Author:
Bill McCall
Iowa State University
United States of America

Obtained BSEE from Iowa State University. Held positions with the Iowa Department of Transportation and Lockheed Corporation. Joined Iowa State University in 1995, where he is Associate Director of the Center for Transportation Research and Education.

Abstract
The objective of this paper is to present a brief overview of the *States Successful Practices Weigh-in-Motion Handbook,* published December 1997, and prepared for the U. S. Department of Transportation, Federal Highway Administration, Travel Monitoring Division. The Handbook provides practical advice for users of weigh-in-motion (WIM) technology and is based on six guiding principles: 1) decide on “site design life” and accuracy necessary to support the end user, 2) budget the necessary resources, 3) develop and maintain a thorough quality assurance program, 4) purchase WIM equipment with a warranty, 5) manage the equipment installation, 6) conduct preventive and corrective maintenance on the site.
Keywords: Weigh-in-Motion, WIM.

1. Establish Site and WIM 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 and influence decisions concerning the type of equipment, location and condition of the site, installation of equipment, and analyses performed on the collected data.

1.1 Site Geometric Design and Location

The site selected for a WIM system should be based on meeting the required site design life and accuracy necessary to support the user requirements. The American Society for Testing and Materials (ASTM) Standard E 1318-94 sets the geometric guidelines for the horizontal curvature, longitudinal gradient, cross (lateral) slope, and 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 (American Society for Testing and Materials 1994). Further, the site needs to be located in an area with specific qualities including availability of access to power and phone, adequate location for controller cabinet, adequate drainage, and traffic conditions.

1.2 Site Pavement Condition

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" (American Society for Testing and Materials 1994). The standard also states that a foundation must be provided and maintained to accommodate the sensors.

California Department of Transportation's (Caltrans) successful practice requires that all WIM systems be installed in Portland cement concrete (PCC) pavement to provide roadway stability, durability, and smoothness to achieve a 10 to 15 year site design 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 (Caltrans 1992). 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 17,400 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 (Halenbeck 1996).

1.3 Establish WIM System Requirements

The first step in choosing a WIM system is to clearly define the requirements expected from the system, the staff resources necessary to monitor and maintain the system, the site design life and the accuracy level. 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.

1.4 Economic Analysis

According to research by Taylor and Bergan, each WIM system provides a different level of accuracy at different system and maintenance costs (Taylor and Bergen 1993). The least expensive WIM system uses piezoelectric technology and the most expensive use load cell technology. However, load cell technology provides a much more accurate estimate of static weight than piezo technology (see Table 1).

Table 1 - 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	$ 4,000
Bending Plate Scale	+/- 5%	$ 18,900	$ 5,000
Double Bending Plate Scale	+/- 3-5%	$ 35,700	$ 8,000
Deep Pit Load Cell	+/- 3%	$ 52,500	$ 7,000

The Handbook includes a spreadsheet developed for LTPP to estimate the cost of purchasing, installing, operating, and maintaining WIM equipment (Halenbeck no date). The spreadsheet allows for scale replacement, electronics replacement, pavement rehabilitation, calibration, and the necessary office and maintenance staff.

2. Budget for the Resources

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.

3. Develop and Maintain a Quality Assurance (QA) 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.

3.1 WIM Accuracy and QA

Although 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 QA program. 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.

3.2 Long Term Pavement Performance (LTPP) and Vehicle Travel Information System (VTRIS) Software

State agencies can use the LTPP software to help identify potential errors in any WIM data, whether or not they are intended for submission to the LTPP program, as long as those data are in a record format the LTPP QA software can read (Halenbeck 1996). VTRIS software replaces the Truck Weight Software and uses the standards, formats, and methods specified by the Traffic Monitoring Guide (TMG), 1995 edition (Federal Highway Administration 1995). VTRIS is a recommended, but not required, method to submit data to the Federal Highway Administration (FHWA) in a uniform format.

3.3 Caltrans Successful Practice: QA Program

The QA procedure developed by Caltrans is discussed in the Handbook as a successful practice, due in part to the 10-plus years experience they have using WIM data (Quinley 1994). Although their procedure bears several similarities to the procedure used for the LTPP program, it is distinctly different in many respects.

The Caltrans QA process applies to bending plate systems and consists of four parts (see Table 2). 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 included in the Handbook.

Table 2 - Quality assurance principles checklist

	Quality Assurance Principles
1	**Develop and maintain a thorough and scheduled data analysis program.**
2	**Fix any site problems the data analysis program reveals.**
3	**Part 1, Develop, maintain, and record a permanent site database.**
3.1	Record the site's physical characteristics.
3.2	Record the traffic and truck behavior.
3.3	Record the WIM system's vehicle processing.
4	**Part 2, Conduct a Real Time Review.**
4.1	Review of snapshot of the site's performance via telemetry.
4.2	Review the files for proper date, time, and sizes.
4.3	Review the real time data for proper axle weights and spacings.
4.4	Identify and repair any system component problems.
4.5	Identify and adjust any calibration parameter problems.
5	**Part 3a, Conduct a First Level Data Review - Summary Report.**
5.1	Identify any loop or loop processing problems.
5.2	Identify any erratic weighpad behavior causing ghost axles or missed axles.
5.3	Identify any time periods in which the WIM system is not reporting data.
6	**Part 3b, Conduct a First Level Data Review - Individual Truck Report.**
6.1	Identify any system equipment malfunctions.
6.2	Identify any atypical traffic patterns.
6.3	Identify any atypical truck operating characteristics.
7	**Part 4, Conduct a Second Level Data Review.**
7.1	Identify and correct any problems with the calibration parameters.
7.2	Identify and correct any problems with the weighpads.

3.4 System Calibration

Calibration is used to ensure that the estimation of the static weight produced by the WIM system is as close to the static weight as possible. System calibration offsets the effects of site conditions such as pavement temperature, vehicle speed, and pavement conditions. The ASTM Standard Specification E 1318-94 concerning highway WIM systems lists recommendations for the calibration procedure, which includes the acceptance and initial calibration processes (American Society for Testing and Materials 1994). 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 (see Table 3).

Table 3 - System calibration principles checklist

	System Calibration Principles
1	**Follow a set initial calibration procedure.**
2	**Perform two-part calibration procedure; acceptance and testing.**
3	**Perform acceptance testing.**
3.1	Perform a system component operations check.
3.2	Perform an initial calibration.
3.3	Perform a 72-hour continuous operation check.
4	**Perform fine tuning or recalibration when the outcome of the quality assurance data analysis indicates recalibration is necessary.**
5	**Automatic recalibration**

4. Establish WIM Equipment Warranty

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

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. Installation checklist is in Table 4.

Table 4 - Installation principles checklist

	Installation Principles
1	**Overall Process**
1.1	A Vendor representative should be on-site to ensure vendor requirements are met.
1.2	A State representative should be on-site to ensure state requirements are met.
1.3	Pre-construction meetings should be held before lane closure.
1.4	All necessary equipment, materials, and WIM components should be on-site before starting the job.
1.5	Complete site plans should be available on-site to ensure proper placement of equipment.
1.6	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.
1.7	Junction box and roadside cabinets need to be placed away from water collection areas.
1.8	An accurate set of as-built plans should be developed for future construction and maintenance work.

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. 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.

7. Conclusion

In conclusion, the intended use of the data collected using WIM is the major consideration when deciding on site design life and accuracy, developing the budget for resources throughout the site design life, developing and using a thorough quality assurance program, and conducting preventive and corrective maintenance on the site. Customer satisfaction is a key element in achieving successful WIM data collection program.

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