WEIGH-IN-MOTION POCKET GUIDE

PART 1

WIM TECHNOLOGY, DATA ACQUISITION, AND PROCUREMENT GUIDE

U.S. Department of Transportation
Federal Highway Administration
Office of Highway Policy Information

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NOTICE

QUALITY ASSURANCE STATEMENT

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https://www.fhwa.dot.gov/policyinformation/knowledgecenter

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A/C	Alternating current
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt concrete
ACF	Axle Correction Factor
ALDF	Axle Load Distribution Factors
APT	Axles per Truck
B-WIM	Bridge WIM
BP	Bending plate
CDS	Comparison data set
CPU	Central Processing Unit
DC	Direct Current
DOT	Department of Transportation
DOW	Day of the week
ESAL	Equivalent single axle loading
FHWA	Federal Highways Administration
GFCI	Ground-Fault Circuit Interrupter
GPS	Global Positioning System
GVW	Gross Vehicle Weight
HDF	Hourly Distribution Factor
HOD	Hour of the day
IRI	International Roughness Index
LC	Load cell
LPR	License plate reader
LTPP	Long-Term Pavement Performance
MAF	Monthly Adjustment Factors
MEPDG	Mechanistic-Empirical Pavement Design Guide
MOT	Maintenance of traffic
MOY	Month of the year
MUTCD	Manual for Uniform Traffic Control Devices
NCR	Non-Compliance Report
NEMA	National Electrical Manufacturers Association
OWL	Optimal WIM Locator
PCC	Portland cement concrete
PPE	Personal protection equipment

PV	Photovoltaic
PVC	Polyvinyl Chloride
PVF	Per Vehicle Format
QA	Quality assurance
QC	Quality control
RMC	Rigid metal conduit
SIM	Subscriber identity module
SPS	Special Pavement Studies
TMG	Traffic Monitoring Guide
TMAS	Travel Monitoring Analysis System
TPF	Transportation Pooled Fund
U.S.	United States
UL	Underwriters Laboratories
VCD	Vehicle Class Distribution
VWS	Virtual Weigh Station
WIM	Weigh-in-Motion

INTRODUCTION TO WIM POCKET GUIDE

Purpose of WIM Data Collection

Weigh-in-motion (WIM) is a primary technology used for monitoring vehicle weights and axle loads on roadways. Traffic loading data collected by WIM include wheel (single or dual tires) loads, axle loads, and gross vehicle weights (GVW). These data can be reported for each vehicle that passes over a WIM sensor. In addition, WIM devices collect traffic volume, axle spacings, vehicle classification, and speed data.

State and other highway agencies collect WIM data for many reasons, including highway planning, pavement and bridge design, freight movement studies, motor vehicle enforcement, and legislative and regulatory studies (e.g., truck weight and size studies). Motor vehicle enforcement officers use heavy truck axle load data to plan enforcement activities, as well as to screen and identify specific vehicles that violate weight limits during real time on-site monitoring. Highway planners and designers use WIM data to develop summary statistics by time of day, day of week, month of year, and annually. These summary statistics are used to develop inputs for pavement and bridge design, including equivalent single axle loadings (ESAL) and axle load distributions.

Purpose of the WIM Pocket Guide

This guide serves as a quick reference source for common WIM topics. The guide provides sufficient technical details that enable traffic monitoring professionals to make sound decisions on WIM-related issues. It is built on states' successful practices in using WIM systems and references the available standards and guides related to WIM data collection. It contains practical advice and easy-to-follow instructions and illustrations. In addition, the guide has four instructional video supplements that show installation for different types of WIM sensors. The guide also contains references to web-accessible appendices that provide guidance on the various elements of procuring, installing, and maintaining WIM systems.

Guide Content and Organization

The Federal Highway Administration (FHWA) Weigh-In-Motion (WIM) Pocket Guide consists of three main text documents, four instructional video supplements, and six appendices. The video supplements and appendices are only available on the FHWA website:

https://www.fhwa.dot.gov/policyinformation/knowledgecenter.

The WIM Pocket Guide is divided into three parts intended for use by different personnel involved in WIM operations. Each part is as a self-contained document available in paper and electronic formats.

- **Part 1** – WIM Technology Selection, Data Acquisition Requirements, and Procurement Guide
  - ◎ Target audience: WIM program manager, WIM program-level decision maker.
- **Part 2** – WIM Site Selection, Design, and Installation Guide
  - ◎ Target audience: Traffic engineer or senior specialist, WIM site-level decision maker.
- **Part 3** – WIM Maintenance and Calibration Guide
  - ◎ Target audience: Technician involved in routine WIM maintenance and calibration.

INTRODUCTION TO PART 1

Purpose

This document is designed to assist WIM program managers with program-level decision making, including review of WIM measurement principles and applicable standards, selection of WIM sensor and controller technologies, development of contract language for data acquisition and data format requirements, and analysis of WIM costs.

Principles of Weighing in Motion

The process of weighing vehicles in motion is designed to capture and record axle spacings and weights by wheel (single or dual tires), axle, and/or total vehicle (GVW) as vehicles drive over sensors installed in a roadway or under a bridge. In

In ASTM E1318 – 09 Standard Specification for Highway Weigh-In-Motion (WIM) Systems with User Requirements and Test Methods, 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.” *(1)*

Weighing vehicles at normal operational speed makes the weighing process more efficient and less disruptive than pull-out permanent or portable static weigh stations that require vehicles to be stopped. These systems measure the transient forces applied by the tires as vehicles pass over the sensor. Dynamically measured forces are used to estimate the weight of the vehicle when it is at rest. Several WIM technologies exist to capture the applied forces and predict static weight; these technologies are described in the next chapter.

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WIM Standards and Performance Requirements

ASTM E1318-09 is the primary WIM standard accepted in the U.S. *(1)*. Other countries have their own standards *(2, 3)*. The ASTM E1318-09 standard classifies WIM systems according to four distinct types, depending on the application and functional performance requirements.

ASTM E1318-09 WIM Types

- **Type I and Type II systems:** Suitable for traffic data collection purposes, with Type I systems having slightly more stringent performance requirements. Vehicle speed range to meet functional performance requirements is 10 to 80 mph.
- **Type III systems:** Suitable for screening vehicles suspected of weight limit or load limit violations and have stricter functional performance requirements than Type I and Type II systems. Vehicle speed range to meet functional performance requirements is 10 to 80 mph.
- **Type IV systems:** Not approved for use in the United States but intended for use at weight enforcement stations. Vehicle speed range to meet functional performance requirements is 2 to 10 mph.

Table 1 summarizes the ASTM E1318-09 WIM system performance requirements. The 95 percent compliance defined in ASTM E1318-09 specifies the minimum percentage of measurements (i.e., no less than 95 percent) that should be within the specified tolerances to satisfy the performance requirements. Since Type IV WIM systems have not yet been approved for use in the United States, specifications for these systems are not provided.

Table 1 – ASTM 1318E-09 Functional Performance Requirements for WIM Systems

Function	Tolerance for 95% Compliance		
	Type I	Type II	Type III
Wheel Load*	±25%		±20%
Axle Load	±20%	±30%	±15%
Axle-Group Load	±15%	±20%	±10%
Gross Vehicle Weight	±10%	±15%	±6%
Speed	±1 mph		
Axle-Spacing and Wheelbase	±0.5 ft		

* Includes single or dual tires

Enhanced WIM performance requirements were developed under the FHWA Long-Term Pavement Performance (LTPP) Program in an effort to collect research-quality WIM data *(4).* LTPP tolerances are the same as in ASTM E1318-09, but instead of 95 percent compliance, LTPP uses a statistically computed 95 percent confidence interval plus mean error to characterize the spread of measurement error and compares it with the tolerances listed in Table 1. The LTPP performance requirements include provisions for performance testing at three temperature and three speed ranges, requirements for road smoothness, and requirements for the accuracy of the vehicle length measurements.

WIM TECHNOLOGY REVIEW

WIM System Components

The major components of permanent WIM systems include:

- WIM sensors embedded in the roadway surface or placed on the surface or on/under a bridge deck to detect, weigh, and classify vehicles. The combination of WIM sensors and loop detectors within a weighing lane is called the sensor array.
- Electronics to control system functions, measure and process sensor outputs, and provide vehicle records for display and storage.
- Infrastructure, including conduit, directional bore, cabinet, poles, and junction boxes.
- Support devices, such as power (A/C, wind or solar) devices to power the WIM electronics, lightning protection, grounding rods, and communication devices to transmit the collected data to a remote server.
- Software and/or firmware installed in the WIM electronics to process sensor measurements, analyze, format, and temporarily store collected data.

An example of a typical WIM system design is shown in Figure 1. In this example, two full lane-width WIM sensors are installed in each lane, providing a double-threshold configuration. For quartz piezo sensor layouts, two half-lane width sensors are installed adjacent to one another to create a full-lane width sensor.

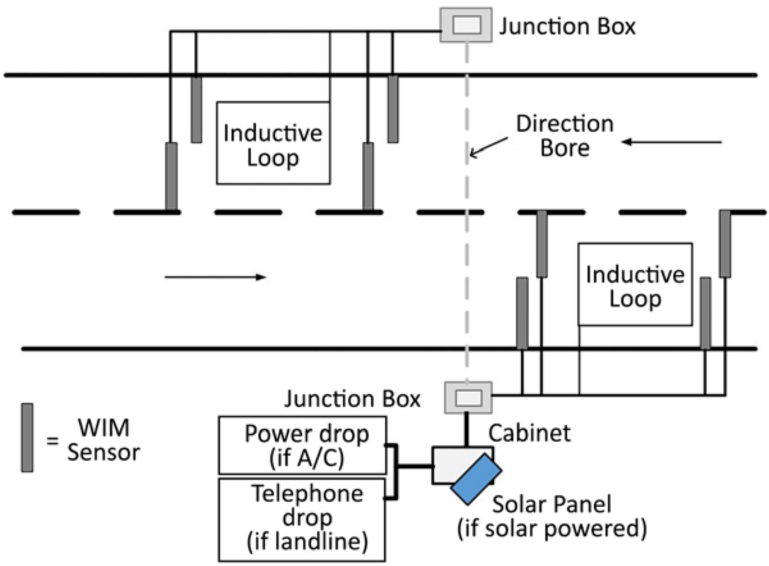


Figure 1 – Typical 2-Lane Bidirectional WIM System Design

Most of the WIM system infrastructure is buried, either beneath the pavement or in the soil. Junction boxes, such as the one shown in Figure 2, are installed to route the sensor wires to the cabinet and provide access for splicing the sensor wires, if used.

Figure 2 – Junction Box (lid cover removed)

The WIM controller, supporting electronics, and communications devices are usually located in a roadside cabinet (see Figure 3).

Figure 3 – Cabinet Interior Components

Communication devices may include telephone jacks or a cellular modem, which is shown in Figure 4.

Figure 4 – Cellular Modem

The following sections provide more details about the WIM system components, including the in-road WIM sensors and the WIM controller. For information about installation of the sensors and infrastructure components, refer to Part 2 of the guide.

Inductive Loops

Inductive loops are frequently installed in the roadway as part of the WIM array. They consist of four parts: a wire loop of one or more turns of wire embedded in the roadway pavement, a lead-in wire running from the wire loop to a pull box, a lead-in cable connecting the lead-in wire at the pull box to the controller, and an electronics unit housed in the controller cabinet. The electronics unit contains an oscillator and amplifiers that excite the embedded wire loop *(5)*. Not all WIM arrays require the use of a loop sensor, such as the portable WIM array.

If inductive loops are used as part of the WIM array, several considerations need to be addressed:

- The number of inductive loops, and their locations within the array, differs according to WIM controller manufacturer and application.
- Loop sizes vary based on the lane width. Loops sizes of 8 feet by 6 feet are gaining popularity to accommodate motorcycle counting.
- Loops within an array, and loops installed in adjacent lanes, must be installed far enough away from one another to avoid interference, or “crosstalk.”
- The loop lead-ins must be twisted, and the twisted loop lead-ins for each loop must be run in separate slots to avoid crosstalk.
- A second loop may be installed to provide a back-up mechanism for capturing timing information should one of the WIM sensors fail to detect the wheel as it passes.

WIM Sensors

Sensor Types

Several types of in-road WIM sensors are available in the United States. The most frequently used sensors include bending plate, load cell, quartz piezo, polymer piezo, and the strain gauge strip sensor. Sensors like bending plate and load cell are wide and allow the full tire footprint to rest on the sensor. Other sensors are narrow and come in contact only with a part of the tire footprint at any given time, as a vehicle moves over the sensor. The narrow sensors, also called strip sensors, include polymer piezo, coax piezo, quartz piezo, and strain gauge strip sensor.

The WIM sensors vary in accuracy and cost, and each sensor type has advantages and disadvantages that must be considered during the selection process. Details about each sensor type are provided in the ensuing sections.

Sensor Selection Considerations

The required level of data quality (WIM measurement accuracy) combined with the available funding often drives the type of installation/sensor an agency will use. A higher level of data quality requires more precise WIM sensors and system.

Six Key Questions for Sensor Selection

When considering the type of sensor and array to use, five key questions need to be addressed:

1. How many WIM sites are needed, and what funding is available? The requirement for a greater number of sites (for more comprehensive road network coverage) typically requires selection of a less accurate sensor to stay within budget constraints.
2. What level of weight data accuracy is acceptable for users? Higher levels of accuracy would require more expensive sensors or a different sensor array, which may lead to a decision to have fewer sites, to stay within budget constraints.
3. Do you need WIM in all lanes and directions?
4. What are the personnel, material, and equipment costs associated with maintaining each WIM site?
5. What is the pavement type and its current condition?
6. Is it likely that pavement condition would deteriorate over the intended WIM service life? If so, what is the cost of maintaining the pavement over the intended WIM data collection period?

If users require high accuracy weight data collection over long periods of time, and the budget allows for high accuracy sensors/arrays and maintenance of pavement smoothness and pavement integrity at the WIM site locations, then either a load cell or bending plate sensor is the preferred solution. The accuracy of WIM systems utilizing these technologies meets or exceeds all the requirements for highway truck weight data monitoring.

Over long periods of data collection (say, more than 7 years), the difference in life cycle costs of bending plate and load cell, when compared to piezo sensors, decreases while data quality stays consistently high, if properly maintained/calibrated. These sensors have to be installed in portland cement concrete (PCC) pavements. If the pavement is asphalt concrete (AC), the installation of a continuously reinforced concrete pavement segment (preferably with no joints) is recommended to improve the structural integrity of the WIM site installation. This recommendation should be weighed against the agency's requirements for minimum/maximum PCC slab length and pavement type.

The formula below (recommended by TRB/FHWA LTPP Traffic Expert Task Group, author David Cebon) may be used to determine the appropriate length of the concrete slab based on the speed of truck traffic at the site. For typical highway speed, total slab length is 300 to 400 feet. (For a 400-foot slab, use 325 feet before the array and 75 feet after the array.)

Slab length in feet = 2.93(Truck Speed in mph) + 150*

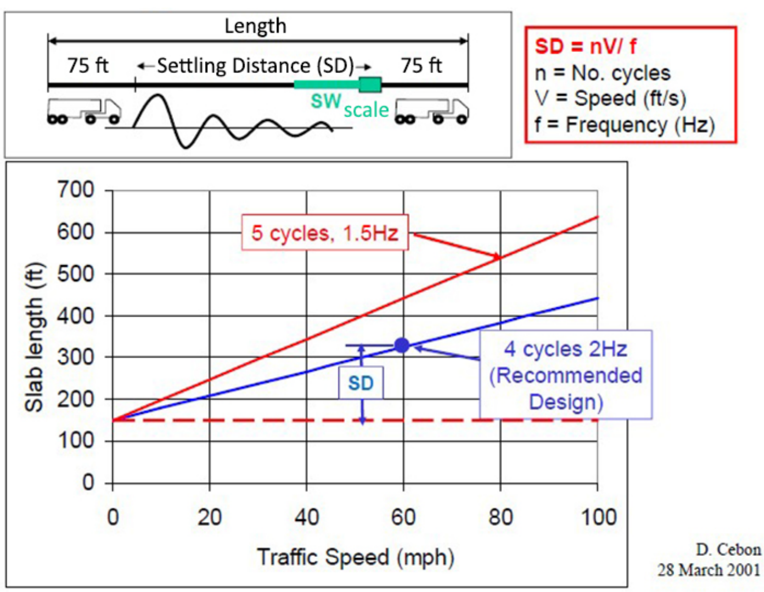


Figure 5 – Slab Length for Minimum WIM Error

If pavement conditions that initially meet ASTM E1318-09 specifications cannot be maintained over a long time period (over 3 years), then polymer piezo sensors may be the only viable choice based on functionality and cost. The flexibility of the polymer piezo enables it to tolerate some pavement rutting, and the cost is less than that of the other WIM sensors. Also, when the sensor's ability to collect accurate weight degrades, the WIM site could be converted to a vehicle classification site so the agency's investment can continue to be productive.

Polymer piezo sensors are affected by temperature fluctuations and by seasonal changes in pavement stiffness. Consequently, polymer piezo sensors must be calibrated every 6 to 12 months to maintain accuracy in weight measurements. Also, due to precision limitations, the polymer piezo sensor is less capable of accurate prediction of heavy loads and loads over the legal limit. However, when installed on high truck volume roads and properly calibrated, they adequately predict the average axle loads and GVW, typically within ASTM WIM Type II performance requirements.

Sensors like the quartz piezo and strain gauge strip sensor fall in between the two classes of sensors described above in terms of cost, accuracy, and longevity and calibration. As a result, these sensors frequently represent a desirable combination of cost and accuracy. Quartz piezo and strain gauge strip sensors can be installed in both AC and PCC pavements. This versatility, along with accuracy and cost considerations, makes these sensors a popular choice for new WIM installations.

In summary, it is the required level of data quality combined with the ability to maintain a smooth pavement condition that determines how long a WIM site can be operated. Load cell or bending plate sensors would be the choice for projects with a typical life expectancy of 8 to 10 years, provided the PCC pavement requirement can be satisfied. Quartz piezo or strain gauge strip sensors are the best options for 3 to 5 years. Additional site longevity for these sensors could be gained by using a double threshold configuration. Piezo polymer sensors are best suited for short-term studies of 1 to 3 years, or where a smooth pavement condition cannot be achieved or maintained, provided that lower accuracy and average weight vs. high precision heavy and overweight measurements are acceptable.

The function, accuracy, and typical application for each type of WIM sensor, along with the strengths and weaknesses of each, are discussed in greater detail in the following sections.

Bending Plate

Sensor Description

Bending plates utilize strain gauges bonded to the underside of the plate to collect loading data. The bending plate WIM sensor, illustrated in Figure 6, is typically 6 feet long, 20 inches wide, and 1 inch thick. It weighs approximately 250 pounds. It may be black or grey in color. Figure 7 shows a bending plate installed in the pavement.

Figure 6 – Bending Plate Sensor

Figure 7 – Bending Plate Installation

How it Works

As axles pass over the bending plate, the system measures the strain on the plate approximately 2,000 times per second at highway speeds and calculates the load required to induce that level of strain.

Sensor Configuration and Layout

Each bending plate is installed to cover one-half of the travel lane. Therefore, there are typically two bending plates installed in each lane. For Type I and Type II WIM systems, the bending plates are typically installed in a staggered configuration, as shown in Figure 8. In this configuration, the first loop provides vehicle detection and signals the presence of a vehicle. The bending plates provide the weights and the timing information to determine speed and axle spacing. A second loop may be installed, which is used for timing if full contact is not made with either of the bending plates.

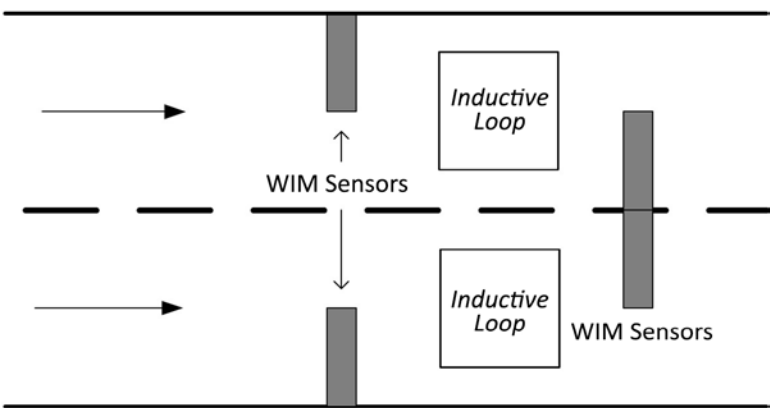


Figure 8 – 2-Lane Unidirectional Bending Plate – Staggered Configuration

Alternatively, the in-line configuration shown in Figure 9 provides single threshold detection. In this configuration, the bending plates provide weight information and the loops provide vehicle presence and the timing information for speed and axle spacing. The speed and axle measurements are less accurate with this configuration than with the staggered configuration since they are using an inductive field rather than axle detection for timing.

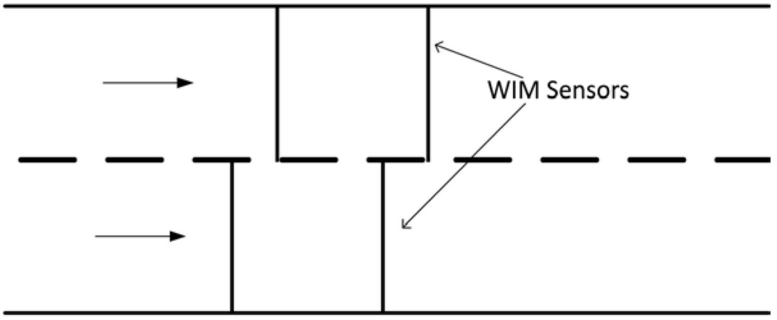


Figure 9 – 2-Lane Unidirectional Bending Plate In-Line Sensor Configuration

The configuration for Type III WIM systems, as shown in Figure 10, utilizes four bending plates installed in two lines—before and after the trailing loop inductor. These systems are typically low-speed and are installed in a single lane either before or in a weigh station for pre-screening and sorting.

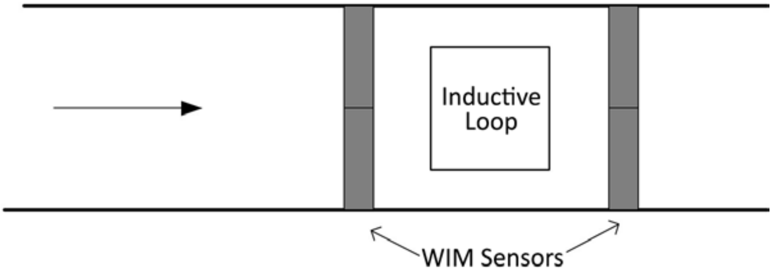


Figure 10 – Single Lane Type III Sensor Configuration

Strengths

The bending plate has proven to be one of the most accurate WIM technologies available in the U.S., capable of producing consistently accurate data over time when regularly maintained. When installed and maintained properly in good pavement, the bending plate sensor and mounting frame are very durable and may last 8 to 12 years when installed in new concrete pavements. The bending plate sensor demonstrates very little speed dependency, especially in smooth pavements, and almost no temperature dependency. These sensors are capable of achieving a calibration accuracy range of +/- 3.0 percent. The initial cost of the bending plate sensor is slightly more than quartz piezo sensors or strain gauge strip sensors and less than load cell sensors.

Weaknesses

The bending plate sensor is typically only recommended for use in PCC pavements. AC pavement designs with the proper depth and material composition have shown some success. If installed in AC pavement, the pavement around the frame begins to break up after time and allows the frame to become loose, creating a hazard for the traveling public. To avoid this problem, a concrete vault may be installed to embed the frames or a concrete road segment may be installed, but this increases the cost significantly and may lead to pavement distress over time, causing adverse truck dynamics and decreasing WIM system accuracy.

Bending plate maintenance should be performed on an annual basis. Service intervals in warm climates can be increased to 2 years. Bending plate maintenance requires short-term lane closure and may pose some safety risk to WIM technicians. Proper traffic control is essential.

Accuracy

This system can be classified as an ASTM Type I, II, or III system, depending on the application of the device and the number of scales placed in the lane. The bending plate system, when properly installed in smooth pavement, well maintained, and calibrated may consistently provide accuracies well within ASTM 1318-09 Type III performance specifications. When properly installed and calibrated, bending plate WIM systems using two 6-foot-long bending plates in each lane may be expected to provide GVW with an error of 10 percent or less of the actual vehicle weight for 95 percent of the trucks measured. For example, the bending plate sensor typically provides GVW measurement accuracy within +/- 4.0 percent over time, according to a study conducted on the LTPP bending plate installations *(6)*.

Recommended Use

The bending plate sensor is well suited for a variety of applications, including weight enforcement, pre-screening for static truck scales, research requiring high-quality traffic loading data, highway and bridge design, planning, and warranty. This sensor is the most cost-effective method for long-term data collection that requires a high degree of accuracy. Bending plates are frequently used to collect loading data when the user specifies ASTM E1318-09 Type I WIM performance requirements.

Load Cell

Sensor Description

The load cell scale system consists of two weighing platforms, each with a surface size of 6 feet by 3 feet, 2 inches, placed adjacent to each other to fully cover a 12-foot traffic lane in line or in a staggered configuration. Hydraulic or mechanical transducers measure the force applied to the scale. The installation of a load cell scale requires the use of a concrete vault. The size of vault can be as large as 12 feet long, 5 feet wide, and nearly 3 feet deep. The load measurements are recorded and analyzed by the system electronics to determine tire and axle loads. Figure 11 shows an illustration of a load cell sensor. Figure 12 shows a load cell installed in the pavement.

Figure 11 – Load Cell Sensor

Figure 12 – Load Cell Installation

How it Works

Load cell WIM systems utilize two scales to detect an axle and weigh both the right and left side of the axle approximately 2,000 times per second at highway speeds per axle passage. The scale mechanism transfers loading on the weighing surface to the load cell sensor. The load cell sensor utilizes a transducer which creates an electrical signal whose amplitude is directly proportional to the force being measured. The system records the weights measured by each scale and sums them to obtain the axle weight. Storing data from the individual load cells by wheel weights is the best method, and this can be presented using the data format described in the 2016 FHWA Traffic Monitoring Guide (TMG) per vehicle format (PVF) “Z” data format *(7)*.

Sensor Configuration and Layout

Typical load cell system configurations consist of two load cell platforms and at least one inductive loop. It may also include an axle detector and/or an independent off-scale detector. There are two standard layouts for the load cell WIM system.

For the in-line configuration (shown in Figure 13), a load cell threshold is placed across the traffic lane. It uses two in-line scales. The inductive loops are placed upstream and downstream of the load cells to detect vehicles and alert the system of an approaching vehicle. An axle sensor may be placed upstream of the load cell to determine axle spacing and vehicle speed.

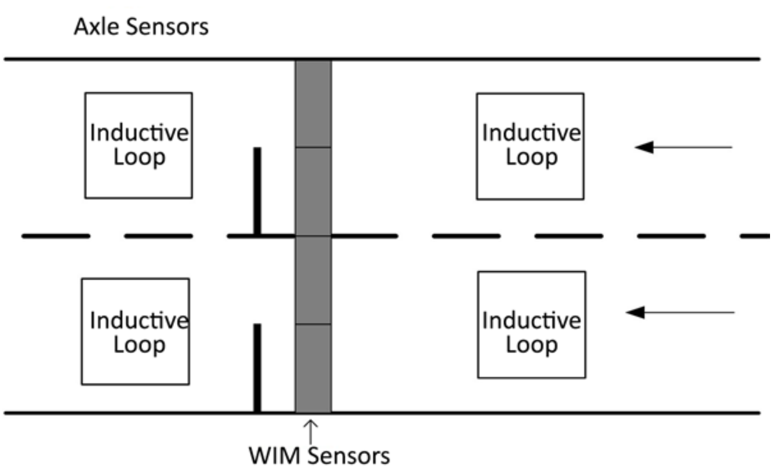


Figure 13 – 2-Lane Unidirectional In-Line Load Cell Configuration

Load cells may also be installed in a staggered configuration, as shown in Figure 14. Off-scale detectors may be installed independently or integrated into the scale assembly to sense any vehicles off the weighing surface.

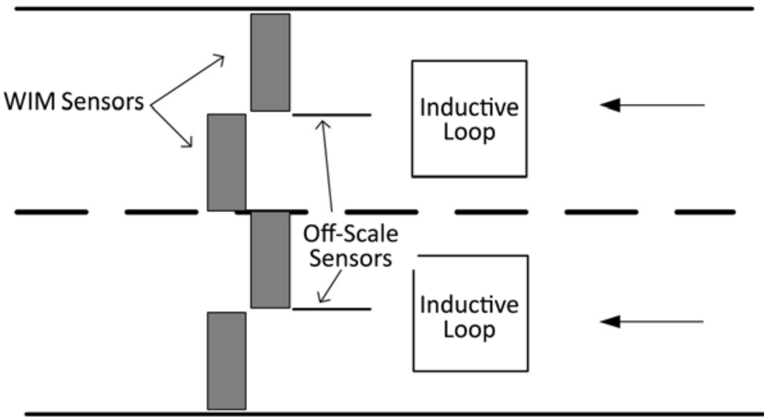


Figure 14 – 2-Lane Unidirectional Staggered Load Cell Configuration

Strengths

This sensor is the most accurate among the commercially available WIM sensors. Based on feedback from state agencies, the load cell sensor could consistently measure GVW with an accuracy of +/- 6 percent error or better at highway speeds. The load cell sensor, when properly installed and maintained, can be expected to last up to 12 years before major refurbishing work is required, which may add another 12 years of service life. The scale frame and vault have an expected service life of 25 years. Based on the high accuracy expectation of the load cell WIM system, the load cell system should be calibrated every 12 to 24 months. Sites requiring highly accurate data, such as weight enforcement and research-related sites, should be calibrated annually. Sites used for planning or freight movement may be calibrated up to every 24 months.

Weaknesses

The load cell scale is the most expensive and time-consuming WIM sensor to install. The installation of a load cell scale requires the use of a crane and the installation of a concrete vault. This installation often makes the load cell cost-prohibitive for highway applications, unless data collection is for a longer term (10 years or more). It is also difficult to implement in asphalt pavements (due to the concrete vault requirement).

Accuracy

Based on manufacturer information, when properly installed and calibrated, load cell WIM systems should be expected to provide GVW that are within 6 percent of the actual vehicle weight for 95 percent of the trucks measured (ASTM Type III). This system can also be classified as ASTM Type I or II, depending on the application. These WIM sensors have a history of being the most accurate WIM sensor, providing better than ASTM Type III accuracy over the 12-year life of the sensor.

Recommended Use

Load cell WIM scales can be used in low, medium, or high speed weigh-in-motion applications. Since the load cell provides high accuracy, it is best suited for data collection and enforcement pre-screening applications (both on mainline and ramp applications).

Polymer Piezo Sensor

Sensor Description

The basic construction of the polymer piezo sensor consists of a copper strand, surrounded by a piezoelectric polymer material, which is covered by a brass sheath (see Figure 15). The polymer piezo sensor can be ordered in several different sensor and lead-in cable lengths. A WIM system utilizing the polymer piezo WIM sensor consists of at least two full-lane polymer piezo WIM sensors and one inductive loop (see Figure 16). Polymer piezo sensors are classified as class 1 and class 2 accuracy by manufacturers. A class 1 sensor is needed for WIM installations. Class 2 sensors are suitable for vehicle classification monitoring. To improve accuracy, four full-length sensors should be used in each weighing lane, as shown in Figure 17.

Figure 15 – Polymer Piezo Sensor

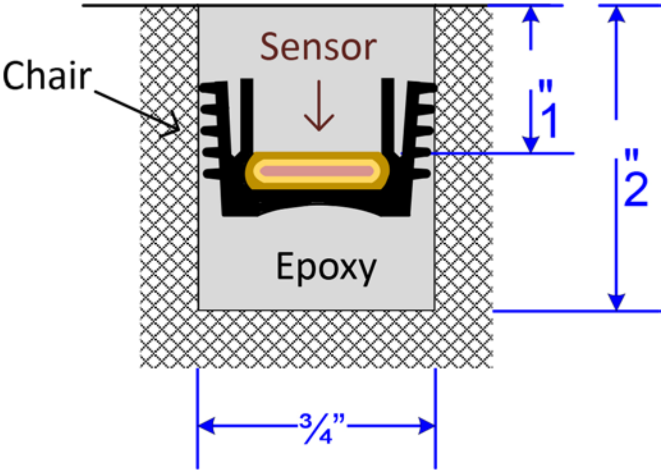


Figure 16 – Polymer Piezo Installation Depiction

Sensor Configuration and Layout

Each polymer piezo sensor is typically installed for half-lane coverage, with four sensors installed in each lane, 2-inch deep slot, with at least 1 inch of grout cover. Each set of sensors in each wheel path is spaced 16 feet apart. A chair is used to hold the sensor in place during installation. Using four sensors in this way provides a dual-threshold capability. A single inductive loop is installed between the two sets of staggered WIM sensors to provide vehicle presence detection and vehicle length measurement. The sensors are placed in the travel lane perpendicular to the direction of travel.

How it Works

Polymer piezo WIM systems utilize piezo sensors to detect a change in voltage caused by pressure exerted on the sensor by the tires on an axle. When pressure is applied to the piezoelectric material, an electrical charge is produced. The larger the charge, the greater the output signal amplitude, the more the weight. By measuring and analyzing the charge produced, the weight due to a passing tire or axle group can be estimated. As a vehicle passes over the piezo sensor, the system records the electrical charge created by the sensor and calculates the dynamic load.

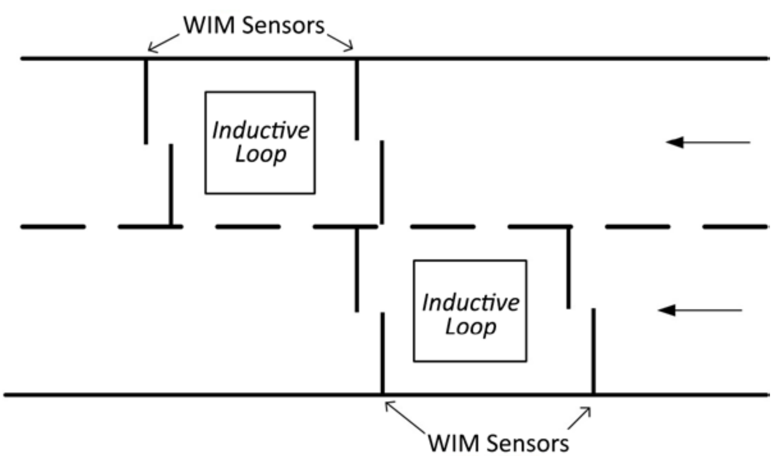


Figure 17 – 2-Lane Unidirectional Polymer Piezo 2-Sensors per Lane Configuration

Strengths

Polymer piezo WIM systems are the least expensive among WIM systems. The sensors are the easiest to be installed and replaced. In addition to measuring traffic loads, polymer piezo sensors are widely used for vehicle classification. The sensor installation is very durable, so the sensor rarely needs to be replaced due to the sensor becoming loose in the roadway. With proper calibration and temperature compensation, these sensors could be used for monitoring of average truck loads on high truck volume roads.

Weaknesses

Polymer piezo sensors are much less accurate than bending plates, load cells, linear strain gauges, or quartz piezo sensors due to temperature sensitivity and sensitivity to changes in pavement stiffness. The need for auto-calibration also limits applicability of these sensors on roads with low truck volumes. Some WIM vendors' controllers utilize a temperature compensation function that uses a temperature probe embedded in the roadway as a way of reducing the effect of temperature on the sensor operation. To be successful, this function needs to be set based on the sensor behavior observed over time at the WIM site. Polymer piezo sensors are not suitable for accurate measurement of overloads or a narrow range of heavy loads; they are better suited for monitoring average truck loads. Use of piezo polymer sensors is more successful in temperate climates (less temperature effect) and on high truck volume roads (more successful auto-calibration).

These sensors require frequent calibration due to high sensitivity to temperature changes—a 30 to 50 percent voltage change in sensor output may be expected when passing through 32 °F. Auto-calibration used to compensate for temperature sensitivity may not be successful in providing accurate measurements of heavy loads for multi-axle groups on low-volume roadways, since the effectiveness of the auto-calibration feature is highly dependent on a high enough number of front-axle measurements to compute reasonably accurate compensation (auto-calibration) factors. Auto-calibration effectiveness is also diminished if a stable relationship between the front axle weight and the weight of heavy axle groups cannot be successfully defined at the site.

The service life of these WIM sensors is the shortest among all WIM sensors, typically 1 to 3 years.

Narrow-width sensors may have higher error when compared to wider bending plates or load cells due to additional approximations resulting from the fact that the sensor measures only part of the tire footprint at any point in time.

Roadway roughness resulting in adverse truck dynamics also plays an important role in any strip-type sensors.

Accuracy

When properly installed and calibrated on roads with truck volumes that provide conditions for an effective auto-calibration and temperature compensation, a polymer piezo WIM system using four half-lane width sensors could provide GVW measurement accuracy that is within 15 percent of the actual vehicle weight for 95 percent of the trucks measured on most days. This is consistent with the requirements for ASTM E1318-09 Type II WIM systems. This accuracy is likely to deteriorate with time or temperature changes or with pavement deterioration. Semi-annual or a data quality driven calibration schedule may be needed to maintain the desired accuracy level, especially in regions with wide changes in seasonal temperatures. The auto-calibration feature is ineffective for low truck volume roadways.

Recommended Use

The polymer piezo sensor is well suited for determining whether roadways are loaded or unloaded, monitoring average truck weight on the roads with heavy truck volumes, and large-scale WIM data coverage studies where accuracy is less important than the number of measurement locations. This sensor is most cost-effective for short- to mid-term data collection. Polymer piezo sensors can be installed in any types of AC or PCC pavements. Polymer piezo sensors are frequently used to collect loading data when the user specifies ASTM E1318-09 Type II WIM performance requirements. With proper installation and frequent calibration, it is possible to collect loading data that meet ASTM E1318-09 Type I WIM performance requirements for roads with high volumes of class 9 trucks, especially in temperate climatic regions.

Quartz Piezo Sensor

Sensor Description

Each quartz piezo sensor is either 1.5 or 2 meters in length and can be combined in varying lengths to provide half-lane or full-lane width coverage. The quartz piezo WIM sensor is approximately 2 inches wide, 2 inches thick, and weighs 12 to 20 pounds, depending on the length of the sensor. Figure 18 illustrates a quartz piezo sensor. Figure 19 illustrates a quartz piezo sensor embedded in a pavement cross section.

Figure 18 – Quartz Piezo Sensor

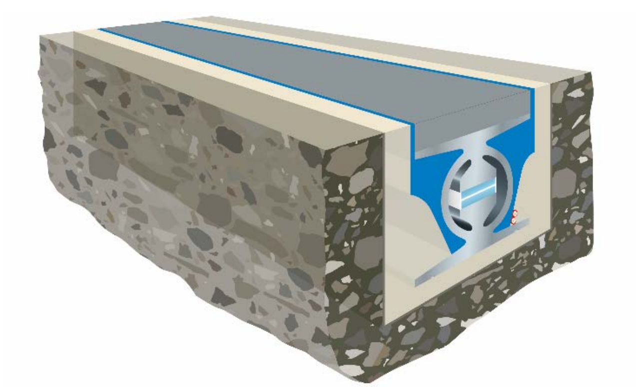


Figure 19 – Quartz Piezo Installation Depiction

Sensor Configuration and Layout

To maximize measurement accuracies by improving the sampling of each side of the vehicle, the sensors are typically installed to cover one-half of the travel lane, two for the left wheel path and two for the right wheel path, with each set of staggered sensors spaced 16 feet apart. Figure 20 illustrates this sensor configuration.

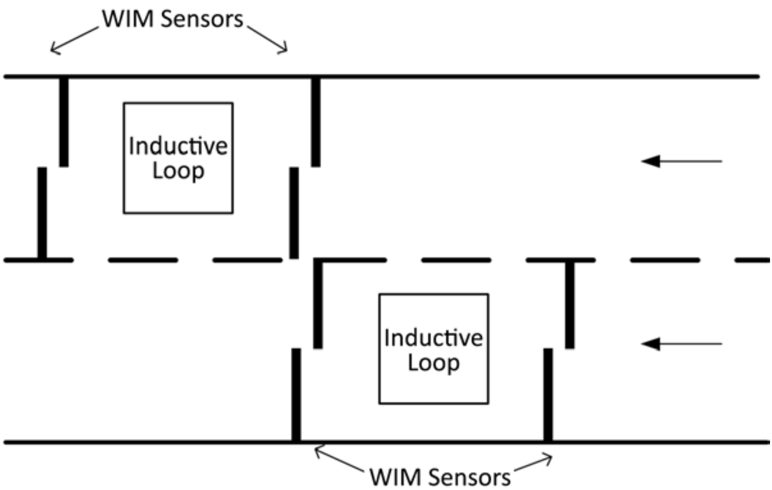


Figure 20 – 2-Lane Quartz Piezo Sensors Staggered Double Threshold Configuration

How it Works

The quartz piezo WIM sensor is a force sensor based on quartz crystal technology. A wheel rolling over the sensor applies vertical forces which are distributed through the quartz crystals in the sensor. The quartz elements produce an electrical charge that is proportional to the vertical forces applied.

Strengths

Quartz piezo WIM sensors can be installed in AC (over 4 inches thick) or PCC pavements, but the installation is much more durable in PCC pavements. The sensors themselves are ordinarily maintenance free. In case of pavement rutting, the top of the sensor may be ground to conform to the pavement surface, which helps maintain system accuracy. The quartz sensor material has the distinct advantage of being much less sensitive to changes in temperature as compared to polymer sensors, but it is more expensive, per sensor, than the other piezo style sensors. Unlike load cell or bending plate systems, the quartz piezoelectric sensor requires almost no maintenance but needs to be calibrated every 12 to 18 months to meet Type I WIM system accuracy requirements due to calibration drift. There is more than one type of quartz piezo sensor available.

Weaknesses

Because the sensor relies on structural support from the pavement, if the pavement strength is significantly affected by environmental conditions (material softening due to high temperatures, high soil moisture content), the sensor output may be also affected by these changes in pavement support, even though the sensor material itself is not affected by the temperature. These sensors continue to be popular due to easier and less costly installation.

Narrow-width sensors may have a higher range of error (less precision) when compared to wider bending plates or load cells due to additional approximations resulting from the fact that only a partial tire footprint is being measured at any point in time. However, one manufacturer of quartz piezo WIM sensors has been certified by the International Organization of Legal Metrology for vehicle weighing with quartz sensors at highway speeds. This certification paves the way for the use of quartz piezo sensors in weight enforcement applications.

Roadway roughness, which results in adverse vehicle dynamics, plays an important factor in the quality of the data, as with any in-the-road WIM system.

Accuracy

This system can be classified as an ASTM E1318-09 Type I or Type II system depending on the use of the device and the number of scales placed in the lane. To meet ASTM E1318-09

Type III requirements, the full-width, double-threshold configuration must be used. The quartz piezo system, when properly installed in smooth pavement, well-maintained, and calibrated may consistently provide accuracies well within ASTM E1318-09 Type I specifications. For example, quartz piezo sensors typically provide GWV measurement accuracy within +/- 6 percent, based on the long-term monitoring of the performance for the FHWA LTPP WIM systems that use the quartz piezo sensor.

Recommended Use

WIM systems utilizing the quartz piezo sensor are well suited for a variety of applications, including pre-screening for static truck scales, research requiring high accuracy WIM data, pavement and bridge design, planning, and warranty. This is frequently the sensor of choice for collecting axle loading data for pavement design. Quartz piezo sensors are frequently used to collect loading data when the user specifies ASTM E1318-09 Type I WIM performance requirements. This sensor is most cost-effective for mid-term data collection (3 to 5 years) that requires a high degree of accuracy.

Strain Gauge Strip Sensor

Sensor Description

Each strain gauge strip sensor is 59, 69, or 79 inches long and is installed in sets of 1 to 4 pairs (2 to 8 strip sensors) that can be combined to cover different road widths, with one pair covering the width of a single road lane. Each strain gauge WIM strip sensor is approximately 3 inches wide, 3 inches tall, and weighs 45 to 65 pounds, depending on the length of the sensor and cable length. Sensors less than 3 inches tall have recently become available. Figure 21 illustrates a typical strain gauge strip sensor.

Figure 21 – Strain Gauge Strip Sensor

Sensor Configuration and Layout

Each sensor is installed to cover one-half of the travel lane. Working in pairs, the two sensors are installed in a staggered configuration in each lane, the left side staggered 2 feet in front of the right sensor, and each set of sensors for each wheel path is placed 16 feet apart. The inductive loop is installed before the leading set of WIM sensors, as shown in Figure 22.

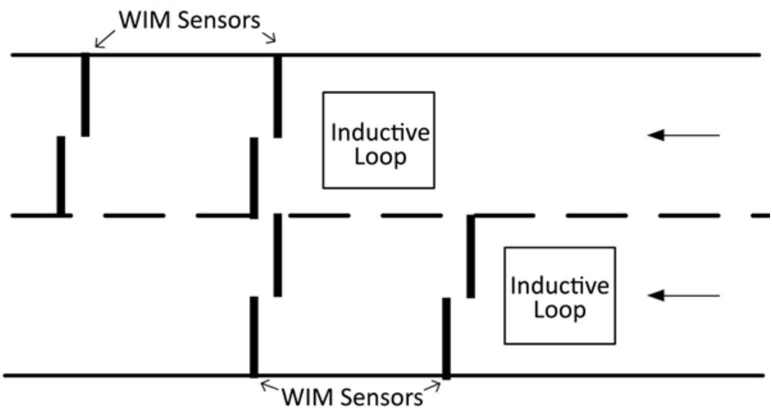


Figure 22 – 2-Lane Unidirectional Strain Gauge Strip Sensor Staggered Double Threshold Configuration

How it Works

The strain gauge WIM sensor is based on strain gauge load cell technology. As a vehicle passes over the WIM sensor, the system measures the vertical strain placed on the sensor by the weight of the wheel. The resultant change in the electronic properties of the strain gauge load cells are translated into the dynamic load and the wheel, axle, and GVW are produced by the WIM controller or software.

Strengths

Strain gauge strip sensors can be installed in AC or PCC pavement. If installed in AC, the pavement must be thick enough to accommodate a 3-inch-deep sensor in the top 1/3 of the asphalt layer (to prevent cracking through asphalt layer thickness). The sensors themselves are ordinarily maintenance free and, in case of pavement rutting, the top of the sensor may be ground flush up to 0.25 inch to conform to the pavement, which helps maintain system accuracy. Strain gauge strip sensors are comparable to or slightly less expensive per sensor than quartz piezo sensors, and they are less sensitive to changes in temperature than polymer piezo sensors. Reliable lifetime expectancy for these sensors has not been field tested beyond 5 years.

The sensor is less reliant upon structural support of the pavement than quartz piezo sensors. This decreased reliance in structural support is due to the design of each strain gauge strip sensor, which is slightly larger than quartz piezo sensors.

Weaknesses

The strain gauge strip sensor installation currently recommends 3-inch-deep channels cut in pavement for installation. This installation requirement limits applicability of strain gauge strip sensor for thin pavements. To prevent pavement cracking at the sensor location, it is recommended that the sensor depth does not exceed 1/3 of the pavement structural layer thickness.

Narrow-width sensors may have higher error when compared to wider bending plates or load cells due to additional approximations resulting from the fact that only part of the tire footprint is being measured by the sensor at any point in time. Improved accuracy can be obtained by additional rows of sensors and/or careful WIM site selection and installation.

Due to the new product/technology, there is limited long-term (beyond 5 years) sensor performance information available. More information is expected to be available in a few years (by 2020), since several state agencies are currently using this type of sensor at multiple data collection locations (FL, IN, MN, OR, TX, and WA).

Roadway roughness, which results in adverse vehicle dynamics, plays an important factor in the quality of the data, as with any in-the-road WIM system.

Accuracy

This system can be classified as an ASTM E1318-09 Type I, II, or III system depending on the installation, use, and the number of sensors placed in the traffic lane. The strain gauge strip sensor system consisting of a single pair of sensors, when properly installed in smooth pavement, well maintained, and calibrated is expected to provide accuracies well within ASTM E1318-09 Type I performance specifications. Configurations with two pairs of strain gauge strip sensors provide GVW measurement accuracy within +/-5 percent. Typical WIM calibration intervals of once per year are recommended for proper WIM site performance.

Recommended Use

WIM systems utilizing the strain gauge strip sensor are well suited for truck and axle loading data collection and research, screening for enforcement, pre-selection for static weighing, and bridge and infrastructure protection. Strain gauge strip sensors are frequently used to collect data for enforcement screening at high speeds and when the user specifies ASTM E1318-09 Type I WIM performance requirements.

Portable WIM Technologies

Bridge WIM (B-WIM)

Sensor Description

Bridge WIM system sensors are made up of strain transducers that are mounted to the underside of the bridge deck or structural members, either temporarily with C-clamps or permanently with fasteners. The transducers are connected to portable roadside electronics that collect, process, and store the data. Bridge sensors installed under the bridge deck never come in direct contact with the tires. There are limitations for the type of bridges and traffic conditions these WIM systems will support. Bridge selection is key to quality data collection as not every bridge is a good candidate for B-WIM.

Sensor Configuration and Layout

Two main approaches to B-WIM have been used. The first approach uses strain sensors mounted on the bridge and a separate axle detection sensor installed on the road. The second approach uses only strain sensors installed on the bridge for both axle detection and weight measurements. The second approach provides a simpler design, installation, operation, and maintenance of the B-WIM system. Figure 23 shows the installation of B-WIM sensors.

Figure 23 – B-WIM Installation

How it Works

Bridge WIM systems monitor the bending deformations of a bridge caused by vehicles crossing over the structure. These deformations are measured using strain sensors attached to the structural members. These deformations are analyzed to estimate the GVW and axle loads of passing traffic. Axle spacing, total vehicle length, and speed can also be detected.

Strengths

One advantage of B-WIM systems is their portability. The sensors can be removed and reinstalled on a different structure, provided that easy and safe access is available under the bridge span. Another advantage of B-WIM systems is that the same sensors could be used for evaluating the performance of the structure itself. Because B-WIM sensors are installed under the bridge, they do not pose any risk of becoming a road hazard. B-WIM is installed beneath a bridge with a simple surface installation as opposed to a more costly and time consuming in pavement installation.

Weaknesses

Each time the B-WIM system is moved to a new location, it requires recalibration specific to a bridge's response to moving loads, making these systems unique to each location. Various factors degrade the signal from the strain gauges and limit the accuracy of data obtained from these systems. The most significant of these factors are the presence of other traffic on the bridge at the same time a truck is being weighed (which significantly increases the noise in the weight signal) and the lack of documented information at the highway agencies about the expected structural bridge responses to various loading conditions, which limits the accuracy of load estimation based on B-WIM sensor inputs.

B-WIM application is limited by the type of structures and traffic conditions. They work more efficiently on small single-span bridges or large culverts with well understood and documented structural responses. They are good for bridges that are not subjected to high traffic volume (ideally, a single truck crosses the bridge at the time of measurement). These systems are best suited for estimating GVW and not with individual axle or wheel loads.

Installation of B-WIM sensors may require special safety precautions, depending on the terrain beneath the bridge and the bridge's height.

Accuracy

The accuracy of B-WIM systems can be affected by the presence of multiple trucks, whether in parallel or serial configurations, and by other traffic on the bridge. Accurate axle spacing detection also is a concern with B-WIM. Since the accuracy of B-WIM load estimation is highly dependent on each bridge structure and the skills of the engineer setting up the system, no reliable long-term information on the average B-WIM system performance can be provided at this time.

Recommended Use

B-WIM could be suited for a variety of applications, including bridge protection and safety, planning, bridge management and design, and warranty. These systems require availability of skilled personnel to make a selection of the acceptable bridge structures, to evaluate bridge structural responses to moving truck loads, and to set up and calibrate the system. It is expected that the cost of B-WIM sensors is far less than the cost of system set-up and calibration. Several states (AL, CT, NJ, and MS) have experience with this technology, albeit limited.

Portable Piezo Sensors

Sensor Description

There are two basic styles of portable piezo sensor installations: a bare polymer piezo (brass linguini) sensor taped directly to the pavement and a piezo that is encased in a sleeve and then fastened to the pavement, as shown in Figure 24.

Figure 24 – Single Lane Portable WIM Sensor

Sensor Configuration and Layout

For portable weighing operations, sensors (each sensor is roughly one lane width in length) are either taped or fastened to the roadway, perpendicular to traffic, as shown in Figure 25. Normally, two sensors are placed 3 to 6 feet apart. The University of Minnesota developed a sensor that is long enough to cover two lanes *(8).*

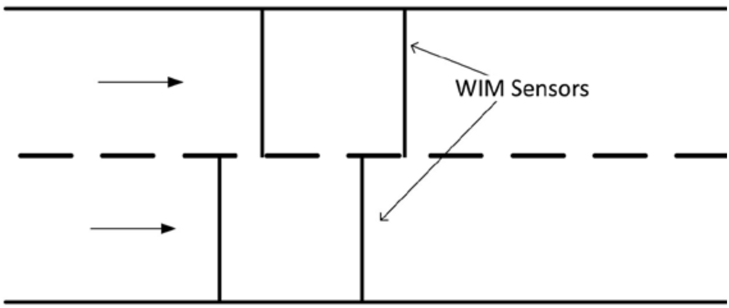


Figure 25 – 2-Lane Unidirectional Portable Piezo Full Lane Width Sensors

How it Works

When a mechanical force is applied to a piezoelectric sensor, it generates a voltage proportional to the weight by causing electrical charges of opposite polarity to appear at the parallel faces of the piezoelectric material. When placed on a rigid surface, the measured voltage is proportional to the force or weight of the wheel or axle (if a dynamic loading component is present due to truck bounce, or pavement stiffness changes over time, it may degrade the proportionality relationship).

The time difference between the wheel contacts on the two sensors is used to determine vehicle speed, which is then used to determine the wheel and axle spacing needed for vehicle classification.

Limitations

The sensor installation itself creates bumps in the road, which is counterintuitive to the road smoothness requirements for collecting high-quality WIM data.

There is often a burn-in time for the sensor to embed itself in the material used to hold the sensor in a line. Road roughness must be considered, and rough pavement should be avoided when locating where the portable WIM data collection should be undertaken. Lastly, on-site calibration of the WIM sensors must be performed using heavy trucks after the burn-in is completed. This is very important to know the accuracy with the variables of pavement stiffness, vehicle dynamics, and sensor response for different loadings.

The installation and removal of portable WIM sensors likely requires temporary traffic control to ensure the safety of the installers.

Strengths

These systems are relatively easy to set up, although they are routinely placed only in the outside lane of traffic in order to allow the lead wires to be placed on the roadway shoulder. These sensors are the least expensive among WIM sensors.

Weaknesses

Polymer piezo sensors used in portable operations suffer from significant limitations in accuracy for the following reasons:

- The sensor installation itself creates bumps in the road, which is counterintuitive to the road smoothness requirements for collecting high-quality WIM data.
- Because the sensor is mounted on the surface, there is a horizontal force acting on the sensor with each wheel strike, causing it to deform in the wheel path. This often degrades the quality of the WIM measurements and can cause the sensor to fail.
- Polymer piezo sensors are temperature sensitive, making it difficult to keep them in calibration when temperature changes during the day.
- The sensor narrowness allows tires being weighed to “fold” over them, meaning that at no time during the axle weighing process is an entire tire positioned on the sensor. Therefore, changes in tire pressure or tire tread

patterns may affect the force measured by this type of sensor more significantly than by many other WIM technologies.

- Calibration of the sensors to site-specific vehicle dynamics and environmental conditions using heavy trucks of known weight is necessary to obtain the level of accuracy needed for direct inclusion of these data into the pavement design process. The cost of these efforts often far exceeds the cost of placing and retrieving the data collection sensors and greatly increases the cost of collecting accurate weight data with these systems. The lack of site-specific calibration significantly affects the portable piezoelectric WIM system ability to accurately estimate the static axle weights.
- Because pavement response to traffic loads has a non-linear effect on WIM sensor measurements, auto-calibration based on light or moderate loads leads to poor prediction of heavy loads.
- Depending on system set-up, weight measurements of lighter trucks can be significantly overestimated when compared with heavy truck weight estimations.
- Sensors have a relatively high signal-to-noise ratio.
- Narrow-width sensors may have higher error when compared to wider bending plates or load cells due to additional approximations resulting from the fact that the sensor measures only part of the tire footprint at any point in time.

Accuracy

The accuracy of a piezoelectric portable WIM system is highly dependent on the set-up and calibration. When properly calibrated using heavy test trucks, typical accuracy for this system is +/– 25 percent of the actual vehicle weight for 95 percent of the trucks measured. This accuracy is likely to deteriorate with time or temperature changes.

Recommended Use

Portable piezo data collection is best suited for a short-term data collection application when temperatures are above freezing and low-accuracy WIM data are acceptable to the user. These systems are suitable for identifying general trends in traffic loading and comparing loading patterns among different sites. The data from these systems are not recommended as direct input for pavement design or motor vehicle law enforcement operations.

WIM Sensor Technology and Performance Comparison Table

The performance, accuracy, and life expectancy of WIM sensors and the systems that utilize them are dependent upon several factors.

Major Factors Affecting WIM Performance

1. Sensor type
2. Number and spacing of sensors in the array
3. Pavement support and surface smoothness
4. Roadway geometry and traffic flow
5. Proper installation, including oversight
6. Type of installation material (grout)
7. Routine maintenance
8. Calibration using heavy test trucks
9. Weekly data quality monitoring for weights and spacing

Although each of these factors plays an important role in the quality of data that the WIM system produces, it is widely accepted that the type of sensor and the roadway array are the most important considerations. The capabilities of the WIM controller can also be an important consideration when determining which technology will be used to collect data that will meet the customer’s needs.

Table 2 summarizes information presented in the previous sections and could be used to compare the main characteristics of different sensors, and to identify sensors appropriate for different applications/uses.

Table 2 – Summary of WIM Sensor Technology Assessment

Sensor Type	Strengths	Weaknesses	ASTM Type	Recommended Use/Applications
Load Cell	High accuracy	Use in concrete only High cost High maintenance	I, II, III	Highway Monitoring, Highway Design, Planning, Pre-screening
Bending Plate	High accuracy	Use in concrete only High to Moderate cost	I, II, III	Highway Monitoring, Highway Design, Transp. Planning, Pre-screening
Quartz piezo	High accuracy, low maintenance	Moderate cost	I, II, III	Highway Monitoring, Highway Design, Transp. Planning, Pre-screening
Strain Gauge Strip Sensor	High accuracy, low maintenance	Limited long-term performance record Implemented with limited number of controllers	I, II, III	Highway Monitoring, Highway Design, Transp. Planning, Pre-screening
Permanent Polymer Piezo	Low cost, low maintenance	Temperature sensitive Needs frequent local calibration	II	Highway Monitoring, Transp. Planning
Portable Polymer Piezo	Low initial cost, easy to set up, portable	Low accuracy Temperature sensitivity, needs local calibration	II	Planning
Bridge WIM (strain gauge)	Quick to set up, portable	Depends on local bridge structural response, needs local calibration Safety risk & special equipment for tall bridges	II	Add-on operation to bridge monitoring

WIM Controllers

Purpose

The WIM controller collects and processes the input signals from each of the in-road WIM sensors, computes timing information to determine axle spacing and speed of a vehicle, processes raw WIM sensor signals and computes static weight based on system weight compensation factor settings, provides vehicle record data, and stores the data for later transmission to the host computer.

Main Components and Functions

The type of WIM controller depends on the WIM data collection application and the necessary functions required of the WIM system. For example, the WIM controller used for a virtual weigh station (VWS), which is used for enforcement pre-screening, must be able to perform video data collection and real-time data transmission to a remote location. It may also require an automatic license plate reader and/or an over-height detector integration. A functional diagram of a typical WIM controller is provided in Figure 26.

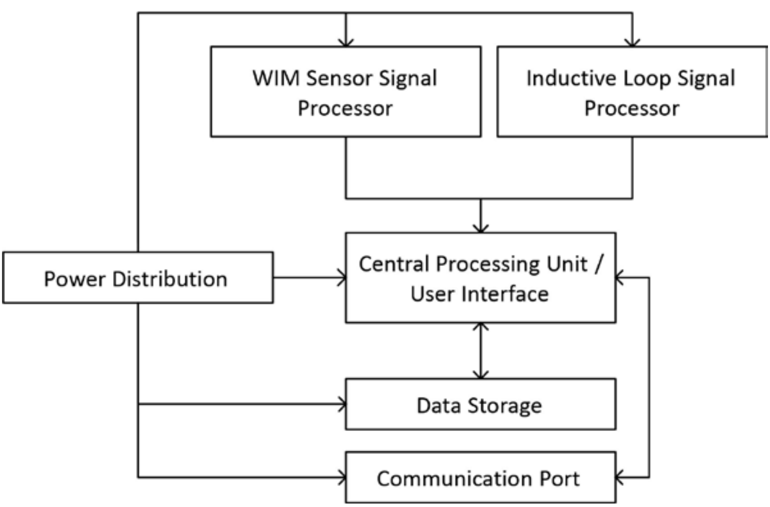


Figure 26 – WIM Controller Internal Components Functional Diagram

The six basic functions that are contained in most WIM controllers include the following.

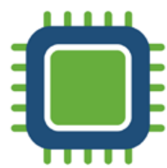
1. Power Distribution

The power distribution function feeds power from the external power devices such as batteries, charge controllers, environmental power, or alternating current (A/C) converters to the WIM controller components. In the case of a power surge, power is diverted to grounding devices through power surge devices installed in line with sensors, telephone, power, and ground.

2. Sensor Signal Collection and Processing

The signal processing function of the WIM controller collects the analog signals from the loop inductors, WIM sensors, and temperature sensors, then converts the analog signals to digital signals and sends them to the central processing unit (CPU).

3. Central Processing Unit



The WIM controller CPU contains all of the routines that the WIM system uses to process the various digital input signals and produce individual vehicle records that include date, time, speed, weight, axle spacing, and vehicle classification data.

It also contains the WIM vendor’s software and/or firmware that is used to format the vehicle records into the data files containing information about vehicle weight, speed, and vehicle classification. This information may include:

- Site identification (including global positioning system, GPS)
- Direction and lane number

- Time and date of each vehicle passage
- Vehicle sequence number
- Vehicle speed and classification
- Vehicle length
- Sequence and spacing of axles
- Weight of all wheel paths, axles or axle groups
- Code for invalid measurement
- Inductive signature

The CPU data files could be in binary or ASCII format. These files are eventually downloaded to the off-site host computer and processed using WIM data processing software to produce various reports and other usable file formats.

4. User Interface

The user interface provides a communication link between the CPU and the user. The user interface is a system menu that may be accessed and viewed remotely using an off-site computer through a wired or wireless communication device, or it could be accessed through a display mounted on the front or top of the WIM controller's chassis, or both. The WIM controller's menu is used to set up or change system settings, check the operational status of the WIM sensors, or download data.

The individual vehicle records can be seen in real-time, as they are being collected, on a display provided in the controller cabinet or on an external computer screen.

The user interface provides access to various operating parameters and calibration factors that can be adjusted by the user. Some of the user menu functions include:

- Real-time vehicle viewing selectable by lane
- Resetting of the system clock

- Monitor system memory in terms of storage remaining
- Setup and initiate the generation of summary reports on data previously collected by the system
- Transfer selected raw data files
- Classification parameters
- View and adjust calibration/system settings
- View system internal troubleshooting parameters such as voltages, sensor output signals, and data signatures

5. Data storage

The data storage function of the WIM controller consists of on-board memory devices that store the data as collected until the data are transmitted to the host computer through an external communication device. The WIM controller data storage function should provide data storage capability for a minimum of 7 days to prevent overlap or loss of data.

6. Communications

The WIM controller's data output devices, such as a serial T10 or Ethernet port, can be connected directly to a personal computer at the field site using a communications cable or remotely accessed through a wired or wireless modem connection that transmits the WIM data off-site. The individual vehicle records can also be seen in real-time, as they are being collected, on a display screen installed on the top of the controller, or on the external computer screen.

Additional Recommended Functionality

The recommended additional features for a WIM controller are based on the data application and may include:

1. Calibration Features:
    a. Front-axle weight compensation factor independent from GVW compensation factors
    b. Temperature compensation/temperature measurement. An in-pavement sensor is best.
    c. Auto-calibration (for polymer, coaxial and ceramic piezo sensors only). Caution: Auto-calibration works best on high truck volume roads and may not be applicable on low truck volume roads. It also should be set in a way to assure accurate GVW, not just accurate front axle measurement.
2. Self-diagnostics Features
    a. Sensor waveform
    b. Timing information
    c. Sensor presence analysis
    d. System power monitoring

3. Enforcement Features (screening for enforcement only):
    a. Video processing
    b. Real-time data streaming
    c. Over-height vehicle detection
    d. Automatic license plate reader data processing
    e. Overweight limit setting for single, tandem, tridem, and GVW

DATA REPORTING REQUIREMENTS

WIM Vendor Software and Firmware Requirements

It is a good practice to provide a set of specific requirements for WIM data format(s) or a WIM data specification as part of WIM procurement documentation. WIM vendor software and firmware requirements should be based on the user's needs for WIM data. In addition, WIM software should have data quality control (QC) functions to monitor and report weight data accuracy.

FHWA recommends that users ask WIM vendors provide vehicle weight data as individual vehicle records, preferably in the 2016 TMG PVF data format. Individual vehicle records provide:

- A detailed analysis of traffic patterns and vehicle characteristics.
- Development of axle correction factors and statistical procedures for data summarization and estimation.
- Detailed data QC checks.
- Troubleshooting WIM equipment performance issues, vehicle misclassification, or data collection and sampling issues.
- The ability to store individual records for all vehicle types, not just classes 4 through 13.

In addition, the WIM data processing software should be capable of generating daily, weekly, monthly, and annual summary reports, including vehicle speed, classification, ESAL, and axle loading and GVW distribution summaries by vehicle class, by lane, and by direction, as well as data summaries in hourly increments. WIM systems could also be used to collect vehicle classification data and should be capable of reporting vehicle classification data sets. The software should be able to generate reports on errors, auto-calibration, site history, calibration history, and overweight vehicles.

Axle correction factors (ACF) are an important output from WIM, and they are critical to assure proper animalization of single road tube counts. Annual updates of ACFs are necessary. This is detailed in TMG 2016 chapter 1.2.6 *(7).*

Many WIM vendors have very effective controllers for data collection but their software has very limited data QC and quality assurance (QA) features. Several agencies use WIM vendor firmware and software to generate data records that could be transferred to a different software for data processing and QA/QC of the data.

FHWA WIM Data Format

If a WIM system is procured, at least in part, for collecting and reporting data to FHWA, the WIM vendor software should be capable of data processing and reporting in the FHWA TMG format (currently, TMG version October 2016). Data files generated by the WIM vendor software should be formatted for direct upload to national databases maintained by the FHWA, including the Travel Monitoring Analysis System (TMAS) and any of its successors. See chapter 7 in the 2016 TMG for the FHWA WIM data formatting requirements.

The recommended format for reporting WIM data to FHWA is PVF. The WIM vendor software should be capable of producing data in the “W” or “Z” variants of the FHWA PVF described in sections 7.7.4 and 7.7.5 of the 2016 TMG, respectively *(7)*. The advantages include the availability of the detailed information that could be used to monitor WIM data quality and to investigate its dependency on external factors such as speed and temperature and the ability to aggregate data in different ways that suit the needs of different users.

Mechanistic-Empirical Pavement Design Guide (MEPDG) Format

If a WIM system is procured for collecting data to support pavement design based on the MEPDG method, then the WIM data processing software or other agency available software should be capable of generating traffic data in the MEPDG format, including:

- Axle load distribution factors (ALDF)
- Number of axles per truck (APT)
- Vehicle class distribution (VCD)
- Monthly adjustment factors (MAF)
- Hourly distribution factors (HDF)
- Wheelbase of the power unit for tractor-semitrailers
- Axle spacing, and axle spacing frequency distribution.

WIM sensor ability to measure truck lateral wander (outer wheel position from the pavement edge for each truck, in inches) is an advantage for MEPDG use. See the AASHTOWare Pavement ME Design user's guide for MEPDG traffic data formats *(9)*.

Download Method

WIM data are typically downloaded and stored by an off-site host computer using telemetry and vendor software. The sites are typically polled automatically every night. For sites without reliable telephone or cellular service, the data are downloaded manually at the site. Manual download also requires vendor software to be installed on the field technician's laptop computer. The field person connects to the WIM controller directly using a connected cable, and then utilizes the controller's user menu to select the data files for transfer to the laptop. Downloaded data may be stored in the agency's central traffic database or at an on-site or off-site database maintained by the WIM data service provider. Data may also be stored as flat files in a TMG or user-specified format.

Automated polling is the most desirable method of WIM data download. It is good practice to include auto polling software functionality capable of generating flat files in the current TMG format in the WIM procurement documentation. Automated polling of data should be accomplished every day to reduce the risk of missing or overlapping data.

PROCUREMENT CONSIDERATIONS

User Requirements and Vested Involvement

The intended use of the WIM data will help to determine the type of WIM equipment, the specific locations, and physical and traffic characteristics of the road segments selected for WIM sites installation. Therefore, the first step in choosing a WIM system is to clearly define the user requirements, including:

- Data types
- Data accuracy
- Data storage and size of data
- Data collection frequency and length (days of collected data)
- Lane array and sensor type
- WIM sampling requirements (number of sites for types of routes)
- WIM site locations

It is important to get the users of WIM data to advocate for continuous WIM program support within the agency. Integrating WIM data into vital Department of Transportation (DOT) functions such as pavement design, performance measurement, and safety and freight studies is a key to a WIM program’s longevity and continuous agency support from DOTs. Otherwise, it may be difficult to get a commitment to fund a given WIM operation over the long-term. Although decision makers may recognize the need to collect the WIM data, a lack of a mandate or low utilization of WIM data in an agency’s vital operations may lead to reduction or elimination of the program funding when budgets are limited.

Factors Affecting WIM Technology Selection

Factors influencing selection of a specific WIM technology include:

- Reliability of a WIM system and its components (i.e., the ability of the system to consistently collect weight data that meet the performance requirements over long periods of time)
- Locations where a given technology can be successfully installed
- Array of sensors to be installed
- Sensitivity of WIM sensors to various factors (temperature, vehicle dynamics, traffic volume, and speed)
- Traffic conditions observed at the proposed site (number of lanes and directions)
- Frequency and ease of the WIM system set-up, maintenance, and calibration to assure consistent performance
- Resilience of sensor installation (e.g., the ability to continue to collect data if one or more sensors fails)
- Life span of sensors and other WIM components in comparison with the data collection period
- Number of WIM sites needed
- Local weather conditions
- Cost of the WIM system components and their installation
- Cost, time, and effort to order and replace failed parts, vendor’s customer support

WIM Sensor Longevity Considerations

When selecting a WIM sensor, in addition to accuracy requirements and operation costs, the period of data collection and sensor life cycle costs are an important consideration. Cost estimations for WIM sites that are intended to operate for more than 5 years should consider replacement of piezo sensors and possible pavement remediation to improve smoothness. The use of bending plates or load cells would be cost-prohibitive for sites that are installed to operate less than 5 years.

Availability of Funding and Resources

The cost of the WIM system is directly related to the overall WIM system performance. The need for resources increases as the required accuracy level increases to provide for additional data and equipment QA to maintain higher levels of accuracy.

To address these financial considerations, a balance must be struck between the number of WIM data collection locations, the duration of data collection, and the accuracy of WIM data.

User requirements and anticipated costs to procure and maintain WIM systems should be evaluated against the available or projected funding. If funding is not sufficient to address all user needs, traffic monitoring personnel in cooperation with the data users must decide what is more important: data sampling (number of sites/locations covered) or data accuracy.

If sampling is more important, a decision may be made to procure WIM systems that are less expensive to install and/or maintain. The data users must decide if lower quality data still would be suitable for use in their applications.

On the other hand, if accuracy is more important, a decision may be made to procure WIM systems that are more accurate and inherently more expensive. Strategic selection of prospective WIM site locations based on functional class of the roadway, truck traffic distribution, and regional road usage may partially overcome sampling/coverage problems.

Another cost-saving option is to approximate vehicle weights at vehicle classification sites, using WIM data from sites that have similar vehicle classification and road use characteristics. To do so, road usage by different truck types should be well understood.

Life Cycle Costs

When making a decision about purchasing a WIM system, costs beyond the initial WIM system purchase and installation need to be considered. Availability of the staff and other resources necessary for continuous WIM program operation also plays an important role in procurement decisions. Continuous funding support and resources are needed for routine WIM performance verification and calibration, site maintenance and repairs, data processing, and QA. The costs associated with software upgrades and pavement rehabilitation at the WIM site may also need to be considered.

Breakdown of WIM Life Cycle Costs

The following is a comprehensive list of the life cycle costs associated with procuring and maintaining WIM systems:

1. WIM Site Preparation and Installation Costs
    a. Site selection, design, and field investigation (site selection report and design/construction plans)
    b. Pavement preparation for WIM site installation to improve smoothness (if any)
    c. Other site improvements
        i. Vehicle pull off area
        ii. Power service drop by power supply company (if not solar)

iii. Telephone service drop by telephone service company (if not cellular)
iv. Equipment protection (guardrail or barrier)

d. WIM system installation turn-key (WIM equipment and supporting infrastructure purchase, installation, initial calibration and acceptance testing)

2. Central Computer Processing System
    a. Dedicated host computer for data downloading and storage
    b. Software for auto polling, quality control and quality assurance (QA/QC), processing, and reporting
3. Annual Operating Costs
    a. System operating expenses
        i. Power costs per site
        ii. Telecommunication costs per site
    b. WIM data processing, reporting, and QA/QC per site
    c. WIM site maintenance and calibration expenses per site per year (cost of calibration truck is an additional expense)
    d. Sensor replacement cost, averaged over 5 years, per site
    e. Pavement smoothness improvement costs, when applicable (for calculations, spread over a 5-year period)

Pavement Condition and WIM Life Cycle Costs

To optimize the available resources, it is important to match the design life of the WIM equipment with the life and condition of the pavement. The lifespan of the in-road piezoelectric WIM sensor should be equal or less than the service life of the pavement in which it is placed. For bending plates, the sensor can be removed, but the frames into which the bending plates are set are not removable. If installing bending plates or load cell sensors on a road with AC pavement, the feasibility and cost of a concrete slab installation should be considered. If needed, the WIM controller and WIM cabinet may be successfully moved between different locations.

The costs to maintain pavement smoothness near the WIM site over time (to minimize effects of road roughness on dynamic tire forces that affect WIM measurement accuracy) should be considered. Major pavement rehabilitation is not typically included in the WIM life cycle cost analysis, since the service life of the WIM system is usually dictated by the condition of the pavement. Pavement rehabilitation activities such as chip sealing, thin mills and overlays, thin overlays, and ultrathin overlays may reduce the output of polymer piezo sensor and consequently prevent the WIM system’s ability to provide viable data. However, pavement maintenance activities, such as crack sealing and seal coating, may be necessary to extend the life of the WIM system, and so these costs must be considered.

Figure 27 – Smooth Pavement Section

Cost Comparison

When budgeting for a WIM site, or comparing different WIM site options, the following cost categories need to be considered:

1. Initial WIM sensor and site installation costs
2. Annual operation costs
    a. Routine maintenance costs
    b. Routine calibration costs

c. Annualized sensor replacement costs
3. Additional infrastructure, maintenance of traffic (MOT), and mobilization costs

Sensor Costs

The most significant cost difference between WIM system installations is the type of WIM sensor that is used. Table 3 summarizes the average costs for the different types of sensors. Installation costs are discussed in the next section. The costs in dollars shown in Table 3 reflect the following sensor layout that is required to produce ASTM Type I or Type II performance:

- Polymer piezo – 4 half-lane width sensors
- Quartz piezo and strain gauge strip sensor – 2 half lane width sensors
- Bending plate and load cell – 2 half-lane width sensors

Table 3 – WIM Sensor Costs

Sensor Type	Number of half-lane sensors	Range of costs for 1 lane of sensors		
		Life (years)	Sensor Installation	
			low	high
Polymer Piezo	4	2-3	4,000	6,400
Quartz Piezo	2	3-5	16,000	24,000
Strain Gauge Strip Sensor	2	3-5	16,000	24,000
Bending Plate	2	6-8	18,000	28,000
Load Cell*	2	10-12	44,000	53,000

*Includes cost of the pit.

In addition to the costs shown in Table 3, installation of a concrete slab is required for bending plates and load cells installed in AC pavements. This additional cost must be added to the costs listed in Table 3. Due to high added costs, bending plates and load cells are rarely used for WIM installations in AC pavements.

Initial Installation Costs

Table 4 provides costs associated with the WIM site installation that are in addition to the WIM sensor costs provided in Table 3. The values in the table represent the costs for installing a 2-lane and 4-lane WIM system for sensor layouts described in the previous section. The 2-lane WIM system shown in Table 4 shows necessary system elements other than WIM sensors. The assumptions used to develop the cost table for the 2-lane WIM system include:

1. The pavement condition is acceptable for a WIM installation
2. The National Electrical Manufacturers Association (NEMA)-rated roadside cabinet is mounted on a breakaway-design and located outside of the clear zone, per AASHTO Roadside Design Guide, 4th Edition *(10)*
3. Directional boring (recommended)
4. Two traffic-rated junction boxes are required
5. Polyvinyl chloride (PVC) conduit is used to route the sensor leads to the junction boxes and to the cabinet
6. Host computer vendor software for data processing and download is included
7. Cellular or landline modem
8. Solar panel (typically one 80-watt panel)

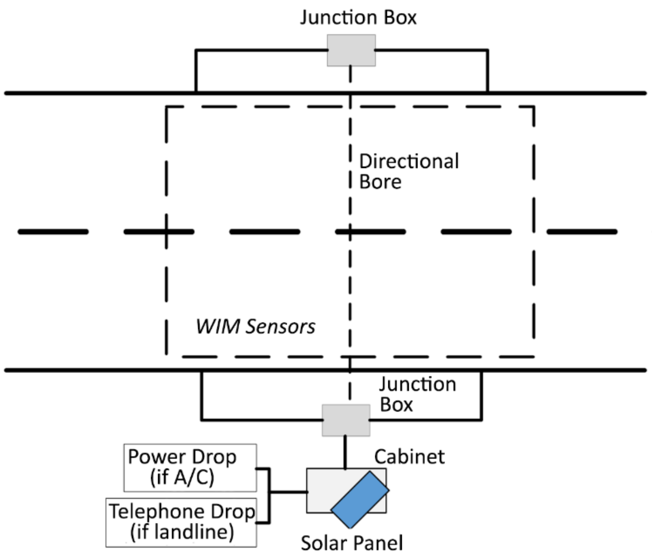


Figure 28 – 2-Lane Infrastructure

The 4-lane WIM system shown in Figure 28 shows necessary system elements other than WIM sensors. The assumptions used to develop the cost table for the 4-lane WIM system include:

1. The pavement condition is acceptable for a WIM installation
2. The NEMA-rated roadside cabinet is mounted on a breakaway-design and located outside of the clear zone, per AASHTO Roadside Design Guide, 4th Edition *(10)*.
3. Directional boring (required)
4. Three traffic-rated junction boxes are required.
5. PVC conduit is used to route the sensor leads to the junction boxes and to the cabinet (approximately 250 feet)
6. Host computer vendor software for data processing and download is included.
7. Cellular or landline modem
8. Solar panel (typically one 80-watt panel)

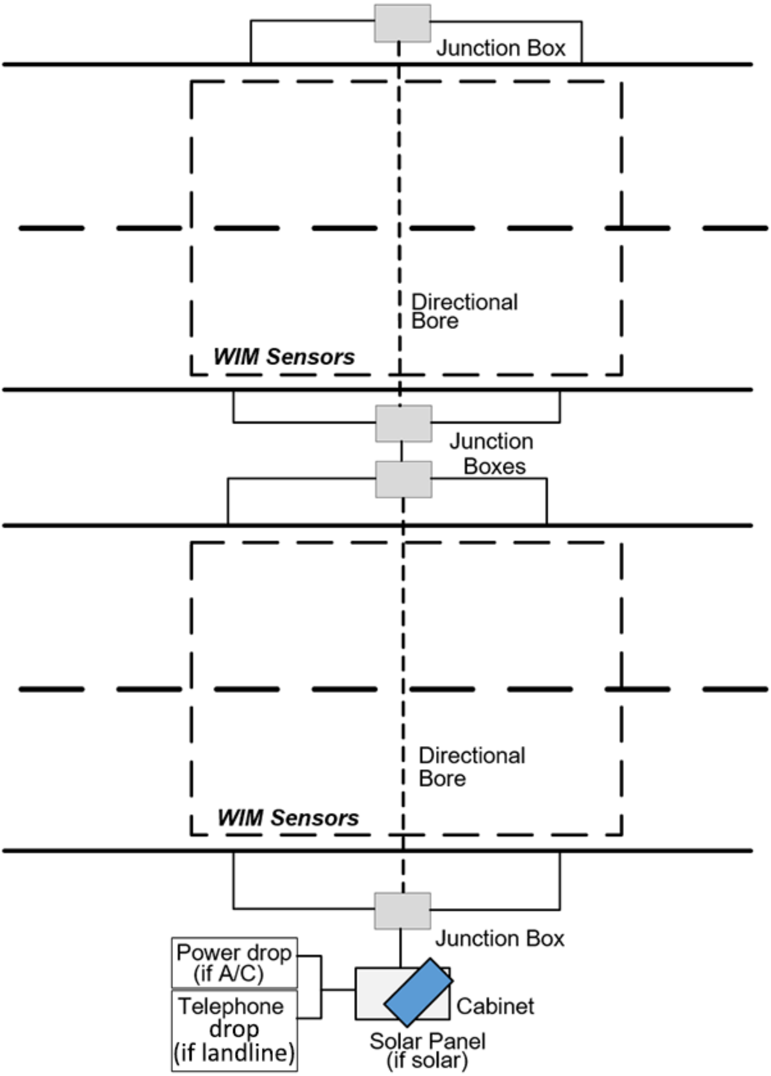


Figure 29 – 4-Lane Infrastructure

Table 4 – Initial Installation Costs
(Excludes Sensor Installation Costs Shown in Table 3)

Element	Range of costs			
	2 lanes		4 lanes	
	low	high	low	high
1. Installation (a+b+c)	20,500	56,500	32,000	78,000
a. Controller	7,500	24,000	9,000	26,000
b. Infrastructure	13,000	28,000	23,000	45,000
c. Initial calibration	0*	2,500	0*	5,000
2. Vendor software installed on host computer **	0*	2,000	0*	2,000

*The initial calibration cost may be included in the cost of the sensor purchase.
**Considers only WIM vendor software for rudimentary data processing and reporting.

Continuous Operation Costs

Table 5 provides costs associated with maintaining and calibrating the WIM system throughout its expected lifetime. The assumptions used to develop the operations cost table include:

- Annual calibration per ASTM E1318-09, including cost of using one 5-axle semi-trailer truck
- Routine maintenance is 2 visits per year
- Software updates

Table 5 – Continuous Operation Annual Costs

Element	Range of Annual Costs			
	2 lanes		4 lanes	
	low	high	low	high
1. Routine Maintenance	500	1,200	750	1,500
2. Routine Calibration*	2,500	6,000	4,000	7,500
3. Sensor Replacement**	**Average Annual Cost per Lane*****			
a. Polymer Piezo	4,300			
b. Quartz Piezo	10,600			
c. Strip Sensor	10,600			
d. Bending Plate	7,000			
e. Load Cell	9,000			

*Using one Class 9 truck (typically $90 to $135 per hour), maximum 20 runs per lane. Bending plates and load cells may be calibrated every 2 years.
** Includes parts, MOT and labor, but does not include mobilization.
*** Based on the number of sensors in each lane and the expected life of the sensor shown in Table 3.

It is important to consider that software upgrades may also be needed. However, these are program costs not associated with a particular type of sensor and are difficult to estimate.

Additional Costs Considerations

There are several additional considerations that may affect the cost of the WIM installation, including the need to provide power service or landline telephone services at the cabinet, as well as traffic control requirements. The use of agency personnel to perform the construction or initial calibration, as opposed to contractors, may also affect the cost. Costs associated with data processing and reporting are not included in the estimates described in the previous sections.

In addition to the costs provided above, other costs that may be incurred, which could affect the life cycle costs for WIM systems, include:

1. Mobilization costs – Costs to mobilize equipment and crews to the WIM site (est. $1,000 to $2,500).
2. Maintenance of traffic – The location of the WIM installation will dictate the level of MOT that is required. WIM installations on high-volume highways, with multiple interchanges, may increase the installation costs substantially. Typical lane closure costs range from $800 to $2,500 per day.
3. Power – Solar power requires an initial investment of $800 to $1,600, depending on the system's power requirements, but little ongoing maintenance cost. A/C power service requires an initial investment to get the power to the cabinet (est. $5,000 to $10,000) and ongoing minimal monthly delivery and usage fees (under $20 per month).
4. Cellular service requires a small initial investment of $350 to $650 for the modem and ongoing $25 to $35 monthly service fees. Traditional landline requires an initial investment to get the telephone service to the cabinet, which may range from hundreds to thousands of dollars (est. $5,000). Traditional landline modems cost from $250 to $750, depending on features and data transfer rates. Ongoing monthly service fees may range from $15 to $35.
5. Pavement improvement costs – For asphalt pavements, at least minimum pavement maintenance such as crack sealing is typically required every 5 years (est. $1,000 per 400-foot section). Concrete slab installation required for bending plate and load cell sites installed in AC pavements.
6. WIM installations that are incorporated into larger pavement design and construction projects may increase the cost of the WIM system dramatically. One

state agency reported that it sometimes doubles their installation cost.

7. Additional calibration costs – Turnaround times, length of trip per run, number of test truck runs, truck hourly rates, fuel surcharges and accuracy requirements can double calibration costs.
8. Staff – Additional resources may be needed for dedicated or shared in-house staff and/or contractor staff. The cost depends on the size of the WIM program and data quality requirements; estimate ½ to 2 full-time equivalent personnel at the transportation specialist level, including:
    a. Data processing and analysis staff
    b. Field technicians
    c. WIM operation manager

Total WIM Costs

To compute the total cost for installing and maintaining a WIM system using a specific type of sensor, first multiply the per lane costs in Table 3 by the number of WIM lanes and then add to the costs calculated based on Table 4 and the costs provided in Table 5. Then, add estimates derived from the additional cost items listed above to compute the total cost. These numbers could be used for WIM program/operation budgetary planning.

Benefits of Upgrading Existing Traffic Volume or Classification Monitoring Sites to WIM

To reduce the cost of a permanent WIM installation, upgrading an existing traffic count or volume site to WIM could be an attractive option. The primary benefit to upgrading an existing site is the reduction in cost, since the majority of the required infrastructure is already in place. Secondary to that, the existing site may have in-road sensors already installed for counting or classifying that may be used for WIM, such as inductive loops. However, the existing site must meet the requirements for a

WIM installation with regard to pavement condition, geometrics, traffic flow, and safety (see ASTM E1318-09 for the requirements). In addition, the location should meet data user needs.

WIM Pilot Study Implementation

First-time users or users looking into new technology implementation should consider a pilot program prior to any large-scale projects. A pilot study allows the opportunity to evaluate commercially available WIM sensor and controller technologies, power options, and communication devices before developing standard WIM design and procurement specifications.

Installing the first unit in a lane directly in advance of an enforcement fixed scale near the agency's office is one recommended approach to reduce cost and provide a way of tracking yearly performance. A pilot study also gives the buyer extra leverage in getting small issues resolved quickly by a contractor or vendor promoting their product. The minimum pilot test time should be one year.

Procurement Recommendations

Standards and Specifications

To ensure a durable WIM installation, standards for each element of the installation should be explicitly stated in the contract, leaving no room for interpretation. On-site observers (WIM installation QA inspectors), acting as an agent for the agency, should strictly hold the contractors to each of the installation standards and specifications.

Appendices C and D provide examples of WIM procurement contract, manufacturer's installation standard, and warranty statement.

WIM Performance Characteristics

For every WIM system procurement contract, the minimum WIM performance characteristics (measurement accuracy and means for evaluating this accuracy) should be clearly stated with references to the applicable standard (in the U.S., ASTM E1318-09).

Technology Selection

If budget permits, it is recommended to select one type of WIM sensor, controller, and data processing software. Use of multiple types of controllers and software packages could pose significant challenges with keeping up with hardware and software improvements and cross compatibility. Agencies that experience a high rate of personnel turnover would have the added financial burden of training new technicians and data managers on several different types of equipment and software packages.

Site Locations

The site locations should be evaluated against the requirements specified in ASTM E1318-09 and vetted by the stakeholders before procurement documentation is assembled. Once WIM site locations are finalized, GPS coordinates, road name, and milepost information should be included in the procurement documentation.

Bidding/Award

In addition to the practices established by the highway agency for installation of traffic monitoring sites, the following recommendations specific to WIM installation, calibration, and/or maintenance contracts should be considered.

Contractor's Previous WIM Experience and Certification

The installation and calibration of WIM systems is extremely technical in nature. An incorrect layout or the failure of an installation contractor to follow manufacturer specifications can be detrimental to the lifespan and quality of the data collected by the system.

It is extremely important that the installation contractor's on-site supervisor have several years' experience in installing and calibrating WIM systems and certified by the WIM manufacturer in installation of sensors and controller set-up.

Basis for Award

Technical capability, experience, and cost should all be evaluated when awarding WIM installation contracts. Agencies should incorporate a scoring system that evaluates the experience, past performance and technical aptitude of prospective bidders, specific to the type of WIM system being installed. Low cost should not be used as a single determining factor due to highly technical nature of the job. Minimum qualifications related to the extent of WIM installation and calibration experience should be established, and no awards should be made to contractors not meeting these minimum qualifications.

Sole-Source Justification

Although the process can be quite difficult, and the justification for doing so can be challenging to WIM program managers, sole-source justification can significantly reduce the costs associated with trying to maintain a consistently high level of expertise and can provide a means for stretching funding by reducing the investment on different vendor software packages and possibly eliminate the need to create customized software to handle the different data outputs from different WIM controllers. Sole-source can typically be justified if these initial and annual cost savings can be demonstrated.

Turn-Key System Delivery

Use of multiple contractors to install WIM system components (sensors, controller, infrastructure, software) may lead to troubles down the road if issues with data quality arise. It may be difficult and time-consuming to determine fault if something goes wrong. Therefore, it is recommended to use a single contractor responsible for turn-key fully functional WIM system delivery.

WIM Data Purchase versus WIM System Purchase

Paying for WIM data as a commodity is another option. Under this type of contract, the contractor owns and maintains all of the WIM data collection equipment, either including or excluding the in-road sensors, and the agency pays for the acceptable data that they receive. Data acceptability is determined using a qualifying and quantifying data acceptability system. This arrangement incentivizes the contractor to provide good quality WIM data for the maximum number of days and takes the burden off the contracting agency in maintaining and servicing the WIM sites in a timely manner, thus solving the problem with qualified or limited human resources.

Warranty

The WIM equipment procurement contract should have a warranty period that is reasonable in regards to the equipment and its intended use. For example, a 5-year warranty on parts may be deemed reasonable. To keep the warranty, a regular preventive and corrective maintenance program should be established for the site to help to ensure that the expected “site design life” is attained.

Appendix C provides an example of contract warranty language.

Installation

Supervision

The solicitation shall state that the WIM installation contractor's on-site supervisor must be experienced in WIM installation. Additionally, it is recommended to require a manufacturer's representative to be on-site during WIM installation.

Quality Assurance Inspection

Even the most experienced WIM installation contractor can make mistakes. Without proper independent QA and oversight, it is possible that a contract specification will be overlooked. Therefore, it is in the best interests of the agency to stipulate in the procurement solicitation that they will assign a QA inspector who is knowledgeable in WIM installations to act as an agent of the state to oversee all installation efforts.

The solicitation shall state that the on-site QA inspector shall be responsible for enforcing all contract standards and specifications, ensuring that all work proceeds safely, and that all processes are properly documented using checklists and photography, and possibly video. The solicitation shall give power to the QA inspector to stop work if specifications are not being followed or if unsafe practices are occurring and shall not continue until the work deficiencies are corrected.

Electrical Testing

The procurement solicitation should include language that requires the manufacturer's representative to test all WIM components to ensure that all in-road sensors are operating within manufacturer tolerances, power service is sufficient, the equipment is properly grounded, there is lightning protection, and all communication devices are working properly.

Final Inspection

As part of the payment terms, the solicitation should state that the QA inspector, the manufacturer's representative, and the contractor's on-site supervisor will make a final inspection of all elements of the WIM system, documenting any substandard aspects and ensuring that each deficiency is corrected prior to the contractor leaving the site or final payment will be withheld until proper corrections of deficiencies are made.

Site Acceptance

The acceptance of the site includes a review of the installation and a determination if the installation has met the contract specifications and is installed in accordance with the manufacturer's specifications. Site acceptance should be based on the following criteria:

1. All equipment is installed as per manufacturer's specifications
2. All equipment is installed as per contract specifications
3. All sensors have been successfully tested
4. All support equipment (solar, A/C, telephone) has been successfully tested
5. System has been calibrated per manufacturer procedures and validated to be performing per contract specifications
6. System has successfully passed vehicle classification test
7. System has operated for 30 consecutive days without failure and produces data of consistent acceptable quality
8. All site documentation and as-built drawings have been submitted and accepted

Site acceptance and acceptance testing should be done by the contracting agency or contracting agency agent that is independent of the installation contractor. Similarly, WIM system performance verification should be done independent of the WIM maintenance contractor.

Calibration

Accuracy Standards

Initial WIM calibration requirements should be included in the WIM site installation procurement package. If the routine calibration function is being outsourced, use the following recommendation for the solicitation.

The initial calibration should be done in accordance with ASTM E1318-09, and references to existing standards used by state and federal agencies for WIM system calibration should be provided in the procurement documentation. Examples of calibration procedures are provided in Appendix E.

Reporting

The solicitation shall state that once a calibration of the system has been performed, the results of the calibration should be reported. The report should include:

1. Site ID
2. Date of calibration
3. Air and pavement temperature and weather conditions
4. Type and weight of test trucks. At least one loaded FHWA class 9 vehicle is recommended. Supply a weigh scale ticket documenting weights.
5. Number of calibration test truck runs (minimum 10 before and after calibration) for each lane
6. The measurement accuracy of each WIM lane when compared with the static weights of the test trucks, including:
    a. Mean percent error (measurement bias) for axle weights and GVW
    b. 95 percent confidence interval for the percent error (measurement precision expressed as statistical +/- percent error range) for axle weights and GVW
    c. Percent of axle weights and GVW measurements meeting ASTM E1318-09 performance parameters

for a given type of WIM system (ASTM Type I, II, III, IV).

7. The classification accuracy of the WIM system for each lane (percent classification errors in different vehicle classes, and percent of unclassified vehicles, using agency's vehicle classification rules or classification method).
   a. 2 percent or fewer misclassified or unclassified vehicles in the manual sample in FHWA vehicle classes 4 through 13 combined.
   b. 10 percent or less misclassification in each individual class of vehicles from 4 through 13. If the number of vehicles collected during the 3-hour testing period is under 30 for any vehicle class, the maximum number of misclassified vehicles:
      - 20-29 for one class = +/-3 vehicles
      - 10-19 for one class = +/-2 vehicles
      - 0-9 for one class = +/-1 vehicle
8. The axle spacing and overall length measurement accuracy for each lane
9. Statement if each lane of the WIM system met or failed ASTM E1318-09 performance parameters for given ASTM type of WIM system
10. Final calibration settings for each lane

Maintenance

A WIM installation is a significant investment that must be protected. A routine maintenance program is essential to maintain the WIM system's ability to produce high-quality data. Routine maintenance, such as annual or semi-annual site visits to inspect, clean, and calibrate WIM systems can be done using in-house personnel, incorporated into the installation contract, or can be awarded separately either to the manufacturer or to an independent agency. If the routine WIM maintenance function is being outsourced, use the following recommendations for solicitation development.

Routine Maintenance

The solicitation shall state that the technician assigned to maintain the WIM system should have a proven acceptable level of expertise with maintaining the specific type of WIM system that is installed. The timeliness of filed maintenance visits should be clearly stated. Include a sample maintenance report in the solicitation.

Spare Parts

Lost data can be costly to a WIM program. Without replacement parts readily available, parts can take months to arrive and be installed, resulting in extensive system down times. Therefore, include in the solicitation a requirement for the contractor to maintain a stock of ready service spare parts. Pricing for additional parts should be requested in the solicitation.

Repairs

As part of the procurement process, a warranty should be worded so that the conditions warranting the repairs that need to be made are explicit. The warranty language should indicate the reaction time by the installation contractor and/or the manufacturer to correct system failures and the penalties that will be incurred if the reaction time is not met.

REFERENCES

1. ASTM Standard E1318-09, *Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Methods*. West Conshohocken, PA: ASTM International, West Conshohocken, PA, 2009, DOI: 10.1520/E1318-09, www.astm.org.
2. European Cooperation in Science and Technology (COST): Action 323. 1998. *Weigh-in-Motion of Road Vehicles*. Paris: 2002.
3. NMi International WIM Standard: *Specification and Test Procedures for Weigh-in-Motion Systems*, NMi Certin, Dordrecht, Netherlands, 2016. http://www.nmi.nl/nmi-wim-standard/
4. Federal Highway Administration (FHWA). 2012. *LTPP Field Operations Guide for SPS WIM Sites Version 1.0. Draft.* McLean, VA: Federal Highway Administration: 2012.
5. Klein, Lawrence A. 2006. *Traffic Detector Handbook: Third Edition – Volume I*. Publication FHWA-HRT-09-108. Washington D.C.: Federal Highway Administration (FHWA):2006. https://www.fhwa.dot.gov/publications/research/operations/its/06108/
6. D. Walker, O. Selezneva, and D. Wolf, *Findings from LTPP SPS WIM Systems Validation Study,* Proceedings of the 6th International Conference on Weight-In-Motion, Dallas, Texas, June 2012
7. Federal Highway Administration (FHWA). 2016. *Traffic Monitoring Guide*. Washington, DC: Federal Highway Administration: 2016. https://www.fhwa.dot.gov/policyinformation/tmguide/

8. T. M. Kwon. 2016. *Weigh-Pad-Based Portable Weigh-in-Motion System User Manua*l. Report No. MN/RC 2016-07. Duluth, MN: University of Minnesota Duluth: 2016.
9. AASHTOWare Pavement ME Design software. User Manual. http://www.aashtoware.org/Pavement/Pages/default.aspx
10. American Association of State Highway and Transportation Officials (AASHTO). 2011. *Roadside Design Guide.* 4th Edition. Washington, D.C. 2011. https://bookstore.transportation.org/collection_detail.aspx?ID=105

APPENDICES

The appendices for the FHWA WIM Pocket Guide are available on the FHWA website:

https://www.fhwa.dot.gov/policyinformation/knowledgecenter

General Appendices

- Appendix A – Technical Report Documentation Page Form DOT F 1700.7
- Appendix B – Acknowledgements

Part 1 Appendices:

- Appendix C – WIM Procurement Resources
    - Example WIM Contract Language (GDOT)
    - Example of IRD Standard Warranty Statement
    - Example of IRD WIM System Installation Standards

Part 2 Appendices:

- Appendix D – WIM Site Design and Installation Resources
    - Example Pavement Surfacing Plans (SDDOT)
    - Example Polymer Piezo Installation Plan
    - Example SLC Layout (Mettler-Toledo)
    - Example WIM Installation Standard (NJDOT)
    - Example WIM Site Design (MT DOT)
    - Example WIM Cabinet Wiring Diagram
    - Example Non-compliance Report

Part 3 Appendices:

- Appendix E – Maintenance and Calibration Resources
    - Example WIM Calibration Report (AZ DOT)

- Example Calibration Test Truck Procurement (LTPP)
- Example WIM Site Maintenance Forms and Reports (AZ DOT)

WIM Program Operation and Management Checklists

- Appendix F – WIM Program Operation and Management Checklists
    - WIM Technology Selection Table
    - WIM Site Selection Checklist
    - WIM Site Design Checklist
    - WIM Site Installation QA Checklist
    - Initial Calibration Checklist
    - WIM Site Acceptance Checklist
    - Test Truck Selection for WIM Calibration
    - Routine WIM Calibration Checklist
    - WIM Maintenance Tools, Materials, and Supporting Documentation
    - WIM Preventive Maintenance Checklist
    - WIM Troubleshooting Checklist
    - WIM Data QA/QC Checklist

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