.
2. They show any exceptions to otherwise "valid" data and show any warnings, if appropriate, as to the use of the data for general or specific use.
3. They track trends of site characteristics which may be added to the “site database.” Therefore, the trends may be checked quickly by the reviewer for comparison reasons in future data analysis.

When data are requested, the logs may be used as “guides” for determining whether or not available data are suitable for the intended use. Since data from a particular lane may be questionable or invalid, the log sheets are used to quickly determine what data can be used from that WIM site. Since a portion of the questionable or invalid records may still be used in research, Caltrans rarely discards WIM data.

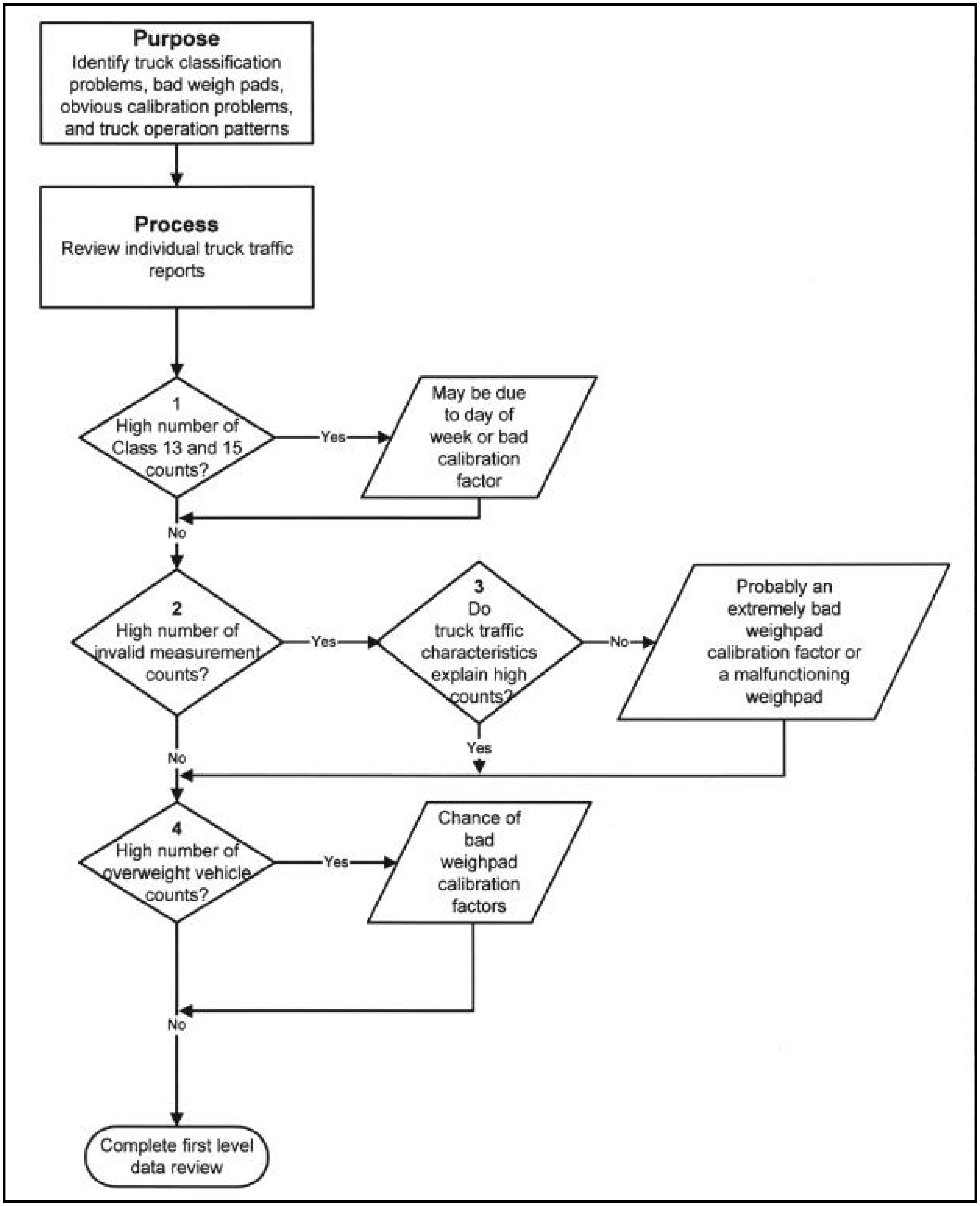


Figure 7.10 First Level Data Review - Individual Truck Report Flowchart

Example Data Review:

- This review is for all lanes.

- Considering that this is "truck" only data, the 2.3 percent unclassifieds is below the allowable 4.0 percent and indicates that there is no major problem with classification.

- The eight data errors for speed (out of range errors) is below the allowable 0.1 percent and indicates that there are no major loop problems.

- The 4.0 percent of "invalid measurement" trucks is acceptable for an overall review (4.0 percent is the maximum).

- This report shows almost 3000 Class 11's, which is twice the average for this site. These additional trucks are seasonal tomato haulers.

- By understanding the way overweight vehicles are recorded, the percent vehicles overweight in this report is considered high and the calibration parameters should be reviewed.

- Since the operating characteristics of the seasonal tomato haulers are well known, these trucks are used to check the WIM systems calibration.

DISTRIBUTION OF WEIGHT VIOLATIONS AND INVALID MEASUREMENTS FOR VEHICLE CLASSES 4-15

SITE NO : 001 Location : LODI 005. 43.7 Lane(s) : 1 2 3 4
DATE : 08/10/94 County : SJ State ID : CA Direction : N N S S

CLASSIFICATION	TOTAL VEHICLES COUNTED	VEHICLES WITH INVALID MEASURE	TOTAL VEHICLES WEIGHED	TOTAL VEHICLES OVERWT.	PERCENT VEHICLES OVERWT.	****** NUMBER OF WEIGHT VIOLATIONS ****** AXLE	TANDEM	GROSS	BRIDGE
4	46	1	45	11	24	11	0	0	0
5	1146	42				25	0	0	0
6	240	22				30	12	0	12
7	0	0	0	0	0	0	0	0	0
8	698	28	670	21	3	19	2	0	3
9	5095	204	4891	1522	31	365	1326	747	1374
10	86	3	80	32	40	3	29	21	28
11	2963					451	0	434	461
12	226					5	0	13	13
13	12					1	1	1	1
14	201	8	158	78	39	44	41	53	64
15	255	33	222	20	9	8	12	5	14
TOTALS	16971	442	10529	2378	23	962	1423	1274	1970

Probably exceptions

Approximately half are seasonal tomato haulers

Very high, questionable

NUMBER OF VEHICLES WITH DATA ERRORS : 9
SPEED : 8 WEIGHT : 1

"out of range" errors

PERCENT VEHICLES NOT CLASSIFIED (CLASS 15) : 2.3

PERCENT VEHICLES WITH INVALID MEASUREMENTS : 4.0

Acceptable

Figure 7.11
Distribution of Weight Violations and Invalid Measurements for Vehicle Classes 4-15

Example Data Review:

- In that only a small percentage of trucks use the inside ("fast") lanes at this site (Lanes 2 and 3 on this report), the malfunctioning loop or weighpad from one of these lanes might not be evident in reviewing the "combined lanes" report shown in the Figure 7.11.

- It is noted that the invalid percentages for Lanes 2 and 3 are quite high, but these higher percentages are common for the "fast" lanes due to trucks crossing the lane lines to pass.

DISTRIBUTION OF TRUCK RECORD DATA BY LANE

SITE NO : 001
DATE : 08/10/94

Location : LODI - 005. 43.7
County : SJ
State ID : CA

Lane(s) : 1 2 3 4
Direction : N N S S

LANE NUMBER

CLASS	L 1		L 2		L 3		L 4		L 5		L 6		ALL LANES	
	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%
1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2	5	0.1	7	0.8	11	1.5	20	0.4	0	0	0	0	43	0.4
3	130	2.6	124	15	91	12.6	165	3.4	0	0	0	0	510	4.4
4	12	0.2	8	1.0	6	0.8	20	0.4	0	0.0	0	0.0	46	0.4
5	407	8	150.0	18.2	144	20.0	445	9.1	0	0.0	0	0.0	1146	9.9
6	101	2.0	17	2.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0.0	246	2.1
7	0	0.0	0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0.0	0	0.0
8	328	6.4	33	4.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0.0	698	6.1
9	2400	47.1	272	33.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0.0	5095	44.2
10	45	0.9	5	0.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0.0	83	0.7
11	1305	25.6	157	19.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0.0	2963	25.7
12	117	2.3	9	1.1	10	1.4	90	1.8	0	0.0	0	0.0	226	2.0
13	6	0.1	0	0.0	1	0.1	5	0.1	0	0.0	0	0.0	12	0.1
14	93	1.8	17	2.1	10	1.4	81	1.7	0	0.0	0	0.0	201	1.7
15	142	2.8	25	3.0	25	3.5	63	1.3	0	0.0	0	0.0	255	2.2
TOTAL	5093	100.0	824	100.0	720	100.0	4887	100.0	0	0.0	[illegible]	[illegible]	[illegible]524	100.0

Vehicles with steer axles exceeding 3,500 lbs. with short wheelbases not meeting Class 4 thru 14 criteria.

Acceptable

LANE NUMBER

CLASS	L 1		L2		L 3		L4		L5		L 6		ALL LANES	
	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%
LEGAL	3804	74.7	660	80.1	484	67.2	3751	76.8	0	0.0	0	0.0	8699	75.5
OVERWT	1077	21.1	93	[illegible]	183	[illegible]	1025	21.0	0	0.0	0	0.0	2378	20.6
INVALID	212	4.2	71	8.6	53	7.4	111	2.3	0	0.0	0	0.0	447	3.9
TOTAL	5093	44.2	824	[illegible]	720	[illegible]	4887	42.4	0	0.0	0	0.0	11524	100.0

Typically higher percentage for "inside" lanes acceptable

Figure 7.12
Distribution of Truck Record Data by Lane

Quinley

WIM MONTHLY SUMMARY SHEET　　MONTH APRIL　　YEAR '93

SITE NO. 10　　SITE NAME FRESNO

DATE	DAY	HOURLY PERIODS	NO. VEHICLES	NO. CL. 2	SPEED CHECK	NO. CL. 15	% 15	NOTES
1	TH							
2	FR							
3	SA	24						
4	SU							
5	MO							
DST 6	TU	-1						
7	WE				SPD			
8	TH		59 317	39 973	0.5%	436	0.7	
9	FR	24						
10	SA							
11	SU							
12	MO							
13	TU	11 4/21	LANE 1		1.3%	CL 15		
14	WE		LANE 6		2.5%	CL 15		1200-1400
15	TH		✓ 6		1.2%	< 5 MPH		–
16	FR		✓ 6		1.6%	< 30		–
17	SA				SPD			
18	SU	24	43 768	33 913	0.3%	193	0.4	
19	MO		54 766	36 727	0.5%	401	0.7	
20	TU		54 490	36 175	0.5%	408	0.7	
21	WE		53 720	35 335	0.7%	628	1.2	1200-1400 11
22	TH		55 349	36 613	0.5%	468	0.8	LANE 6: [illegible]
23	FR		62 092	42 869	0.4%	413	0.7	
24	SA	24	42 521	32 135	0.4%	257	0.6	
25	SU							
26	MO							
27	TU							
28	WE							
29	TH							
30	FR							
~~31~~								

LANES 1 & 6 SOME LOOP PROBLEMS

Figure 7.13 Sample Log Sheet

7.3.5 Second Level Data Review

Typically, the Second Level Data Review, shown in Figure 7.14, is performed on one day's accumulation of individual vehicle records data per month per WIM system. If such review causes calibration parameter changes, an immediate follow-up review is normally performed to verify the results of such changes.

The Second Level Data Review reports, shown in Figures 7.15 - 7.18, are generated using the Caltrans WIM System Analysis program. The figures were obtained from Caltrans and were not converted to metric units. This program, written in the C++ programming language, was developed after several years of importing vehicle record data into a database program. This information was then analyzed to determine the relationships between Class 9 and Class 11 trucks as well as the relationships between speed and weight based upon observation at the WIM sites. The program can also provide statistical information on California's Class 14 vehicles.

7.3.5.1 Purpose

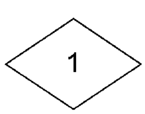
The Second Level Data Review is conducted to determine if adjustments are needed in the calibration parameters for the weighpads or the loops. This review may also disclose or lead to the disclosure of equipment idiosyncrasies or malfunctions not noted in the First Level Data Review.

7.3.5.2 Process 1

The review of the distribution of gross weight by lane report, shown in Figures 7.15 and 7.16, allows the analyst to evaluate gross weight relationships. Although the WIM vendor's application software is required to generate gross weight distribution reports, the Caltrans program displays the distributions for each lane in a single report and displays additional statistical data.

The usefulness of this report in analyzing whether or not a WIM system is properly calibrated for weight is dependent upon several site and truck characteristic factors, including:

1. How well the empty and loaded truck weight groups are distributed
2. How consistently the system reports accurate static weight predictions for different types of vehicles
3. The proportionality of the WIM weight accuracies in the lower and higher weight ranges



Determine if the empty and loaded truck weights are properly distributed.

2 If not, determine if the truck traffic characteristics explain the atypical data.

If the truck traffic characteristics do not explain the atypical data there is probably a problem with a calibration parameter.

7.3.5.3 Process 2

The weight and axle spacings by speed report, Figure 7.17 and 7.18, provides various data and relationships for weight, speed, axle spacings, and vehicle lengths for each lane.

3 Determine if the Class 9 average tractor tandem axle spacings and the Class 11 average vehicle lengths are accurate.

Checking the accuracy of axle spacings and overall vehicle lengths gives an indication of problems with the calibration parameters for speed and spacing. Caltrans has determined that the Class 9 tractor tandem axle space should average 1.3 meters (4.3 feet) and the average length for a Class 11 vehicle should be approximately 1.5 meters (5 feet) longer than the average wheelbase.

4 Determine if the left and right average steer axles weights balance for Class 9 and 11 vehicles.

When the report shows different values for the weights reported by the left and right weighpads of each lane, it is an indication of a malfunctioning weighpad or the need to adjust the calibration factor for one or both of the weighpads. The average left and right steer axle weights should be the same.

5 Determine if the weights over different speeds are consistent.

In reviewing the distribution of average weights by speed, the average gross weights should be consistent for different speed ranges, provided there is a large number of samples and all trucks are able to operate at a “cruising” speed. Any significant differences in the average gross weight through different speed ranges would indicate that the calibration parameters may need adjustment for certain speed ranges. A review of the most recent test truck calibration documentation on speed versus weight might be helpful in analyzing the speed versus weight report.

Certain key elements and comments of the Second Level Data Review process are entered onto a log sheet. A log sheet is a valuable tool in several respects, including:

1. Identifying the effects of calibration parameter changes on the WIM data for weight, axle spacings, and vehicle length
2. Establishing weight trends over a long period of time, including seasonal variations; by collecting site-to-site comparisons the analyst can determine whether any seasonal variations are due to differences in truck operating characteristics (such as hauling heavy produce in the summer) or to the effect of temperature on the weighpads' reporting weight
3. Determining whether or not WIM weights "drift" over a period of time
4. Monitoring any changes in axle spacings or vehicle lengths which may indicate problems with loops.

The log information is added to the "site database," so that the information may be reviewed at a future time.

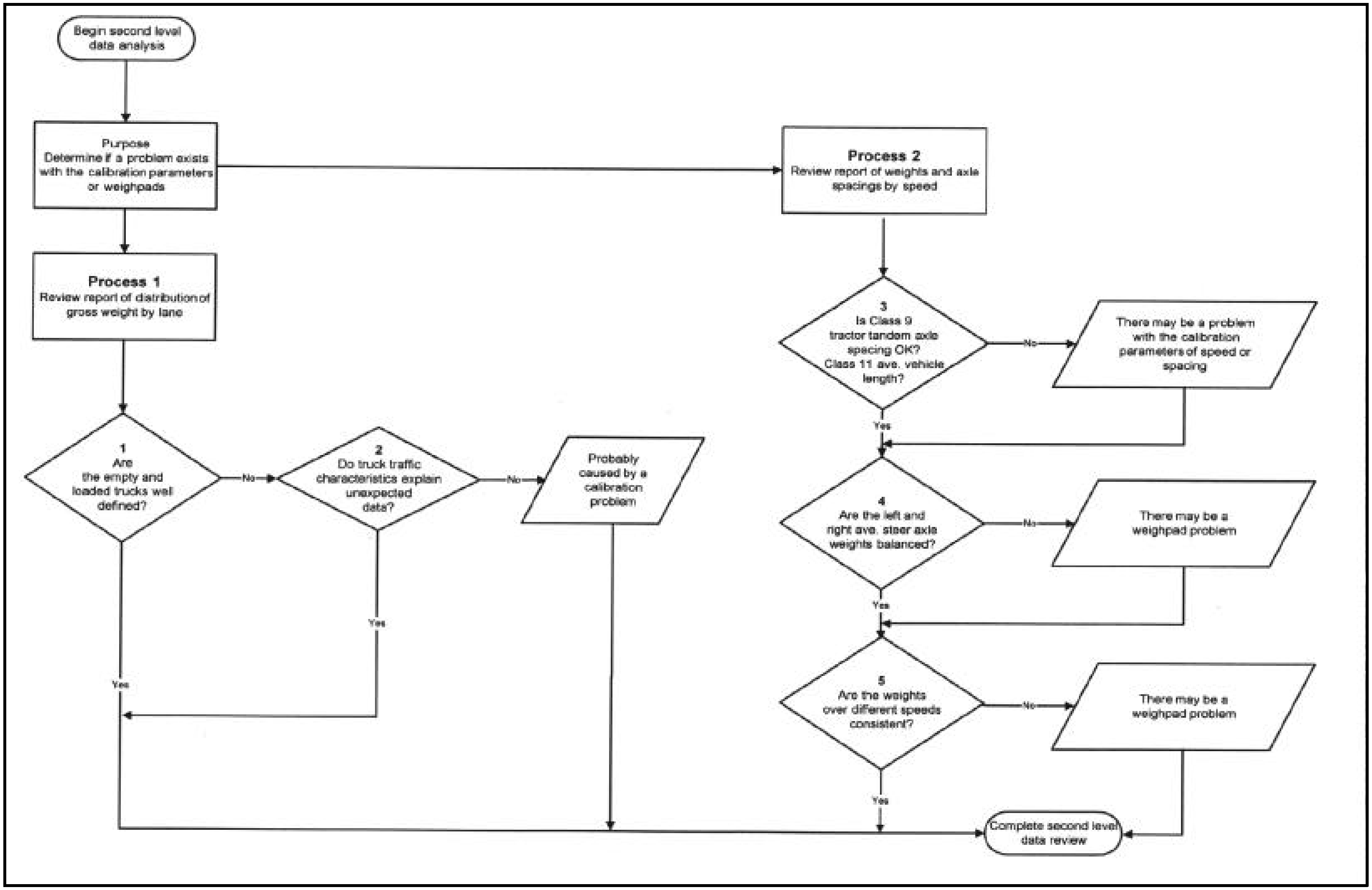


Figure 7.14 Second Level Data Review Flowchart

Example Data Review:

- A review of this report allows an analyst to evaluate empty and loaded gross weight relationships.

- This report has well defined empty and loaded distributions for both Class 9 and Class 11 trucks in both truck lanes (1 and 4).

- Many of the Class 11's in this report are seasonal tomato trucks which travel empty (26,000 lbs. + or -) in Lanes 1 and 2 and fully loaded in Lanes 3 and 4. Being that there is a weigh station between the tomato fields and the WIM site, counts exceeding 80,000 lbs. should be minimal, as is reflected in this report.

- Figure 7.16 displays a report of the kind in this figure, but is more difficult to analyze.

DISTRIBUTION OF GROSS WEIGHT BY LANE
SITE NO. 27 - TRACY 7/20/94

**** CLASS 9 ****

LANE

Gross Wt. Range			1 COUNT	1 %	2 COUNT	2 %	3 COUNT	3 %	4 COUNT	4 %	ALL COUNT	ALL %
	<	20.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
20.0	TO	25.0	7	0.6	1	1.9	0	0.0	4	0.3	12	0.5
25.0	TO	30.0	81	6.9	7	13.5	1	1.8	48	3.7	137	5.3
30.0	TO	35.0	202	17.1	13	25	2	3.6	114	8.8	331	12.8
35.0	TO	40.0	84	7.1	4	7.7	6	10.7	96	7.3	189	7.3
40.0	TO	45.0	71	6.0	3	5.8	5	8.9	84.0	6.5	163	6.3
45.0	TO	50.0	58	4.9	2	3.8	5	8.9	85	6.6	150	5.8
50.0	TO	55.0	53	4.5	3	5.8	6	10.7	87	6.7	149	5.8
55.0	TO	60.0	71	6.0	1	1.9	4	7.1	81	6.3	157	6.1
60.0	TO	65.0	127	10.8	3	5.8	3	5.5	181	14.0	314	12.2
65.0	TO	70.0	179	15.2	3	5.8	8	14.3	177	13.7	367	14.2
70.0	TO	75.0	225	19.1	9	17.3	12	21.4	270	20.8	516	20.0
75.0	TO	80.0	20	1.7	3	5.8	4	7.1	64	4.9	91	3.5
	>	80.0	1	0.1	0	0.0	0	0.0	5	0.4	6	0.2
ALL			1179	100.0	52	100.0	56	100.0	1296	100.0	2582	100.0
Avg Gross Wt			53.3	n/a	47.7	n/a	57.5	n/a	57	n/a	55.1	n/a
Standard Dev			16.5	n/a	18	n/a	14.1	n/a	15.1	n/a	15.9	n/a
Avg Gross Wt			9.5	n/a	9.3	n/a	9.9	n/a	9.7	n/a	9.6	n/a
Standard Dev			1.0	n/a	1.1	n/a	0.9	n/a	1.0	n/a	1.0	n/a

Empty distribution

Loaded distribution

**** CLASS 11 ****

LANE

Gross Wt. Range			1 COUNT	1 %	2 COUNT	2 %	3 COUNT	3 %	4 COUNT	4 %	ALL COUNT	ALL %
	<	20.0	5	0.8	0	0.0	0	0.0	6	0.9	5	0.4
20.0	TO	25.0	236	38.8	11	39.3	0	0.0	10	1.6	257	20.2
25.0	TO	30.0	123	20.2	7	25.0	0	0.0	32	5.2	162	12.7
30.0	TO	35.0	11	1.8	2	7.1	0	0.0	14	2.3	27	2.1
35.0	TO	40.0	21	3.4	0	0.0	0	0.0	9	1.5	30	2.4
40.0	TO	45.0	24	3.9	0	0.0	1	4.0	13	2.1	38	3.0
45.0	TO	50.0	32	5.1	3	10.7	1	4.0	31	5.1	67	5.2
50.0	TO	55.0	24	3.9	2	7.1	1	4.0	41	6.7	68	5.3
55.0	TO	60.0	34	5.6	0	0.0	6	24.0	48	7.7	87	6.8
60.0	TO	65.0	22	3.6	1	3.6	2	8.0	62	10.2	87	6.8
65.0	TO	70.0	30	4.9	1	3.6	2	8.0	122	20.0	155	12.2
70.0	TO	75.0	46	7.6	1	3.6	6	24.0	206	33.6	258	20.3
75.0	TO	80.0	1	0.2	0	0.0	6	24.0	22	3.6	29	2.3
	>	80.0	0	0.0	0	0.0	0	0.0	2	0.3	2	0.2
ALL			609	100.0	28	100.0	25	100.0	610	100.0	1272	100.0
Avg Gross Wt			37.1	n/a	33.8	n/a	66.2	n/a	61.7	n/a	49.4	n/a
Standard Dev			17.5	n/a	14.6	n/a	9.8	n/a	14	n/a	20	n/a
Avg Gross Wt			7.2	n/a	7.7	n/a	8.7	n/a	8.1	n/a	7.9	n/a
Standard Dev			0.9	n/a	0.9	n/a	0.8	n/a	0.9	n/a	0.9	n/a

Empty distribution

Loaded distribution

Figure 7.15
Distribution of Gross Weight by Lane

Example Data Review:

- In Lane 1 of the Class 9 report, the empties distribution is poorly defined, and there are too many trucks exceeding 80,000 lbs.

- In Lane 1 of the Class 11 report, over half of the trucks are seasonal tomato trucks which travel empty in Lanes 1 and 2 and loaded in Lanes 3 and 4. Although the empties distribution may be a bit light, the loaded distribution appears to be too heavy.

- In Lane 4 of the Class 9 report, the empties distribution is better defined than in Lane 1, but there are still too many loaded trucks exceeding 80,000 lbs.

- In Lane 4 of the Class 11 report, there are too few empties to make judgement; the loaded tomato trucks are well defined in terms of distribution, but too many exceeding 80,000 lbs.

- What makes this analysis difficult is the high number of trucks exceeding 80,000 lbs. In that much of the truck traffic at this site is short haul and there is no weigh station nearby, it is possible that many or most of the reported trucks exceeding 80,000 lbs. are valid. Another factor to consider is this was one of California's initial WIM systems and there was no pavement preparation at the site.

DISTRIBUTION OF GROSS WEIGHT BY LANE
SITE NO. 1 - LODI 8/10/94

**** CLASS 9 ****

	LANE 1		2		3		4		ALL	
Gross Wt Range	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%
< 20.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
20.0 TO 25.0	27	1.1	0	0.0	1	0.5	21	1.0	49	1.0
25.0 TO 30.0	173	7.4	5	2	16	7.3	203	9.5	397	8
30.0 TO 35.0	197	8.4	27	10.8	32	14.6	278	13	534	10.8
35.0 TO 40.0	127	5.4	26	10.4	10	4.6	140	6.6	303	6.1
40.0 TO 45.0	103	4.4	16	6.4	7	3.2	100	4.7	226	4.6
45.0 TO 50.0	128	5.4	12	4.8	9	4.1	82	3.8	231	4.7
50.0 TO 55.0	116	4.9	16	5.2	9	4.1	90	4.2	248	5.0
55.0 TO 60.0	116	4.9	13	5.2	9	4.1	63	3.0	201	4.1
60.0 TO 65.0	134	5.7	13	5.2	11	5	90	4.2	248	5
65.0 TO 70.0	163	6.9	11	4.4	8	3.7	121	5.7	303	6.1
70.0 TO 75.0	239	10.2	42	16.8	9	4.1	262	12.3	552	11.1
75.0 TO 80.0	413	17.6	49	19.6	33	15.1	439	20.6	934	18.8
> 80.0	416	17.7	20	8.0	65	29.7	246	11.5	747	15.1
ALL	1179	100.0	250	100.0	219	100.0	2136	100.0	4956	100.0
Avg Gross Wt	53.3	n/a	59.6	n/a	61.6	n/a	58.2	n/a	59.6	n/a
Standard Dev	16.5	n/a	17.9	n/a	21.5	n/a	20.4	n/a	19.9	n/a
Avg Gross Wt	9.5	n/a	10.7	n/a	11.1	n/a	10.6	n/a	10.8	n/a
Standard Dev	1.0	n/a	1.3	n/a	1.3	n/a	1.2	n/a	1.3	n/a

Very high!

**** CLASS 11 ****

	LANE 1		2		3		4		ALL	
Gross Wt Range	COUNT	%	COUNT	%	COUNT	%	COUNT	%	COUNT	%
< 20.0	45	3.6	0	0.0	1	0.9	0	0.0	47	1.7
20.0 TO 25.0	435	34.3	0	0.0	3	2.8	43	3.3	481	17.0
25.0 TO 30.0	165	13.0	15	10.7	6	5.5	90	6.9	276	9.8
30.0 TO 35.0	89	7.0	51	36.4	3	2.8	59	4.5	202	7.2
35.0 TO 40.0	44	3.5	15	10.7	2	1.8	25	1.9	86	3.0
40.0 TO 45.0	24	1.9	6	4.3	0	0.0	27	2.1	57	2.0
45.0 TO 50.0	42	3.3	7	5.0	4	3.7	30	2.3	83	2.9
50.0 TO 55.0	40	3.1	7	5.0	1	0.9	43	3.3	91	3.2
55.0 TO 60.0	45	3.5	4	2.9	5	4.6	45	3.4	99	3.5
60.0 TO 65.0	51	4.0	4	2.9	6	5.5	63	4.8	124	4.4
65.0 TO 70.0	46	3.6	3	2.1	3	2.8	74	5.7	126	4.5
70.0 TO 75.0	48	3.8	9	6.4	2	1.8	217	16.6	276	9.8
75.0 TO 80.0	74	5.8	9	6.4	16	14.7	346	26.5	445	15.8
> 80.0	121	9.5	10	7.1	57	52.3	243	18.6	431	15.3
ALL	1270	100.0	140	100.0	109	100.0	1305	100.0	2824	100.0
Avg Gross Wt	41.7	n/a	46.3	n/a	71.9	n/a	65.5	n/a	54.1	n/a
Standard Dev	22.7	n/a	18.4	n/a	20.4	n/a	19	n/a	24	n/a
Avg Gross Wt	8.7	n/a	8.7	n/a	9.4	n/a	9	n/a	8.9	n/a
Standard Dev	1.1	n/a	1	n/a	1.1	n/a	1.1	n/a	1.1	n/a

Very high!

Figure 7.16
Distribution of Gross Weight by Lane

Example Data Review:

- This report specifically displays Lane 4 data for the same vehicles that were displayed in the Figure 7.15 report.

- The Class 9 tractor tandem axle space averages 4.3 ft., which indicates that the parameter for determining speed and axle spacings is correct at this site.

- The Class 11 average vehicle length of 66.1 ft. is roughly five feet longer than the average wheelbase: the parameter for detemining overall vehicle length is good.

- The left and right average steer axle weights match each other for both Class 9 and 11 trucks and the standard deviations show that 68% of the steer axle weights will be close to the average weight.

- The average weights in the "Vehicle Gross" column are consistent for the different speed ranges for which there are large numbers of samples; the calibration seems to be fine.

- For comparison, note another report of this type in the Figure 7.18.

DISTRIBUTION OF AVERAGE WEIGHTS & SPACINGS BY SPEED
WIM SITE NO. 27 - TRACY 7/28/94
**** CLASS 9 ****

**** LANE NO. 4 ****

Speed Range			Weights: Axle 1 Left Wheel	Weights: Axle 1 Right Wheel	Weights: Steer Axle	Weights: Tractor Tandem Axles	Weights: Trailer Tandem Axles	Weights: Vehicle Gross	Counts: All	Counts: Over Weight	Counts: Percent Over Weight	Spacings: Tractor Tandem Axles	Spacings: Trailer Tandem Axles
	<	25.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0
25.0	TO	30.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0
30.0	TO	35.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0
35.0	TO	40.0	5.6	5.3	10.9	31.7	33.1	75.7				4.3	4.1
40.0	TO	45.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
45.0	TO	50.0	5.7	5.3	11.0	29.8	28.0	[illegible]	[illegible]	4	50.0	4.4	4.0
50.0	TO	55.0	4.9	4.9	9.8	25.1	22.5	57.4	130	10	7.7	4.2	4.0
55.0	TO	60.0	4.9	4.9	9.7	24.6	22.4	56.7	607	13	2.1	4.3	4.3
60.0	TO	65.0	4.8	4.8	9.6	24.6	22.1	56.6	411	8	1.9	4.4	4.5
65.0	TO	70.0	4.9	4.8	9.6	25.8	22.8	58.2	116	2	1.7	4.5	4.7
70.0	TO	75.0	4.7	4.7	9.4	25.3	22.4	57.1	[illegible]	1	4.5	4.5	5.0
	>	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
Average All			4.9	4.8	9.7	24.8	22.5	57	1296.0	38	2.9	4.3	4.4
Standard Dev			0.6	0.5	1	6.8	8.2	15.1	n/a	n/a	n/a		1.4

Consistent gross weights at different speed ranges.

Good balance

Indicates axle spacing good

DISTRIBUTION OF AVERAGE WEIGHTS & SPACINGS BY SPEED
WIM SITE NO. 27 - TRACY 7/28/94
**** CLASS 11 ****

**** LANE NO. 4 ****

Speed Range			Weights: Axle 1 Left Wheel	Weights: Axle 1 Right Wheel	Weights: Steer Axle	Weights: Vehicle Gross	Counts: All	Counts: Over Weight	Counts: Percent Over Weight	Over All: Vehicle length	Over All: Wheel Base
	<	25.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
25.0	TO	30.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
30.0	TO	35.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
35.0	TO	40.0	4.2	4.1	8.2	89.7	1.0	1	100	72.8	60.4
40.0	TO	45.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
45.0	TO	50.0	4.5	4.4	8.9	[illegible]	[illegible]	0	0	63.8	58.8
50.0	TO	55.0	4.1	4.2	8.3	64.2	84	1	1.2	65.0	59.7
55.0	TO	60.0	4.0	4.1	8.1	62.2	319	2	0.6	66.0	58.6
60.0	TO	65.0	3.9	4.0	7.9	59.3	167	0	0	67.1	61.6
65.0	TO	70.0	3.9	4.0	8.0	61.6	30	0	0.0	66.7	61.5
70.0	TO	75.0	4.3	4.5	8.8	54.8	1	0	0.0	67.8	61.0
	>	75.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
Average All			4	4.1	8.1	61.7	610	4	0.7	66.1	60.8
Standard Dev			0.5	0.5	0.9	14	n/a	n/a	n/a	4.6	

Indicates vehicle lengths good

Figure 7.17
Distribution of Average Weights and Spacings by Speed

Example Data Review:

- Lane 4 of this WIM system is on a long uphill grade and the heavier trucks travel at lower speeds than the lighter trucks. This is an example of the reviewer needing to know the traffic and truck characteristics for each specific site in order to make the correct analysis.

- The spacing of the tractor tandem axles reads 4.2, but it should be 4.3. This shows that there may be a problem with the calibration parameters.

DISTRIBUTION OF AVERAGE WEIGHTS & SPACINGS BY SPEED

WIM SITE NO. 21 - MOJAVE 8/23/02

**** CLASS 9 ****

**** LANE NO. 4 ****

Speed Range			WEIGHTS: Axle 1 Left Wheel	Axle 1 Right Wheel	Steer Axle	Tractor Tandem Axles	Trailer Tandem Axles	Vehicle Gross	COUNTS: All	Over Weight	Percent Over Weight	SPACINGS: Tractor Tandem Axles	Trailer Tandem Axles
	<	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
25.0	TO	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
30.0	TO	35.0	4.5	4.0	8.6	29.8	27.4	[illegible]	[illegible]	0	0.0	4.1	3.8
35.0	TO	40.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	67.2	31	1	3.2	4.1	4.8
40.0	TO	45.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	67.1	157	18	11.5	4.1	4.1
45.0	TO	50.0	[illegible]	[illegible]	[illegible]	[illegible]	25.5	62.3	286	51	17.8	4.2	4.2
50.0	TO	55.0	[illegible]	[illegible]	[illegible]	[illegible]	15.7	44.1	349	17	4.9	4.2	4.2
55.0	TO	60.0	[illegible]	[illegible]	[illegible]	[illegible]	12.9	38.5	173	1	0.6	4.2	4.2
60.0	TO	65.0	4.2	4.3	8.8	15.7	10.3	34.6	17	0	0.0	4.3	4.4
65.0	TO	70.0	3.9	4.5	8.4	12.0	6.5	20.8	5	0	0.0	4.4	4.2
70.0	TO	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
	>	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
Average All			4.7	4.6	9.5	22.9	20.2	52.4	1025	88	8.6	4.2	4.2
Standard Dev			0.6	0.5	1	8.5	10.3	18.7	n/a	n/a	n/a	[illegible]	1.3

Heavier trucks at lower speeds due to uphill grade

Should be 4.3

DISTRIBUTION OF AVERAGE WEIGHTS & SPACINGS BY SPEED

WIM SITE NO. 21 - MOJAVE 6/23/02

**** CLASS 11 ****

**** LANE NO. 4 ****

Speed Range			WEIGHTS: Axle 1 Left Wheel	Axle 1 Right Wheel	Steer Axle	Vehicle Gross	COUNTS: All	Over Weight	Percent Over Weight	OVER ALL: Vehicle length	Wheel Base
	<	25.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
25.0	TO	30.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
30.0	TO	35.0	4.1	3.6	7.7	[illegible]	2	0	0	64.3	59.0
35.0	TO	40.0	4.1	3.8	7.8	65.0	31	2	6.5	66.0	60.2
40.0	TO	45.0	4.0	3.8	7.8	68.0	49	4	8.2	64.0	58.4
45.0	TO	50.0	4.2	4.0	8.2	61.9	74	7	9.5	65.2	59.5
50.0	TO	55.0	4.0	4.0	8.0	49.5	35	1	2.9	64.8	59.3
55.0	TO	60.0	3.7	3.9	7.6	38.2	15	0	0.0	64.8	59.3
60.0	TO	65.0	3.3	3.8	7.1	22.2	2	0	0.0	58.4	55.7
65.0	TO	70.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
70.0	TO	75.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
	>	75.0	0.0	0.0	0.0	0.0	0	0	0.0	0.0	0.0
Average All			4.1	3.9	8	59.1	207	14	6.8	64.5	59.3
Standard Dev			0.6	0.5	1.1	17.3	n/a	n/a	n/a	4.9	4.1

Figure 7.18
Distribution of Average Weights and Spacings by Speed

8. SITE MAINTENANCE

In order to ensure that a weigh-in-motion (WIM) system performs throughout the established site design life, states need to perform maintenance at each site. Maintenance can either be corrective or preventive. Corrective maintenance repairs or replaces any malfunctioning equipment or roadway deterioration. Preventive maintenance ensures that the site will function properly by periodically inspecting the system and roadway. This section will discuss both types of maintenance and provide a checklist of items to inspect during a preventive maintenance inspection.

8.1 CORRECTIVE MAINTENANCE

Corrective maintenance is performed after a problem is detected in the system. Problems are detected during the quality assurance (QA) procedures discussed in Section 7 of this handbook. These problems can be corrected in several ways. The first corrective method is to adjust the parameters for axle weights, axle spacings, and vehicle overall length. The next corrective method is to repair or replace faulty equipment detected during the QA procedure. A third corrective method is to repair any problems detected in the roadway which could range from lane rutting before or after the sensor to extensive roadway deterioration.

8.2 PREVENTIVE MAINTENANCE

Preventive maintenance is performed in an attempt to circumvent future equipment and site problems. The California Department of Transportation's (Caltrans) successful practice includes using the checklist in Table 8.1 to perform site inspections one to two times a year (*17*). The California Maintenance Checklist provides an adequate way to perform preventive maintenance on a WIM system. The checklist provides a list of items to be inspected and tasks to be completed. Also included on the checklist is a column for notes about the inspected item. After the inspection a maintenance report is written describing the services performed on-site, other observations, and actions recommended.

Table 8.1
Caltrans Successful Practice Field Maintenance Checklist

	Item	Observation/Action
8.2.1	**WIM Sensor Operation**	
8.2.1.1	Sensor number and type	
8.2.2	**Loop Operation**	
8.2.2.3	Loop number	
8.2.3	**WIM Electronics and Equipment Functions**	
8.2.3.1	Signal Processing (loop, scale, piezo inputs)	
8.2.3.2	Watchdog	
8.2.3.3	Temperature Sensor	
8.2.3.4	Hard drive and floppy drive	
8.2.3.5	Com ports 1 & 2	
8.2.3.6	Uninterruptable power supply	
8.2.3.7	Modem	
8.2.3.8	Cabinet Fan	
8.2.4	**System Maintenance and Cleaning**	
8.2.4.1	Clean interior and exterior of all components	
8.2.4.2	Remove, clean, and inspect all circuit boards	
8.2.4.3	Maintain all electrical connectors of operation of interface components	
8.2.4.4	Test and verify control and sequence of operation of interface components	
8.2.4.5	Adjust zero point of WIM scale interface cards if necessary	
8.2.4.6	Clean Cabinet	
8.2.5	**Visual Inspection of Site**	
8.2.5.1	Frames, weighpads, induction loops, and axle sensors	
8.2.5.2	Roadway through WIM system	
8.2.5.3	Pullboxes adjacent to roadway	
8.2.5.4	Drainage outlet (when drain to side slope)	
8.2.6	**Software Maintenance**	
8.2.6.1	Upgrade software to latest version	

8.2.1 Weigh-in-Motion Sensor Operation

The WIM sensors are inspected to establish operational condition. The sensor number and type are recorded on the checklist form including any observations regarding the equipment.

8.2.2 Loop Operation

The loop detectors at the WIM site are then inspected to establish operational condition. The loop number, loop type, and observations about the equipment are recorded on the checklist form.

8.2.3 Weigh-in-Motion Electronics and Equipment Functions

The WIM electronics and equipment in the roadside cabinet are inspected to establish operational condition. This section of the checklist starts with an evaluation of the signal processing inputs from the loops, scales, and piezo sensors. Once the inputs have been checked the temperature sensor, computer, and the cabinet fan are checked to ensure that the equipment is functioning properly. The hard drive, floppy drive, com ports, uninterruptable power supply (UPS), and modem are checked on the computer. The watchdog, if it is a part of the system, is checked to ensure that it is operational. The watchdog resets the computer to the factory defaults if the system locks up.

8.2.4 System Maintenance and Cleaning

The interior and exterior of all components are cleaned. The circuit boards are cleaned and inspected. The interface components' electrical connectors and sequence of operation are tested and the control is verified. The cabinet is cleaned and the zero point on the WIM scale is adjusted if necessary.

8.2.5 Visual Inspection of Site

Once the system maintenance and cleaning is finished a visual inspection of the site is made. The frames, weighpads, induction loops, and axle sensors are checked for any visible signs of wear and tear on the components. The roadway through the WIM site is inspected for pavement deterioration, rutting, and cracking. The pullboxes and drainage outlets are inspected and, if necessary, cleared of debris.

8.2.6 Software Maintenance

The last step of the checklist is to maintain the computer software by upgrading the software to the latest version.

9. SYSTEM TROUBLE-SHOOTING

The goal of system trouble-shooting is to ensure that the weigh-in-motion (WIM) system will function properly throughout the site design life. The principle guidelines shown in Table 9.1 should be followed to meet this goal.

Figure 9.1
Trouble-Shooting Principles Checklist

	Trouble-Shooting Principles
9.1	Follow a logical trouble-shooting process.
9.2	Devote adequate financial and technical resources to support an efficient and effective trouble-shooting process.

9.1 LOGICAL TROUBLE-SHOOTING PROCESS

The trouble shooting process begins with site selection and continues throughout the “site design life.” One of the main aspects of this process is to follow the guiding principles listed in each section. The process includes failure detection, analysis, and corrective actions.

9.2 REQUIRED RESOURCES

Throughout the “site design life” adequate financial and technical resources need to be devoted to the program. These resources are included for other areas of the WIM operating procedures. Quality Assurance and site maintenance are areas where financial and technical resources are very important.

APPENDICES

APPENDIX 1
RELEVANT STATE DOCUMENTS

CALIFORNIA MAINTENANCE CONTRACT
Example 1

Article II - Contract Management

Caltrans Contract Manager is Rich Quinley, (916)654-5651.

Article III - Contract Period

This contract shall begin on November 1, 1994, contingent upon approval by the State, and expire on October 31, 1996, unless extended by supplemental agreement.

Article IV - Cost Limitation

A. Total amount of this contract shall not exceed $__________ .

B. It is understood and agreed that this total is an estimate and that the State will pay only for those services actually rendered as authorized by the Contract Manager or his/her designee.

Article V - Scope of Work

Scope of work shall be in accordance with Rider A.

Article VI - Rates

Routine maintenance as described in Rider A shall be reimbursed $_____ monthly for November 1994 thru October 1995 and $______ monthly for November 1995 thru October 1996, not to exceed $_______ for the contract term.

On Call Service and Repairs as described in Rider A

1) On call repair work authorized by the State, shall be reimbursed at rates stated in Rider B, Service Rate Schedule and Permanent Price List. Rider B is attached hereto and incorporated by reference.

2) All subcontracted work or other costs no included in Rider B, shall be reimbursed at actual costs.

3) Total costs for on-call repairs shall no exceed $ _______ for the Contract term.

4) Contractor shall be reimbursed for transportation and subsistence costs for on-call repair work at the rates shown in Rider B.

Article VII - Payment

RIDER A
SCOPE OF WORK

Contractor shall provide labor and materials to perform routine maintenance and on-call repairs for forty (40) existing Caltrans WIM systems at thirty-three (33) locations throughout the State.

A. Routine Equipment Maintenance

1. Contractor shall check each WIM system covered by this contract. Contractor shall schedule maintenance visits conforming to requirements of section C and shall advise State of such schedule prior to commencing service. Service shall include, but not be limited to the following:

a) visual inspection of frames & weighpads
b) visual inspection of the roadway in the area
c) visual inspection of junction box lids
d) inspection of battery voltage
e) inspection of humidity indicator on the central unit; replace drying agent if needed
f) inspect induction loop indicators and frequencies as necessary
g) inspect and compensate zero-points of weighpads
h) clean cabinet
i) provide a written service report to the State for each site within 10 working days after the service has been performed

2. Software Maintenance. Contractor shall provide software updates and technical support services as may be necessary to ensure that all existing WIM systems and the State's host computer functions as an integrated data collection system.

B. On-Call Services and Repairs

Upon notice by the State that a particular system is malfunctioning, Contractor shall begin on-site repair within five working days of notification, unless State authorizes an extended repair schedule. Contractor shall notify state if lane closures are necessary to perform repair work. Upon such notification, State shall arrange for State forces to set up lane closures and shall notify Contractor as to scheduling of such closures or shall authorize contractor to subcontract for traffic control services. Contractor shall also verbally notify state at a minimum of twenty-four (24) hours in advance as to the schedule of repairs when no lane closure is needed. Contractor shall verbally notify State a maximum of twenty-four (24) hours after completion of repairs.

The Contractor shall provide the State with a written report of the repairs made for each WIM system within ten (10) working days after the completion of the repair work.

C. WIM Systems covered under this agreement:

SITE NO.	SITE DESIGNATION	DIST-CO-RT-PM	NO. LANES	SERVICES COMMENCE
1	LODI	10- SJ-005-43.7	4	
2	REDDING	02-SHA-005-R24.9	4	
3	ANTELOPE (WB)	03-SAC-080-17.2	4	
4	WHEELER (SB)	06-KER-005-R15.2	2	
5	INDIO	11-RIV-010-R59.4	4	
6	NEWHALL (NB)	07- LA-005-44.6	2	
7	SANTA NELLA	10-MER-005-20.2	4	
8	VENTURA (2)	07- LA-101-37.8	10	
10	FRESNO	06-FRE-099-25.0	6	
11	SONOMA	04-SON-037-2.7	4	
12	VAN NUYS (2)	07- LA-405-42.9	8	
14	SAN MARCOS	11- SD-078-10.7	6	
15	IRVINE (2)	12-ORA-005-25.8	12	
17	HAYWARD (2)	04-ALA-880-14.7	8	
20	LOLETA	01-HUM-101-65.6	4	
21	MOJAVE	09-KER-058-108.1	4	
22	JEFFREY	11-IMP-008-25.8	4	
23	EL CENTRO	11-IMP-008-40.0	4	
24	NAPA	04-NAP-012-2.3	2	
25	NEWBERRY	08-SBD-040-28.9	4	
26	CAMERON	11- SD-008-51.5	4	
27	TRACY	10- SI-005-7.4	4	
30	MT SHASTA	02-SIS-005-11.4	4	
31	WOODSIDE (2)	04- SM-280-5.6	8	
33	BURLINGAME (2)	04- SM-101-17.5	8	
35	PACHECO	04-SCL-152-26.9	4	
36	LOS BANOS	10-MER-152-23.0	4	
37	ELSINORE (2)	08-RIV-015-21.6	8	
39	REDLANDS	08-SBD-030-31.7	4	
40	COACHELLA	11-RIV-086-R15.9	4	
44	BANTA	10- SI-205-9.5	4	4 / 95
45	CARBONA	10- SI-580-6.4	4	2 / 95
47	CASTAIC	07- LA-005-56.1	8	4 / 95
49	AUBURN	03-PLA-049-9.0	4	3 / 95

26 Single system sites
8 Dual system sites

Routine Equipment Maintenance shall be performed four times, at approximately six month intervals, for listed Site No's I through 40. Routine Equipment Maintenance shall be performed three times for the remaining listed sites commencing with the "Services Commence" date.

RIDER B

* Schedule of service classifications, rates, and expense allowances as negotiated

* Listing of equipment and prices

CALIFORNIA MAINTENANCE CONTRACT
Example 2

Article II - Contract Management

Caltrans Contract Manager is Rich Quinley, (916)654-5651.

Article III - Contract Period

This contract shall begin on July 1, 1995, contingent upon approval by the State, and expire on June 30, 1996, unless extended by supplemental agreement.

Article IV - Cost Limitation

A. Total amount of this contract shall not exceed $__________ .

B. It is understood and agreed that this total is an estimate and that the State will pay only for those services actually rendered as authorized by the Contract Manager or his/her designee.

Article V - Scope of Work

Scope of work shall be in accordance with Rider A.

Article VI - Rates

Routine maintenance as described in Rider A shall be reimbursed $_____ monthly for July 1, 1995 thru June 30, 1996, not to exceed $_______ for the contract term.

On Call Service and Repairs as described in Rider A

1) On call repair work authorized by the State, shall be reimbursed at rates stated in Rider B, Rider B is attached hereto and incorporated by reference.

2) All subcontracted work or other costs no included in Rider B, shall be reimbursed at actual costs.

3) Total costs for on-call repairs shall no exceed $ _______ for the contract term.

4) Contractor shall be reimbursed for transportation and subsistence costs for on-call repair work at the rates shown in Rider B.

Article VII - Payment

A. The State will reimburse the Contractor monthly in arrears as promptly as State fiscal procedures permit upon receipt of itemized invoices in triplicate. Invoices shall reference this contract number and shall be submitted to the Contract Manager at the following address:

RIDER A

SCOPE OF WORK

Contractor shall provide labor and materials to perform routine maintenance and on-call repairs for eleven (11) existing Caltrans Weigh-In-Motion (WIM) systems at eight (8) locations throughout the State.

A. Routine Equipment Maintenance

1. Contractor shall check each WIM system covered by this contract.
   Contractor shall schedule maintenance visits conforming to requirements of Section C and shall advise Caltrans' Contract Manager of such schedule prior to commencing. Service shall include, but not be limited to the following:

   a. Test response levels, signal levels, and lead cables for:
      - in-road instrumentation
      - WIM scales
      - piezoelectric sensors

   b. Maintain and clean electronics interface and system components:
      - clean interior and exterior of all components; remove, clean and inspect all printed circuit boards
      - maintain all electrical connectors of operation of interface components
      - test and verify control and sequence of operation of interface components; adjust zero point of WIM scale interface card if necessary

   c. Visually inspect condition of:
      - frames, weighpads, induction loops and axle sensors
      - roadway through WIM system
      - pullboxes adjacent to roadway
      - drainage outlet (when drain to side slope)

   d. Clean cabinet

   e. Provide a written report to the State for each WIM system within ten (10) working days after service has been performed.

2. Software Maintenance

   Contractor shall provide software updates and technical support services as may be necessary to ensure that all existing WIM systems and the State's host computer functions as an integrated data collection system.

B. On-Call Services and Repairs

Upon notice by the State that a particular system is malfunctioning, Contractor shall begin on-site repair within five (5) working days of notification, unless State authorizes an extended repair schedule. Contractor shall notify state if lane closures are necessary to perform repair work. Upon such notification, State shall arrange for State forces to set up lane closures and shall notify Contractor as to scheduling of such closures or shall authorize contractor to subcontract for traffic control services. Contractor shall also verbally notify state at a minimum of twenty-four (24) hours in advance as to the schedule of repairs when no lane closure is needed. Contractor shall verbally notify State a maximum of twenty-four (24) hours after completion of repairs.

The Contractor shall provide the State with a written report of the repairs made for each WIM system within ten (10) working days after the completion of the repair work.

C. Location of WIM systems covered under this agreement:

SITE NO.	SITE DESIGNATION	DIST-CO-RT-PM	NO. LANES
28	MACDOEL	02-SIS-097-34.5	2
29	ARCO (SB)	03-SAC-005-28.9	3
41	VACAVILLE (2)	10-SOL-080-30.6	8
43	CHOLAME	05-SLO-046-44.7	2
46	GALT	03-SAC-099-6.9	4
50	ELMIRA	10-SOL-505-2.2	4
53	NEWPORT (2)	12-ORA-001-22.6	6
51	WEST SAC (2)	03-YOL-050-0.6	8

5 Single system sites
3 Dual system sites

Routine Equipment Maintenance shall be performed two (2) times, at approximately six (6) month intervals for the above listed WIM systems except for Site No. 51. For Site No. 51, routine maintenance shall be performed one (1) time after Novermber 1995.

APPENDIX 2
LONG TERM PAVEMENT PERFORMANCE

INSTRUCTIONS FOR COST ESTIMATION SPREADSHEET

COST OF WIM EQUIPMENT

Below are instructions for using the spreadsheet file **WIMCOST.XLS,** which estimates the cost of purchasing, installing, operating, and maintaining WIM equipment.

The spreadsheet is designed for ease of use. At the simplest level, you only need to type in the number of WIM scales that will be purchased and indicate whether the WIM systems will be bending plate or piezo cable based. The spreadsheet will then calculate crude estimates of the cost and staffing required to keep those systems operating at the level expected by LTPP.

The crude estimates initially supplied by the spreadsheet are based on a number of assumed costs and levels of maintenance and operating activity. These assumptions may or may not be realistic for any given state or provincial highway agency (SHA). Consequently, you have the option of changing (and are encouraged to change) the majority of the inputs used in the cost estimation process. You should update the cost and staffing estimates supplied as defaults with the spreadsheet to reflect specific conditions within your SHA and your SHA's experiences. This will provide a more realistic estimate of the staffing and resources needed to install, operate, and maintain the WIM equipment.

STARTING THE WIM RESOURCE ESTIMATION PROCESS

The spreadsheet is stored in a Microsoft Excel 5.0 format.

To open the spreadsheet, start Excel, and open the file WIMCOST.XLS.

Two windows open with the spreadsheet. In the left hand window are the basic data entry requirements. In the right hand window are the total cost estimates calculated by the spreadsheet.

USING THE SPREADSHEET

Basic Input Section

The spreadsheet requires the following inputs:

- the number of WIM sites to be installed, by type of WIM system
- the average number of lanes to be installed at each site
- whether a PC needs to be purchased for the central office operation
- the number of new sites that will need pavement rehabilitation before WIM installation (this is split by type of pavement).

Number of WIM sites to be installed. The number of sites at which WIM devices will be installed is entered in three different cells, depending on the type of equipment being purchased.

Enter the number of piezo cable systems to be installed in Cell B5. Enter the number of bending plate systems to be installed in Cell B6. Enter the number of any other systems being considered in Cell B7.

Piezo cable and bending plate WIM systems have been the most widely adopted technologies in the U.S., so default values are included in the spreadsheet for those systems. <u>If you are intending to use a different technology, you must place the appropriate cost estimates in the lower section of the spreadsheet.</u> (This section is described under the heading "Changing The Basic Assumptions.") Note also that the piezo cable and bending plate cost estimates should be updated if you have better cost estimates that are more specific to your SHA.

<u>Average number of lanes to be installed.</u> For this spreadsheet, a "site" is defined as each set of roadside electronics required. For example, if WIM will be placed on a four-lane, divided highway, this installation could be either a single four-lane site or two two-lane sites. If the median is very large, this location will likely become two separate "sites," both having two lanes of WIM scales. These two sites will have separate power and telephone connections, as well as separate equipment cabinets and data collection electronics. If the median is not too large, and the cabling from all four lanes of sensors can be hooked to a single cabinet and set of data collection electronics, then this configuration would be considered a single four-lane site.

Enter the average number of lanes of WIM sensors for all sites in the cost estimate in Cell B10 (this number can be a decimal fraction).

<u>PC purchases for central office operation.</u>

If your SHA is purchasing WIM for the first time, and/or if your SHA does not have an extra PC that is capable of automatically polling the WIM sites and storing the downloaded data, then place the number of PCs to be purchased in cell B12.

This will cause the spreadsheet to include the cost of this computer(s) in the cost calculation. Note that if your SHA is planning to purchase many WIM systems, more than one PC is usually required to poll, store, process, and report the collected WIM data. A rough estimate (subject to the traffic volumes at the WIM sites, how the sites are operated, and how the collected data are retrieved) is that one central PC is required for every eight to twelve WIM sites.

If this is the first WIM installation to be purchased from this vendor, your SHA will also probably have to purchase the required office processing software.

> If this is the case, place a “1” in cell B13. If central office software is not required, place a “2” in cell B13.

Number of sites requiring pavement rehabilitation. The last entries concern the need for pavement rehabilitation at the WIM sites. WIM equipment can only estimate static truck weights accurately if the pavement in which they are installed is smooth, strong, and in good condition. In addition, the life expectancy of the axle sensors is substantially longer if they are placed in pavement that is in good condition. As a result, it is often necessary (and cost effective) to perform some type of pavement maintenance or rehabilitation before sensor installation.

The spreadsheet can consider two types of pavement rehabilitation efforts, asphalt concrete pavements (ACP) and portland cement concrete pavements (PCC). (The actual estimated costs of these treatments are contained in cells B26 and B27, respectively, where you can change them.) The basic input section requires that you enter the number of new WIM sites that require each type of preliminary pavement rehabilitation.

> If no pavement rehabilitation is required, enter “0” in both cells B15 and B16. Otherwise, enter the number of sites that need ACP rehabilitation in cell B15 and the number that need PCC rehabilitation in cell B16. (Note: the sum of these two cells does not have to equal the total number of new WIM sites.)

Results Section

The spreadsheet outputs (right hand window) include (1) the total initial costs for system purchase and installation and (2) the estimated **annual** cost and staffing requirements for maintaining the systems purchased. These estimates are shown in **bold** type. These costs assume that some initial pavement rehabilitation is needed at the WIM sites for the equipment to operate correctly. (See "Site Preparation Costs" for more information on this subject.)

Below these cost calculations are additional estimates of the annual budget for pavement maintenance and rehabilitation needed to keep equipment at the WIM sites operating within ASTM and LTPP specifications. These estimates reflect the fact that your SHA will need to budget for the repair and replacement of WIM systems because those systems will fail as the pavement deteriorates.

Below the pavement rehabilitation estimates is a cell that shows the initial cost of the proposed WIM system after pavement rehabilitation costs have been removed. This cell assumes that the pavement at the WIM site is in good condition and does not need further rehabilitation, or that the required rehabilitation will be part of a more general pavement construction project and will thus be paid for from a different budget.

The last two items in the Results Section are the number of WIM sites and the number of lanes used to estimate the budget figures. These numbers should equal the values entered in the Input Section in the left hand window. They are placed in the Results Section both to make a printed summary of the results more useful and to serve as a check that the spreadsheet is working correctly.

CHANGING THE BASIC ASSUMPTIONS

The inputs described above must be supplied by you. All other variables used to estimate WIM costs are initially supplied by the spreadsheet. **However**, these estimates are simply reasonable values synthesized from a variety of sources. They do not necessarily accurately reflect local conditions for your SHA. **Consequently**, you are encouraged to change the remaining input assumptions on the basis of experience, professional judgment, and known site conditions.

Although all formulas and text in the spreadsheet are write protected, all input values can be readily changed. Where the spreadsheet provides a default value for an estimate, that default is also listed in a text field near the cell in question (usually one or two cells to the right). Thus, if you change a value and decide later to revert to the default estimate, you can refer to the text field to obtain the default value and re-enter it in the appropriate field. (For example, the cost of ACP rehabilitation per lane is given in cell B26. The default for this cell is also listed in cell D26 under the heading "Default Rates.")

The table on the following pages indicates the input variables that can be changed. Each of these items is discussed in the text of this document that follows the table.

Input Variable	Cell Location
ACP rehabilitation cost per lane	B26
PCC rehabilitation cost per lane	B27
Basic system cost for a one-lane piezo-cable based WIM site, including installation	B33
Basic system cost for a one-lane bending plate based WIM site, including installation	B34
Basic system cost for a one-lane WIM site for some other technology of interest to the SHA, including installation	B35
Cost reduction factor for multi-lane WIM sites	B37
Piezo-cable sensor failure rates	B40
Bending plate sensor failure rates	B41
Other technology sensor failure rates	B42
The replacement cost of a piezo-cable sensor (including installation)	B45
The replacement cost of a bending plate sensor (including installation)	B46
The replacement cost of a sensor from another technology (including installation)	B47
The staff time required to replace a piezo-cable sensor (including installation)	C45
The staff time required to replace a bending plate sensor (including installation)	C46
The staff time required to replace a sensor from another technology (including installation)	C47
The number of sensors required per lane for a piezo-cable WIM system	B50
The number of sensors required per lane for a bending plate WIM system	B51
The number of sensors required per lane for a WIM system using some other technology	B52

Input Variable (continued)	Cell Location
Cost of a single central computer to perform the required office functions (usually a high-end PC)	B55
Cost of the central office software used by the WIM system vendor to poll the remote WIM sites, store and process the data, and create the necessary reports	B56
The cost of an FTE of office staff time	B63
The staff time needed to monitor the operation of, and process data from, a WIM site	C63
The monthly power cost for a WIM site	B66
The monthly telecommunications costs for a WIM system	B67
Expected maintenance expenses per WIM site (but not including expected pavement rehabilitation expenses)	B70
Expected maintenance staff requirements per WIM site (but not including those needed for pavement rehabilitation expenses)	C70
The number of calibration trips expected per site per year	B72
The cost of a single-lane calibration effort when that effort is performed by pulling trucks from the passing traffic stream and weighing them both at the WIM scale and at a nearby static scale	B75
The staff time needed to perform a single-lane calibration effort when that effort is performed by pulling trucks from the passing traffic stream and weighing them both at the WIM scale and at a nearby static scale	C75
The cost of a single-lane calibration effort when that effort is performed by bringing two loaded test trucks of known weight to a WIM site and having them pass repeatedly over the scale.	B76

Input Variable (continued)	Cell Location
The cost of a single-lane calibration effort when that effort is performed using a different calibration technique.	B77
The staff time needed to perform a single-lane calibration effort when that effort is performed using a different calibration technique.	C77
A cost/staff reduction factor that indicates the cost savings associated with calibrating more than one lane of sensors at a single location	B79
An indicator of which calibration technique should be used in the cost estimation procedure	B81
An estimate of the costs required to outfit a maintenance technician so that s/he can diagnose problems with the WIM equipment	B86
An estimated cost for rehabilitating the pavement at an existing scale site (i.e., once the pavement at a site has deteriorated, the cost to bring that site's pavement back up to par).	B89
The percentage of sites that need rehabilitation during any given year.	B90

Site Preparation Costs

As noted above, accurate operation of a WIM system requires that it be placed in strong pavement that is in good condition. Consequently, pavement rehabilitation is often necessary before sensors are installed. The cost of this rehabilitation effort will vary considerably from site to site, depending on the type existing pavement and its condition.

In general, the 200 to 500 feet of pavement immediately surrounding the axle sensors should be in excellent condition (no cracking, no visible rutting). (See the LTPP SPS Traffic Data Collection Protocol for LTPP's recommended pavement specifications for WIM sites.) To achieve this standard may require anything from grinding the surface of an existing PCC pavement to completely rebuilding it. Consequently, costs can vary considerably from site to site.

Because of the cost of pavement rehabilitation, in many cases WIM equipment is only placed in the road as part of an otherwise planned road construction project. In this way, the pavement rehabilitation effort is paid for from a different funding source and is not considered part of the cost of the WIM system.

Each SHA should determine the true cost of pavement rehabilitation at the proposed site with the help of its own pavement engineering section. This requires that the engineering section know the proposed WIM system location, the condition of the existing pavement, and the pavement requirements for the WIM system site. The cost value provided by the engineering section should then be entered in the appropriate cell (B26 or B27), expressed as a cost per lane.

Where multiple sites require pavement rehabilitation, you should total these costs and then divide the sum by the total number of lanes to be rehabilitated. This will compute the average cost per lane to be entered into the spreadsheet.

Hardware System Costs

The cost of installed WIM systems (excluding pavement rehabilitation) will also vary from SHA to SHA and from contract to contract as a result of differences in vendors, the size of different equipment orders, and the special conditions SHAs place on specific vendors.

The estimates included in cells B33 and B34 are approximate values developed from telephone conversations with various SHA personnel involved with the LTPP program. These estimates may not represent well the costs that any one SHA may encounter. More accurate system costs can be obtained from neighboring SHAs that have recently purchased equipment.

The estimates in cells B33 through B35 include the cost of installation, as well as the costs of installing power, communications, and other site necessities. The cost reduction factor (cell B37) is designed to account for the fact that a multi-lane site requires only one power source, one communications line, and one set of central electronics. In addition, there are economies of scale in the areas of traffic control, equipment use, and other construction related items. This cost reduction factor is applied to the cost of all additional lanes at each site.

Sensor Failure Rates, Costs Per Sensor, and Sensors Per Lane

Axle sensors fail for a variety of reasons, including poor installation, pavement failure, sensor fatigue, and faulty sensor design and construction. Sensors tend to fail more quickly under heavy loading and poor environmental conditions. This failure occurs both because of increased fatigue and because pavements tend to deteriorate more quickly under those same conditions.

The “default” sensor failure rates are based on a series of conversations with SHA staff involved with traffic data collection for LTPP. These figures include all kinds of sensor failure and may over-estimate the failure rate of a sensor that is carefully placed in good pavement. (Also note that the failure rate is not linear and can be expected to increase as sensors age. The rate given in this spreadsheet is intended to reflect conditions two or more years from installation to give the SHA a feel for anticipated funding needs.)

If an SHA has experience with specific sensors, more specific failure rates should be substituted for the default rates. Similarly, the replacement costs for sensors listed in the spreadsheet should be overridden whenever possible with more specific values.

The number of sensors listed per site assumes the following sensor configurations. For the piezo cable installation, two 12-foot cables are used along with one 6-foot square loop for vehicle presence detection. For bending plate sites, two 6-foot bending plate scales are placed side by side (one for each wheel path), with 6-foot loops both up- and downstream of the scale.

If the SHA plans on purchasing a WIM system with a different sensor configuration, the number of sensors per lane should be changed accordingly. (Note that the cost of inductive loops is so low in comparison to the other WIM system components that they are not accounted for separately in the spreadsheet.)

Central Computer Hardware and Software

An SHA usually has to have at least one large central PC to collect, store, process, and report the WIM data collected in the field. If your SHA is adding to its existing WIM devices, it may not have to add an additional CPU. This can be accounted for in the spreadsheet by entering “0” in cell B12. If a one or more PCs are required, the appropriate number should be entered in cell B12.

The cost of these PCs should be entered B55. In most cases, this CPU should be the fastest Pentium-based machine available, with a 28.8-bit per second modem, a minimum of 1 GB of hard disk storage, and some kind of disk back-up device (e.g., removable optical storage, tape back-up).

In addition to the basic hardware requirement, the CPU will need the central processing software supplied by the WIM system vendor. If your SHA already owns this software and is simply purchasing additional WIM scales, enter a “2” in cell B13. This removes the cost of the software from the spreadsheet calculations. If central software is needed, enter a “1” in cell B13, and enter the actual cost of the software in cell B56.

Operating Costs

Operating costs are divided into four categories: utilities, calibration, maintenance, and office processing.

Utilities primarily include power and telecommunications costs. These costs are entered as average monthly costs per site in cells B66 and B67. Note that if solar power is used at a site, there may be no monthly power cost. Instead, include the cost of the solar panels in the initial system cost (Cells B33, B34, or B35).

WIM system calibration is crucial to obtaining usable information. Most WIM systems have some kind of “auto-calibration” capability, but work with the traffic data submitted to LTPP has shown that these systems do not always work reliably. Therefore, your SHA should continually monitor the performance of its WIM equipment and periodically perform complete calibration tests.

The “default” in the spreadsheet is that the calibration of each scale will be independently tested and confirmed four times per year. Approximate costs are given for two different calibration methods. The first weighs trucks from the traffic stream at both a static scale and the WIM scale in question. This is an excellent method for calibrating WIM scales, but it is only economically feasible when a static scale is located up- or downstream of the WIM scale.

The second calibration approach for which a cost estimate is included relies on the use of two loaded test trucks (of known weight). These trucks make multiple passes over the scale being calibrated. This method is not as effective as calibrating from the traffic stream, but it is more economically feasible when a static scale is not located near the WIM scale being calibrated.

A number of other calibration techniques are also possible. SHAs selecting one of these techniques should use the category “other techniques” and provide a cost per lane for that technique in cell B77.

When calibration costs are added and/or changed, it is also important to change the staffing requirements listed in Column C. Calibration tends to be staff intensive, regardless of the technique selected, although some techniques are more labor intensive than others.

After specific calibration technique has been selected, make sure to enter a “1,” “2,” or “3” in cell B81 to indicate the appropriate technique. “1” means that your SHA will use the traffic stream and an existing static scale. “2” indicates the use of two test trucks, and “3” indicates the use of an alternative methodology.

Finally, make any necessary changes to the number of calibration efforts per year (cell B72). When a scale is first installed, multiple calibration efforts are required to ensure that it operates accurately throughout the year, as different climatic conditions can change sensor and pavement responses to axle loadings.

Routine maintenance is required for both the site and the equipment at the site. The site maintenance cost estimates are located in cells B70 (funding) and C70 (staff). These estimates do not include major pavement repair, which is covered by the estimates for pavement rehabilitation. They do include electrical repair, repair to the WIM system electronics, and a variety of minor site maintenance tasks.

The last operating expense is for office processing. Although many office tasks have been automated by vendors, the volume of information generated by WIM devices and the need to monitor the calibration and operating condition of these devices to ensure their reliable operation require some fairly substantial office staff time. An estimate of the staff time is given in cell C63. The spreadsheet assumes 0.2 FTE for the very first WIM system purchased and installed. Cell

C63 contains the marginal staff time required for each additional WIM device. Because some central office tasks only need to be performed once, there is some economy of scale in the operation of multiple WIM devices.

Other Potential Costs

If your SHA is just getting into WIM system deployment, some additional “one-time” costs will be incurred to equip your SHA’s maintenance technicians. The items required vary from technology to technology but can include oscilloscopes and volt meters (to measure signal performance) and specialized electronic diagnostic tools. The estimate in the spreadsheet assumes that a vehicle for the maintenance technician is already available through other SHA sources.

Annual Pavement Rehabilitation Costs

The last cost included in the spreadsheet is an annual component for pavement rehabilitation. As pavement ages it deteriorates. As the pavement deteriorates, WIM sensor performance deteriorates and sensor life expectancy decreases. In many cases, sensor failure is caused not by the failure of the sensor itself but by the failure of the pavement around the sensor, which causes the sensor to quit operating correctly or results in sensor damage that would not otherwise have occurred.

Therefore, the pavement that contains WIM system sensors must be rehabilitated periodically. When the pavement is repaired or replaced, the WIM sensors almost always have to be replaced. This repair/replacement needs to be budgeted. In many SHAs, sensors are replaced as part of routine pavement maintenance actions (i.e., overlays). The cost of new sensors and installation is simply included in the cost of the new pavement. However, when this occurs, the data collection function is often interrupted from the time the sensor fails to when the pavement is reconstructed or rehabilitated. This time period can be several years.

Regardless of whether the pavement reconstruction pays for the sensor replacement or the WIM system replacement pays for the pavement reconstruction, it is important that the SHA acknowledge the role of pavement reconstruction in the life-cycle cost of the WIM system. Consequently, this spreadsheet includes these costs (Cell B89 lists the average pavement rehabilitation cost per lane for the WIM site, and cell B90 lists the percentage of sites requiring pavement rehabilitation each year). The “Results” section of the spreadsheet lists them separately.

Major Changes (Unprotecting) to the Spreadsheet

To prevent accidental changes to formulas and default values included in this spreadsheet, the majority of cells in the spreadsheet have been locked. If your SHA determines that it wants to make major revisions to the spreadsheet (as opposed to simply changing the input values), you must "unprotect" the spreadsheet. To do this within Excel, you have to enter a password.

The password for the spreadsheet's protection mechanism is "**LTPP**."

Questions about this spreadsheet can be directed to Mark Hallenbeck at (206) 543-6261, by fax at (206) 685-0767, or by e-mail at tracmark@u.washington.edu.

REFERENCE LIST

1. American Society for Testing and Materials. *Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Method*. ASTM Committee E-17 on Vehicle-Pavement Systems. ASTM Designation E 1318-94. 1994.

2. B. Taylor and A. Bergan, International Road Dynamics, Inc. *The USE of Dual Weighing Elements (Double Threshold) to Improve the Accuracy of Weigh-in-Motion Systems, and the Effect of Accuracy on Weigh Station Sorting*. Oregon Department of Transportation, under Contract for the Port of Entry Advanced Sorting System (PASS) Project. November 1993.

3. M. Halenbeck. *Cost of WIM Equipment Spreadsheet and Instructions*. Long Term Pavement Performance Project. Federal Highway Administration. No date given.

4. S. Ma and M. Caprez, Swiss Federal Institute of Technology Zurich. "The Pavement Roughness Requirement for WIM." *First European Conference on Weigh-in-Motion of Road Vehicles*. Switzerland. 1995.

5. T. Deakin, Trevor Deakin Consultants Ltd. "WIM Systems for High Speed Overloaded Vehicle Pre-Selection and Low Speed Enforcement Weighing." *First European Conference on Weigh-in-Motion of Road Vehicles*. Switzerland. 1995.

6. Caltrans. *Notice to Contractors and Special Provisions for Construction on State Highways in Riverside County*. State of California, Department of Transportation. July 1992.

7. M. Halenbeck, Washington State Transportation Center. *Draft Long-Term Pavement Performance Program Specification*. Federal Highway Administration. April 1996.

8. R. Quinley, Caltrans. Letter to Bill McCall. December 13 1995.

9. Missouri Highway and Transportation Department. *Missouri Best Practices Piezo WIM: Installation and Calibrations*. State of Missouri, Highway and Transportation Department. November 1996.

10. Arkansas State Highways and Transportation Department. *Traffic Data Collection Axle Sensor Modified Installation Procedure*. State of Arkansas, Highways and Transportation Department, Planning and Research Division, Technical Services Section. September 1994.

11. M. Krukar, Oregon Department of Transportation. "The Oregon Experience with Deep-Pit Single Load Cell WIM Systems: 1983-1996." *Presented at the National Traffic Data Acquisition Conference*. New Mexico. 1996.

12. R. Quinley, Caltrans. "Installation of Weigh-in-Motion Systems." *Presented at the National Traffic Data Acquisition Conference*. New Mexico. 1996.

13. Minnesota Department of Transportation. *Specifications for the Procurement of Weigh-in-Motion Systems of Bending Plate Technology with Associated Recording Equipment*. State of Minnesota, Department of Transportation. State Project number 4902-53, State Project number 8286-49. April 1993.

14. C. Dahlin, Minnesota Department of Transportation. Letter to B. McCall. June 5 1997.

15. Federal Highway Administration, Office of Highway Information Management. *Vehicle Travel Information System (VTRIS), User's Guide*. Office of Highway Information Management, FHWA, U.S. Department of Transportation. 1995.

16. R. Quinley, Caltrans. "Panel Discussion - WIM Data Quality Assurance." *National Traffic Data Acquisition Conference*. Connecticut. 1994.

17. R. Maynard, Caltrans. *California Maintenance Report*. State of California, Department of Transportation. August 1996.