AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428
Reprinted from the Annual Book of ASTM Standards. Copyright ASTM

Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Method[1]

This standard is issued under the fixed designation E 1318; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification describes Weigh-in-Motion (WIM), the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle. Gross-vehicle weight (mass) of a highway vehicle is made up of the mass of several contiguous vehicle components, and is distributed among the tires of the vehicle through connectors such as springs, motion dampers, and hinges. Highway WIM systems are capable of estimating the gross weight of a vehicle as well as the portion of this weight that is carried by each wheel assembly (half-axle with one or more tires), axle (with two or more wheel assemblies lying approximately on a common axis oriented transversely to the nominal direction of motion of the vehicle), and axle group on the vehicle.

1.2 Ancillary information concerning the speed, lane of operation, date and time of passage, number and spacing of axles, and classification (according to axle arrangement) of each vehicle that is weighed in motion is desired for certain purposes. It is feasible for a WIM system to measure or calculate these traffic parameters and to process, summarize, store, display, record, hard-copy, and transmit the resulting data. Furthermore, differences in measured or calculated parameters as compared with selected control criteria can be detected and indicated. In addition to tire-load information, a WIM system is capable of producing all, or specified portions of, this information.

1.3 Highway WIM systems generally have three applications: (1) collecting statistical traffic data, (2) aiding enforcement, and (3) enforcement. This specification classifies WIM systems according to their application and gives the related performance requirements and user requirements for each type of system.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are for informational purposes only. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other.

1.5 The following safety hazards caveat applies only to the test method portion, Section 7, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 1155 Test Method for Determining Floor Flatness and Levelness Using the F-Number System (Inch-Pound Units)[2]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *accuracy*—the closeness or degree of agreement (within a stated tolerance and probability of conformity) between a quantity measured or estimated by a WIM system and an accepted reference value. Precision and bias of the test method used to determine WIM-system accuracy are discussed in Section 7.

3.1.2 *axle-group load*—the sum of all tire loads on a group of adjacent axles.

3.1.3 *axle load*—the sum of all tire loads on an axle. An axle is comprised of two or more wheel assemblies lying approximately on a common axis oriented transversely to the nominal direction of motion of the vehicle.

3.1.4 *gross-vehicle weight*—the total mass of the vehicle or the vehicle combination including all connected components.

3.1.5 *tire load*—the portion of the gross-vehicle weight imposed upon the static tire at the time of weighing, expressed in units of mass, pounds (kilograms), due only to the vertically-downward force of gravity acting on the mass of the static vehicle.

3.1.6 *tolerance*—the defined limit of allowable departure from the true value of a quantity measured or estimated by a WIM system.

3.1.7 *weigh*—to measure the tire load on one or more tires by using a vehicle scale, an axle-load scale, a portable axle-load weigher, or a wheel-load weigher (see Sec. 2.20, of the National Institute of Standards and Technology Handbook

[1] This specification is under the jurisdiction of ASTM Committee E-17 on Vehicle-Pavement Systems and is the direct responsibility of Subcommittee E17.52 on Traffic Monitoring Device Interconnect.

Current edition approved April 15, 1994. Published June 1994. Originally published as E 1318 – 90. Last previous edition E 1318 – 92.

[2] *Annual Book of ASTM Standards*, Vol 04.07.

44).[3] These devices are usually subjected to field standard test weights at each locality of use and are adjusted to indicate units of mass (see section 3.2, Appendix B, NIST Handbook 44).

3.1.8 *Weigh-in-Motion (WIM), n*—the process of estimating a moving vehicle's gross weight and the portion of that weight that is carried by each wheel, axle, or axle group, or combination thereof, by measurement and analysis of dynamic vehicle tire forces.

3.1.9 *weight*—synonymous with mass. The mass of a body is a measure of its inertia, or resistance to change in motion.

3.1.10 *wheel load*—the sum of the tire loads on all tires included in the wheel assembly which comprises a half-axle.

3.1.11 *WIM System*—a set of sensors and supporting instruments which measures the presence of a moving vehicle and the related dynamic tire forces at specified locations with respect to time; estimates tire loads, speed, axle spacing, vehicle class according to axle arrangement, and other parameters concerning the vehicle; and processes, displays, and stores this information. This specification applies only to highway vehicles.

4. Classification

4.1 WIM systems shall be specified to meet the needs of the user for intended applications in accordance with the following types. Exceptions and options may be specified. All systems shall be designed to operate on 110V, a-c, 60-Hz power, and lightening protection for affected system components shall be provided by the vendor. The user may specify as options a completely battery-powered system or battery-backup power in case of failure of normal power.

4.1.1 *Type I:* This type of WIM system shall be designed for installation in up to four lanes at a traffic data-collection site and shall be capable of accommodating highway vehicles moving at speeds from 10 to 70 mph (16 to 113 km/h), inclusive. For each vehicle processed, the system shall produce all data items shown in Table 1. A user-controlled feature of the system shall allow tire-force information from the wheel(s) on only one half of an axle to be used to estimate axle load. Provisions shall be made for entering selected limits for wheel, axle, axle-group (including bridge-formula grouping[4]) loads, and gross-vehicle weights as well as speed and for detecting and indicating suspected violation of any of these limits by a particular vehicle. A feature shall be provided so that the user can determine whether or not the WIM system will prepare selected data items for display and recording. Use of this feature shall not inhibit the system from receiving and processing data. Data shall be processed on-site in such a way that all data items shown in Table 1 can be displayed in alphanumeric form for immediate review. Means for recording data items 1, 5, 6, 7, 8, 9, 10, and 11 for permanent record shall be provided. On-site presentation of a hard-copy of all data items produced by the system shall be an optional feature (Option 1) of the system. Option 2 for this type of WIM system shall additionally provide means for counting and for recording hourly the lanewise count of all vehicles traveling in all lanes, up to a maximum of ten lanes, at a data-collection site, including lanes without WIM sensors. Option 3 shall provide for counting, classifying (via axle arrangement), measuring the speed of, and recording the hourly totals concerning all such vehicles by class and by lane of travel.

4.1.2 *Type II:* This type of WIM system shall be designed for installation at traffic data-collection sites and should be capable of accommodating highway vehicles moving at speeds from 10 to 70 mph (16 to 113 km/h), inclusive. For each vehicle processed, all data items shown in Table 1 except Item 1 shall be produced by the system. All other features and options of the Type II WIM system shall be identical to those described in 4.1.1 for the Type I WIM system.

4.1.3 *Type III:* This type of WIM system shall be designed for installation in one or two lanes at weight-enforcement stations to identify vehicles operating at speeds from 15 to 50 mph (24 to 80 km/h), inclusive, that are suspected of weight-limit or load-limit violation. For each vehicle processed, the system shall produce all data items shown in Table 1 except 7, 12, and 13 and shall also estimate acceleration (while the vehicle is over the WIM-system sensors). Provisions shall be made for entering selected limits for wheel, axle, axle-group (including bridge-formula grouping[4]) loads, and gross-vehicle weight as well as speed and acceleration and for detecting and indicating suspected violation of any of these limits by a particular vehicle. Means shall be provided for automatically controlling official traffic-control devices which will direct each suspect vehicle to a scale for confirmation weighing and guide all non-suspect vehicles past the scale without stopping. Manual operation of these official traffic-control devices shall be provided as an optional feature (Option 1) of the Type III WIM system. Information used in determining a suspected violation shall be displayed in alphanumeric form for immediate review and recorded permanently. Option 2 shall provide means for presenting this information in hard-copy form if requested by the system operator. Option 3 may be specified to exempt the Type III WIM system from producing wheel-load information (Item 1 in Table 1) if this data item is not of interest for enforcement. Option 4 for this type of WIM system

TABLE 1 Data Items Produced by WIM System

1.	Wheel Load
2.	Axle Load
3.	Axle-Group Load
4.	Gross-Vehicle Weight
5.	Speed
6.	Center-to-Center Spacing Between Axles
7.	Vehicle Class (via axle arrangement)
8.	Site Identification Code
9.	Lane and Direction of Travel
10.	Date and Time of Passage
11.	Sequential Vehicle Record Number
12.	Wheelbase (frontmost to rearmost axle)
13.	Equivalent Single-Axle Load (ESAL)
14.	Violation Code

[3] "Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices," *National Institute of Standards and Technology Handbook 44*, U.S. Department of Commerce, Washington, DC 20234.

[4] *Traffic Monitoring Guide, June 1985*, U.S. Department of Transportation, Federal Highway Administration, Office of Highway Planning, Washington, DC 20590.

shall provide for recording the following data items shown in Table 1 for every vehicle processed by the system: 1 (2 in lieu of 1 when Option 3 is specified), 5, 6, 8, 9, 10, and 11. These items allow subsequent computation of statistical traffic data.

4.1.4 *Type IV:* This type of WIM system shall be designed for use at weight-enforcement stations to detect weight-limit or load-limit violations. Speeds from 0 to 10 mph (0 to 16 km/h), inclusive, shall be accommodated. For each vehicle that is processed, the system shall produce all data items shown in Table 1 except 7, 9, 12, and 13 and shall also estimate acceleration (while the vehicle is over the WIM-system sensors). Provisions shall be made for entering and displaying selected limits for wheel, axle, axle-group (including bridge-formula grouping,[4]) loads, and gross-vehicle weights as well as speed and acceleration and for detecting and indicating violation of any of these limits by a particular vehicle. Information used in determining a violation shall be displayed in alphanumeric form for immediate review and recorded permanently. Option 1 shall provide means for presenting this information in hard-copy form if requested by the system operator. Option 2 may be specified to exempt the Type IV WIM system from producing wheel-load information (Item 1 in Table 1) if this data item is not of interest for enforcement.

5. Performance Requirements

5.1 Each type of WIM system shall be capable of performing the indicated functions within the accuracy shown in Table 2. A test method for determining compliance with these requirements is given in Section 7. After computation of the data items shown in Table 2, no digit which indicates less than 10 lb (5 kg) (load or weight), 1 mph (2 km/h) (speed), or 0.1 ft (30 mm) (axle spacing) shall be retained.

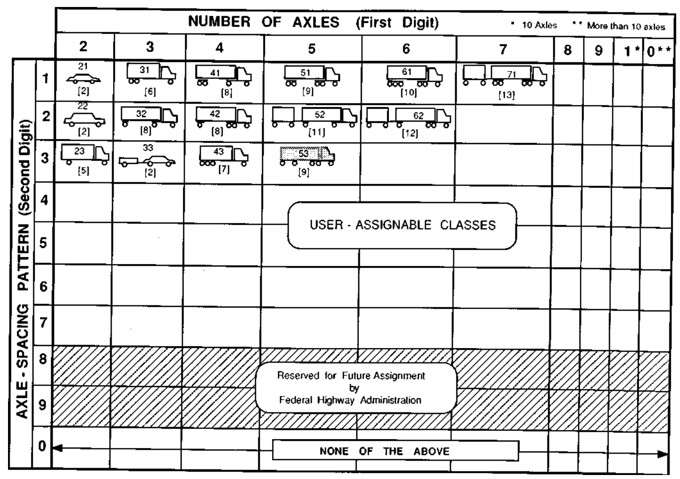
5.2 Vehicle classification according to axle arrangement shall be accomplished by Type I and Type II WIM systems. The vendor shall incorporate software within each Type I and Type II WIM system for using the available WIM-system axle-count and axle-spacing information for estimating the Federal Highway Administration (FHWA) Vehicle Types described briefly in Table 3. See U.S. Department of Transportation Traffic Monitoring Guide[4] for the complete description of FHWA Vehicle Types. The FHWA Vehicle Type shall be indicated by the 2-Digit Code shown in Table 3. A vehicle type code 00 shall be applied to any vehicle which the software fails to assign to one of the types shown.

5.2.1 As an option to the FHWA vehicle classes indicated by the 2-digit code, the user may specify the 3-Digit Vehicle Classes shown graphically in Fig. 1 and numerically in Table 4. In the 3-digit code, the first digit indicates the total number of axles on the vehicle or the combination, the second digit indicates the axle-spacing pattern, and the third digit indicates a user-assigned subset of the axle-spacing pattern. Provisions shall be made for the user to enter additional axle-spacing criteria for the user-assignable classes shown in Fig. 1 as well as for the user-assignable subsets of the axle-spacing patterns which are to be designated by a selected third digit.

5.3 Provisions shall be made in Type I, Type II, Type III, and Type IV WIM systems for entering, displaying, and recording a 10-character alphanumeric Site Identification Code for each data-taking session. This code can be used to incorporate information required for FHWA Truck Weight Data Collection.[4]

TABLE 3 FHWA Vehicle Types

2-Digit Code	Brief Description
01	Motorcycles
02	Passenger Cars
03	Other Two-Axle, Four-Tire Single-Unit Vehicles
04	Buses
05	Two-Axle, Six-Tire, Single-Unit Trucks
06	Three-Axle, Single-Unit Trucks
07	Four-or-More Axle Single-Unit Trucks
08	Four-or-Less Axle Single-Trailer Trucks
09	Five-Axle Single-Trailer Trucks
10	Six-or-More Axle Single-Trailer Trucks
11	Five-or-Less Axle Multi-Trailer Trucks
12	Six-Axle Multi-Trailer Trucks
13	Seven-or-More Axle Multi-Trailer Trucks



NOTE 1—Corresponding Federal Highway Administration (FHWA) Vehicle Types are shown as [ ]. e.g., Class 51 shown above is FHWA [9].Third Digit allows the user to describe a subset(s) of the axle-spacing pattern defined by the second digit.

FIG. 1 Graphical Representation of 3-Digit Vehicle Classes

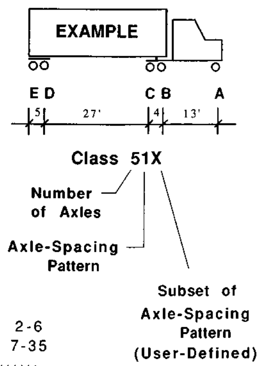
TABLE 2 Functional Performance Requirements for WIM Systems

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

[A]Lower values are not usually a concern in enforcement.

TABLE 4 Axle-Spacing Patterns for 3-Digit Vehicle Classes

CLASS	RANGE OF SPACING BETWEEN PAIRS OF AXLES (FT)					
	A,B	B,C	C,D	D,E	E,F	etc.
21	6-9					
22	9-11					
23	11-25					
20	"OTHER"					
31	8-26	2-6				
32	8-20	11-45				
33	6-10	6-22				
30	* OTHER 3-AXLE *					
41	8-20	11-45	2-6			
42	8-20	2-6	11-45			
43	8-25	2-6	2-6			
40	****** OTHER 4-AXLE ******					
51	8-25	2-6	11-55	2-6		
52	8-20	11-36	6-20	7-35		
50	********** OTHER 5-AXLE **********					
61	8-20	2-6	11-42	2-6	2-6	
62	8-20	2-6	11-30	7-15	11-25	
60	**************** OTHER 6-AXLE **************					



5.4 A lane and direction-of-travel code for each vehicle processed by Type I, Type II, and Type III WIM systems shall consist of a number beginning with 1 for the right-hand northbound or eastbound traffic lane and continuing until all the lanes in that direction of travel have been numbered; the next sequential number shall be assigned to the lanes in the opposite direction of travel beginning with the left-hand lane and continuing until all lanes have been numbered. Provision shall be made for 12 numbers in the code. This code may be used to incorporate information required for FHWA Truck Weight Data Collection.[4]

5.5 Date of passage shall be indicated numerically for each vehicle processed by Type I, Type II, Type III, and Type IV WIM systems in the following format: MM/DD/YY, where M is the month, D is the day, and Y is the year.

5.6 Time of passage shall be indicated numerically for each vehicle processed by Type I, Type II, Type III, and Type IV WIM systems in the following format: hhmm:ss, where h is the hour beginning with 00 at midnight and continuing through 23, m is the minute, and s is the second.

5.7 Type I, Type II, Type III, and Type IV WIM systems shall provide sequential-numbering (user-resettable) for each recorded vehicular data set.

5.8 Type I and Type II WIM systems shall compute wheelbase as the sum of all axle spacings between the front most and the rearmost axles on the vehicle or combination that have tires in contact with the road surface at the time of weighing. This value shall be rounded to an integer value (in ft) (or to the nearest 0.1 m) before display or recording.

5.9 Type I and Type II WIM systems shall compute Equivalent Single-Axle Load (ESAL) as described in the Annex to this standard. The WIM system shall be capable of computing ESALs for single and tandem axles for both flexible and rigid pavements, and provision shall be made for the user to select one of these pavement types for application during any given data-collection session. The system shall compute the total ESALs for each vehicle or vehicle combination and prepare these data for display as part of each vehicle record. When displayed, this value shall be truncated to 2 digits following the decimal and presented in the following format: FESAL = for flexible pavements, and RESAL = for rigid pavements. The parameter for serviceability at the end of time t, P_t, shall be adjustable by the user, but 2.5 shall be programmed as a default value. Similarly, the value for structural number, *SN*, used for computing flexible pavement equivalency factors shall be user adjustable, but shall be defaulted to 3.0. The value for thickness of rigid pavement slab, *D*, used in computing rigid pavement equivalency factors shall be user adjustable, and shall be defaulted to 8.0 in. (203 mm) in the WIM-system program. Provision shall be made in the program to list on demand all parameters actually utilized in the ESAL computation during any given data-collection session.

5.10 Violations of all user-set parameters shall be determined by Type I, Type II, Type III, and Type IV WIM systems. A2-character violation code, such as shown in Table 5, shall be used for each detected violation and shall be included in the displayed data. Provision shall be made for the user to define up to 15 violation codes. An additional optional feature that calls attention to any data items which are in violation of user-set limits may be specified by the user, for example, flashing, underlining, bold-facing, or audio tones.

5.11 Type III and Type IV WIM systems shall measure vehicle acceleration, which is a change in velocity. Negative acceleration is also called deceleration. The forces acting on a vehicle to produce acceleration can effect significant change in the distribution of the gross-vehicle weight among the axles and wheels of the vehicle as compared to the distribution when the vehicle is static. Therefore, any severe acceleration while the vehicle is passing over the WIM-system sensors can invalidate wheel and axle loads estimated by the system. Average acceleration of 2 ft/s^2(0.6 m/s^2) or greater during the time that the wheelbase (see 5.8) of the vehicle is passing over the tire-force sensors should be considered as a violation. This value shall be user-adjustable, but the vendor shall program 2 ft/s^2(0.6 m/s^2) as the default value in these WIM systems.

5.12 For Type I, Type II, Type III, and Type IV WIM systems, provision shall be made to allow manual entry of a user-assignable 3-digit code into any vehicular data set prior to recording.

6. User Requirements

6.1 In order for any WIM system to perform properly, the user must provide and maintain an adequate operating environment. Construction or selection of each WIM site as well as

TABLE 5 Violation Code

Violation	Code
Wheel Load	WL
Axle Load	AL
Axle—Group Load	AG
Gross-Vehicle Weight	GV
Bridge—Formula Load	BF
Over Speed	OS
Under Speed	US
Acceleration	AC
Deceleration	DE

continuing maintenance of the site and the sensors are extremely important considerations. The following site conditions, or better, shall be provided by the user.

6.1.1 The horizontal curvature of the roadway lane for 150 ft (45 m) in advance of and beyond the WIM-system sensors shall have a radius not less than 5700 ft (1.7 km) measured along the centerline of the lane for all types of WIM systems.

6.1.2 The longitudinal gradient of the road surface for 150 ft (45 m) in advance of and beyond the WIM system sensors shall not exceed 2 % for Type I, Type II, and Type III WIM-system installations, and shall not exceed 1 % for Type IV installations.

6.1.3 The cross-slope (lateral slope) of the road surface for 150 ft (45 m) in advance of and beyond the WIM-system sensors shall not exceed 2 % for Type I, Type II, and Type III WIM system installations, and shall not exceed 1 % for Type IV installations.

6.1.4 The width of the paved roadway lane for 150 ft (45 m) in advance of and beyond the WIM-system sensors shall be between 10 and 12 ft (3.0 and 3.7 m), inclusive. For Type III and Type IV WIM systems, the edges of the lane throughout this distance shall be marked with solid white longitudinal pavement marking lines 4 to 6 in. (100 to 150 mm) wide, and at least 3 ft (1 m) of additional clear space for wide loads shall be provided on each side of the WIM-system lane.

6.1.5 The surface of the paved roadway 150 ft (45 m) in advance of and beyond the WIM-system sensors shall be maintained in a condition such that a 6-in. (150-mm) diameter circular plate 0.125-in. (3 mm) thick cannot be passed beneath a 20-ft (6-m) long straightedge when the straightedge is positioned and maneuvered in the following manner:

6.1.5.1 Beginning at the longitudinal center of the WIM-system sensors, place the straightedge along each respective lane edge with the outer end at the distances from the longitudinal center of the sensors as indicated below, pivot the straightedge about this end, and sweep the inner end between the lane edges while checking clearance beneath the straightedge with the circular plate. Equivalent flatness may be determined by an alternative means such as is described in Test Method E 1155.

Lane Edge	Longitudinal distance from Center of Sensors, ft (m)
Right	20, 30, 44, 60, 76, 92, 108, 124, 140, and 156 (6, 9, 13, 18, 23, 28, 33, 38, 43, and 48)
Left	20, 36, 52, 68, 84, 100, 116, 132, 148, and 164 (6, 11, 16, 21, 26, 30, 35, 40, 45, and 50)

6.1.6 The user shall provide and maintain a foundation to accommodate the WIM-system sensors and shall install and maintain the sensors in accordance with the recommendations of the system vendor.

6.1.7 The user shall provide and maintain a climatic environment for the WIM-system instruments in accordance with those specified by the user and agreed upon by the system vendor.

6.1.8 The user shall provide an adequate 110V, ac, 60-Hz electrical power supply at each WIM site and/or specify an optional battery-powered system as suggested in 4.1.

6.2 Any desired optional features described in Section 4 and Section 5, any exceptions, and any additional features of the WIM system shall be specified by the user. The user shall also specify the data items to be included in the display, the number of vehicle records to be displayed simultaneously, and whether the ability to hold a selected record(s) on display without interference with continuous data taking by the system is required. The user should note that the number of data items selected will affect the number of vehicle records that can be displayed simultaneously.

6.3 The user shall recalibrate every WIM system following any maintenance or relocation, and at a minimum annually. Recalibration of system Types I, II, and III shall be performed in accordance with the method presented in 7.5, and system Type IV shall be recalibrated in accordance with the method presented in 7.4.5.

7. Test Method for WIM System Performance

7.1 A test method for evaluating the performance of each type of WIM system is presented in this section. Procedures are given for (1) acceptance testing of any new type WIM system, and (2) on-site calibration (to remove as much bias as practicable from the weight estimates) at the time of system installation or when site conditions have changed.

7.1.1 *Apparatus for Weighing Static Vehicles*—When wheel-load data are required from the WIM system, the corresponding reference tire-load values for Type I, Type III, and Type IV WIM systems shall be determined with wheel-load weighers which meet the respective tolerance specification of the current edition of NIST Handbook 44.[3] The minimum number of wheel-load weighers required is 2 and the preferred number is 6. When wheel-load data are not required, axle-load scales, multi-platform vehicle scales, portable axle-load weighers, or a pair of wheel-load weighers which meet the respective tolerance specification of the current edition of NIST Handbook 44, shall be used for obtaining reference tire-load values for Type II and Type III WIM systems. Either an axle-load scale or a multi-platform vehicle scale, along with wheel-load weighers if required, shall be used for measuring reference tire-load values for Type III and Type IV WIM systems.

7.1.2 *Use of Apparatus for Weighing Static Vehicles*—The tire-pavement contact surfaces of all tires on the vehicle being weighed shall be within 0.25 in. (6 mm) of a plane passing through the load-receiving surface(s) of the multi-platform vehicle scale, wheel-load weighers, portable axle-load weighers, or axle-load scales whenever any tire-load measurement is made. The maximum slope of this plane from horizontal shall be 2 %. Suitable blocking or mats may be utilized, or the weighing device(s) may be recessed into the pavement surface to provide the required vertical orientation of the tire-pavement contact surfaces. When wheel-load information is required, wheel and axle load shall be measured simultaneously using a pair of wheel-load weighers. When wheel-load information is not required, axle-load shall be determined by positioning each axle to be weighed either simultaneously or successively on an axle-load scale(s), a multi-platform vehicle scale, a portable axle-load weigher(s), or a pair(s) of wheel-load weighers. Axle-group load shall be determined either by positioning all axles in the group simultaneously on the required number of weighing devices (preferred) or by successively positioning each axle in the group on a pair of wheel-load weighers or on an axle-load weighing device. The number of movements of the vehicle to accomplish the successive tire-load measurements shall be minimized. A tire-load measurement shall be made only when the brakes of the vehicle being weighed are fully released and all tires are properly positioned on the load-receiving surface(s) of the weighing device(s). Suitable means (for example, chocks) shall be used to keep the tires properly positioned while the brakes are released. Gross-vehicle weight shall be the sum of all wheel loads or axle loads for the vehicle. No tire-load measurement shall be taken until inertially-induced oscillations (for example, via a load of liquid) of the vehicle have subsided to a point that indicated tire load is changing less than three scale divisions in 3s.

7.2 *Acceptance Test for Type I and Type II WIM Systems*:

7.2.1 *Scope*—An acceptance test is described for evaluating the performance capabilities of a new WIM system under excellent conditions and under traffic loading that is representative of that which will be of interest where Type I and Type II WIM systems will be applied. Performance requirements for each type of WIM system are given in Section 5 of this standard, and associated user requirements are given in Section 6. The WIM system being evaluated in the acceptance test shall be subjected to a loading test unit consisting of (a) two test vehicles loaded with a non-shifting load, plus (b) 51 additional vehicles selected from the traffic stream at the acceptance-test site. Other types of vehicles may be added to the loading test unit at sites where large numbers of vehicles of classes not already included are operating. The two test vehicles, which will make multiple passes over the WIM-system sensors at the minimum and at the maximum speed specified by the user between 10 and 70 mph (16 to 113 km/h) and at an intermediate speed, serve two functions. First, they provide a basis for evaluating the performance of the WIM system over the full, specified range of speeds, and second, they provide a means (via repeated measurements on the same static vehicle) for ensuring that reference-value tire-load measurement procedures yield reproducible values. The additional vehicles included in the loading test unit serve the function of subjecting the WIM system to loading by a representative variety of vehicle classes. All vehicles comprising the loading test unit shall be weighed statically on certified weighing devices as described in 7.1.1 and 7.1.2 at a suitable site within reasonable proximity to the acceptance-test site.

7.2.2 *Significance and Use*—Interpretation of the results from the acceptance test will allow the user to determine whether the tested Type I or Type II WIM system is capable of meeting or exceeding the performance requirements stated in Section 5. This can also indicate the potential upper limit of performance which can be achieved by the particular type of system as the road surface conditions, which potentially affect the location and magnitude of dynamic tire forces significantly, shall be the best available for conducting the acceptance test and shall, as a minimum, satisfy the user requirements shown in Section 6. Once a specimen WIM system has passed this rigorous acceptance test, it should not be necessary for each subsequent user to repeat the test for every system of the same type from the same vendor.

7.2.3 *Site for Acceptance Test*—Both the user (or a recognized representative of user's interests) and the vendor shall approve the acceptance test site as well as the WIM-system installation prior to conducting the acceptance test. The actual road-surface and WIM-system sensor conditions which prevail during acceptance testing shall be documented in terms of surface conditions measured in a way that verifies compliance with the user requirements given in Section 6. This documentation, along with all acceptance test results, shall be reported to ASTM Committee E-17 on Pavement Management Technologies so that statements about bias and precision of the test can be formulated as experience is accumulated.

7.2.4 *Test Unit for Acceptance Test Loading*—The test unit for loading the WIM system being evaluated in the acceptance test shall be comprised of two loaded test vehicles which will make multiple runs over the WIM-system sensors at prescribed speeds along with other vehicles selected from the traffic stream at the acceptance test site. One of the loaded test vehicles shall be Class 23 and the other Class 51 (see Fig. 1 and Table 4). These test vehicles shall be loaded to within 90 to 110 % of their respective registered gross-vehicle weight with a non-shifting load and shall be in excellent mechanical condition. Special care shall be exercised to ensure that the tires on the test vehicles are in excellent condition (preferably dynamically balanced) and inflated to recommended pressures. The number of vehicles in each Vehicle Class (see 5.2) to be selected in random order from the traffic stream for inclusion in the test unit is shown in Table 6 (see Fig. 1 and Table 4). If a significant number of vehicles of another class(s) is operating at the site, define the class(s), and add three selected vehicles of each such class to the test unit.

7.2.5 *Calibration and Certification*—Within 48 h prior to beginning the acceptance test, the WIM system shall be calibrated in accordance with the method presented in 7.5. The radar speed meter shall be calibrated by the method recommended by its vendor within 30 days prior to the acceptance test. All weighing apparatus used in the acceptance test shall be certified as meeting the applicable maintenance tolerance specified in National Institute of Standards and Technology Handbook 44 within 30 days prior to beginning the acceptance test.

7.2.6 *Procedure*—The following steps shall be performed in conducting the acceptance test.

7.2.6.1 As a joint effort between the user (or a recognized representative of user's interests) and the vendor, select the best available WIM-system site which, as a minimum, meets the applicable requirements stated in Section 6.

7.2.6.2 Ensure that a suitable site for weighing vehicles

TABLE 6 Composition of Test Unit for Acceptance-Test Loading of WIM Systems

Vehicle Class	Number of Selected Vehicles
23	5
31	5
32	4
41	4
42	4
51	20
52	3
62	3
71	3

statically is available within a reasonable distance of the WIM site, that traffic can be controlled safely at this location, and that test vehicles can turn around safely and conveniently for multiple passes. Obtain approval from the public authority having jurisdiction over the site for the traffic control procedures that will be used during testing.

7.2.6.3 Install the WIM system in accordance with the vendor's recommendations and calibrate as required in 7.2.5.

7.2.6.4 Measure and record surface conditions as described in 7.2.3.

7.2.6.5 Using traffic control procedures approved by the appropriate public authority and other reasonable safety precautions, have each loaded test vehicle (see 7.2.4) make a series of three runs over the WIM-system sensors at the minimum and at the maximum speed specified by the user between 10 and 70 mph (16 and 113 km/h), record all data, and note the vehicle record number for each run of each test vehicle.

7.2.6.6 For reference values, measure the speed of the test vehicle each time it passes over the WIM-system sensors with a calibrated radar speed meter or by some other means (such as wheelbase/time) acceptable to both the user (or a recognized representative of user's interests) and the vendor, and record the observed speed.

7.2.6.7 At the site where the vehicle is weighed statically, measure the center-to-center spacing between axles on each test vehicle and record these data to the nearest 0.1 ft (30 mm) as reference values.

7.2.6.8 Weigh the test vehicle statically as described in 7.1.1 and 7.1.2 for every run to determine reference-value tire loads. Sum the applicable tire loads to determine reference-value wheel, axle, and axle-group loads as well as gross-vehicle weight.

7.2.6.9 Confirm that the procedure used for determining reference-value tire loads yields acceptable results by making the calculations shown in 7.2.7.1 before continuing the test.

7.2.6.10 If all the measured or calculated loads and weights of the two static test vehicles fall within the specified ranges, run each test vehicle over the WIM-system sensors three more times at a speed which is representative of truck traffic speed at the site, make reference-value determinations of load, weight, speed, and axle spacing for each of these runs, record all data, and proceed to 7.2.6.14.

7.2.6.11 If any of the measured or calculated load or weight values exceeds the specified range, correct deficiencies in the reference-value weighing process and weigh each test vehicle three more times.

7.2.6.12 Repeat 7.2.6.11 until the weighing process yields reference-value loads and weights which are within the specified range.

7.2.6.13 After the observed values for load and weight of the two static test vehicles have been found to be within the specified ranges, run each of the loaded test vehicles over the WIM-system sensors three more times at each of the following attempted speeds: the minimum and the maximum specified by the user between 10 and 70 mph (16 and 113 km/h) and at a speed which is representative of truck-traffic speed at the site. Make reference-value determinations of load and weight (verify that all these values satisfy the ranges specified in 7.2.7.1), speed, and axle spacing for every run of the test vehicles, and record all data.

7.2.6.14 Make the calculations shown in 7.2.7.2 for 18 runs (three runs at three speeds by two vehicles) of the loaded test vehicles and compare the performance of the WIM system with all specification requirements stated in Section 5.

7.2.6.15 If any WIM-system data item resulting from the test-vehicle runs fails to satisfy the standard, have the user (or a recognized representative of user's interests) decide whether to continue the test or declare that the system has failed to meet specification requirements.

7.2.6.16 If continuation is approved, select vehicles from the traffic stream to complete the makeup of the test unit for acceptance-test loading as specified in 7.2.4.

7.2.6.17 Allow each of the selected vehicles to pass over the WIM-system sensors at normal speed and require each vehicle to stop for weighing and for measurement of axle spacing.

7.2.6.18 Make the calculations shown in 7.2.7.2 and compare the performance of the WIM system with the specification requirements stated in Section 5 for the remainder of the vehicles in the test unit.

7.2.6.19 Interpret and report the results as described in 7.2.8.

7.2.7 *Calculation*—Calculation is needed for evaluating (a) variability in the reference-value loads and weights of the static test vehicles, and (b) conformity of data items produced by the WIM-system to specification requirements.

7.2.7.1 *Procedure for Calculating Reference-Value Loads and Weights*—Only certified weighing devices shall be utilized for determining reference-value tire loads. Reference-value loads and weights are calculated by summing tire loads. For WIM systems which produce estimates of wheel loads, calculate reference-value axle load by summing two wheel loads, axle-group load by summing four wheel loads for the wheels in each tandem-axle group, and gross-vehicle weight by summing all wheel loads separately for each of the two loaded test vehicles specified in 7.2.4. For WIM systems which do not produce estimates of wheel loads, sum the appropriate axle loads to calculate axle-group loads and gross-vehicle weight, if wheel-load weighers are not used. If wheel-load weighers are used, use the procedure stated above for summing tire loads. Calculate the arithmetic mean for each set of values for wheel load, axle load, axle-group load, and gross-vehicle weight; also calculate the difference, in percent, from this mean of each individual value used in calculating the respective mean. Compare these differences to the following specified range for each applicable load or weight: Gross-Vehicle Weight = ±2 %, Axle-Group Load = ±3 %, Axle Load = ±4 %, and Wheel Load = ±5 %. These limits define a practicable range into which an individual observation must fall in order to demonstrate that the static weighing process is producing acceptable results. When multiple weighings are made, always use the mean as the reference-value for load or weight.

7.2.7.2 *Procedure for Calculating Percent of Non-Conforming Data Items*—For each data item that is produced by the WIM system and shown in Table 2, calculate the difference in the value and the corresponding reference value by the following relationship:

$$d = 100[(C - R)/R] \tag{1}$$

where:

d = difference in the value of the data item produced by the WIM system and the corresponding reference value expressed as a percent of the reference value, %,
C = value of the data item produced by the WIM system, and
R = corresponding reference value for the data item.

Determine the number of calculated differences that exceeded the tolerance shown in Table 2 for each data item and express this number as a percent of the total number of observed values of this item by the following relationship:

$$P_{de} = 100[n/N] \tag{2}$$

where:

P_{de} = percent of calculated differences that exceeded the specified tolerance value,
n = number of calculated differences that exceeded the specified tolerance value, and
N = total number of observed values of the data item.

7.2.8 *Interpretation of Test Results and Report*—If more than 5 % of the calculated differences for any applicable data item (specified in Section 4) resulting from all passes of the two loaded test vehicles (each vehicle made three passes at three difference speeds) and from the single pass of each selected vehicle over the sensors at normal speed exceed the specified tolerance (specified in Section 5) for that item, declare the WIM system inaccurate and report that it failed the acceptance test. Regardless of whether the system fails or passes the acceptance test, tabulate all data used in making the determination, including the surface conditions, and send the results to ASTM Committee E-17 on Pavement Management Technologies within 90 days after completion of on-site data collection so that statements about bias and precision of the test can be formulated as experience is accumulated.

7.2.9 *Precision and Bias*—A statement about precision and bias of a test method should allow potential users of the test to assess in general terms its usefulness for a particular purpose. It is intended to provide guidance as to the amount of variation that can be expected in test results when the test is conducted in one or more comparable laboratories or situations. This is a new test method which produces pass-or-fail results. The precision and bias of the procedure and calculations in this acceptance test for Type I and Type II WIM systems are being determined.

7.3 *Acceptance Test for Type III WIM Systems*:

7.3.1 *Scope*—A procedure is given for conducting an acceptance test of a Type III WIM system. This type of system is designed for installation at weight-enforcement stations to identify vehicles operating within a user-specified range of speeds between 15 and 50 mph (24 and 80 km/h), inclusive, that are suspected of weight-limit or load-limit violation. The system must also control official traffic-control devices which direct suspect vehicles to a scale for confirmation weighing and measurement and direct non-suspect vehicles past the scales without stopping. The acceptance test shall be conducted under excellent site conditions and under traffic that includes vehicles which are representative of the vehicle classes of interest where Type III WIM systems will be installed. Performance requirements for this type system are presented in Section 5, and user requirements are given in Section 6. Tolerances for Type III WIM systems are somewhat smaller than for Types I and II because speeds are lower and, with the required reference-value weighing devices continually available, on-site calibration is practicable at any chosen time. Test loading for the acceptance test is designed to allow evaluation of the variability in measured or calculated loads and weights of static vehicles as well as the accuracy of WIM-system estimates of the various data items produced by the system. Capability of the system to detect excessive acceleration of a vehicle while it is over the WIM-system sensors is also evaluated. All vehicles used for test loading the Type III WIM system shall be weighed statically as described in 7.1.1 and 7.1.2 using the certified scales installed at the weight-enforcement site where the acceptance test is conducted.

7.3.2 *Significance and Use*—Interpretation of the results from the acceptance test will allow the user to determine whether the test Type III WIM system is capable of meeting or exceeding the performance requirements stated in Section 5. This can also indicate the potential upper limit of performance that can be achieved by the particular type of system as the road surface conditions, which potentially affect the location and magnitude of dynamic tire forces significantly, shall be the best available for conducting the acceptance test and shall, as a minimum, satisfy the user requirements shown in Section 6. Once a specimen WIM system has passed this rigorous acceptance test, it should not be necessary for each subsequent user to repeat the test for every system of the same type from the same vendor.

7.3.3 *Site for Acceptance Test*—See 7.2.3.

7.3.4 *Test Unit for Acceptance Test Loading*—The test unit for loading the WIM system being evaluated in the acceptance test shall be the same as specified in 7.2.4, except that each vehicle selected from the traffic stream for inclusion in the loading test unit shall have one or more of the following loads or weights that is 80 % or more of the applicable legal limit: gross-vehicle weight, axle-group load, axle load, or wheel load.

7.3.5 *Calibration and Certification*—See 7.2.5.

7.3.6 *Procedure*—The procedure for conducting the acceptance test for Type III WIM systems shall be the same as described in 7.2.6 with the following exceptions:

7.3.6.1 In 7.2.6.5 and 7.2.6.13, the speeds of the loaded test vehicles shall be at the minimum and at the maximum speed specified by the user between 15 and 50 mph (24 and 80 km/h), and

7.3.6.2 After 7.2.6.15, if continuation is approved, verify the ability of the WIM system to detect excessive acceleration by having the driver of each loaded test vehicle approach the WIM-system sensors at a speed between 30 and 40 mph (50 and 60 km/h) and apply heavy braking for approximately one second while the vehicle is passing over the sensor array. Excessive negative acceleration (deceleration) should be indicated by the Violation Code DE (see Table 5). Compare the WIM-system estimates of weights for these runs with those for steady-speed runs and include these comparisons in the data reported to ASTM Committee E-17 on Pavement Management Technologies. Proceed with 7.2.6.16.

7.3.7 *Calculation*—See 7.2.7.

7.3.8 *Interpretation of Test Results and Report*—See 7.2.8.

7.3.9 *Precision and Bias*—The precision and bias of the procedure and calculations in this acceptance test for the Type III WIM system are being determined.

7.4 *Acceptance Test for Type IV WIM Systems*:

7.4.1 *Scope*—The Type IV WIM system is designed to detect weight-limit or load-limit violations by highway vehicles for enforcement purposes. A procedure for acceptance testing of this type system to determine conformity with the performance requirements specified in Section 5 is presented. The procedure includes data collection needed for evaluating the variability in reference-value tire loads measured by certified wheel-load weighers, axle-load scales, a multi-platform vehicle scale, or a combination thereof, as well as the performance of the WIM-system in either measuring the tire loads of a vehicle stopped on the WIM-system sensors or estimating the tire loads and dimensions of a static vehicle from measurements made with the vehicle moving at a steady speed of 10 mph (16 km/h) or less. Reference-value tire loads shall be measured by a multi-platform vehicle scale or an axle-load scale (see 7.1.1) when Option 2 (see 4.1.4) has been specified for the Type IV WIM system under test. When this option has not been specified, reference-value tire loads shall be measured by placing wheel-load weighers directly on the load-receiving surface of the multi-platform vehicle scale or the axle-load scale and raising all tire-pavement contact surfaces approximately into the same plane as described in 7.1.2. The sum of the tire-load values from the wheel-load weighers should compare, within applicable tolerances, with the corresponding value from the scale upon which they are placed; then, the wheel-load-weigher indications should be used only to apportion the axle load(s) indicated by the scale between/among the wheels on the axle(s).

7.4.2 *Significance and Use*—Interpretation of the results from the acceptance test will allow the user to determine whether the tested Type IV WIM system is capable of meeting or exceeding the performance requirements stated in Section 5. This can also indicate the potential upper limit of performance which can be achieved by the particular type of system as the test conditions at the weight-enforcement site shall be the best available for conducting the acceptance test and shall, as a minimum, satisfy the user requirements shown in Section 6. Once a specimen WIM system has passed this rigorous acceptance test, it should not be necessary for each subsequent user to repeat the test for every system of the same type from the same vendor.

7.4.3 *Site for Acceptance Test*—Either an axle-load scale or a multi-platform vehicle scale is required at the site. Other site requirements are the same as 7.2.3.

7.4.4 *Test Unit for Acceptance-Test Loading*—See 7.3.4.

7.4.5 *Calibration and Certification*—Within seven days prior to beginning the acceptance-test, the Type IV WIM system shall, when subjected to field standard test weights, be adjusted to meet the acceptance tolerance for wheel-load weighers or for portable axle-load weighers as stated in NIST Handbook 44, depending upon whether wheel-load data or only axle-load data (4.1.4, Option 2) are of interest. All weighing apparatus used in the acceptance test for determining reference-value tire loads shall be certified as meeting the applicable maintenance tolerance specified in NIST Handbook 44 within 30 days prior to beginning the acceptance test.

7.4.6 *Procedure*—The procedure for conducting the acceptance test for Type IV WIM systems shall be the same as described in 7.2.6 with the following exceptions:

7.4.6.1 In 7.2.6.2, also ensure that an axle-load scale or a multi-platform vehicle scale is available at or near the site,

7.4.6.2 In 7.2.6.5 and 7.2.6.13, the speeds of the loaded test vehicles shall be 0 and 10 mph (0 and 15 km/h),

7.4.6.3 In 7.2.6.9, calculate the difference in each load or weight from the arithmetic mean, in pounds (kilograms), and compare the difference to one-half the applicable tolerance for a Type IV WIM system shown in Table 2. Also, verify that the sum of the tire loads from the wheel-load weighers agrees with the corresponding value from the scale upon which they are placed within applicable tolerances if wheel-load weighers are used. Then, use the wheel-load-weigher indications only to apportion the axle load(s) indicated by the scale between/among the wheels on the axle(s).

7.4.6.4 After 7.2.6.15, if continuation is approved, verify the ability of the WIM system to detect excessive acceleration by having the driver of each loaded test vehicle approach the WIM-system sensors at a speed between 8 and 10 mph (12 and 16 km/h) and apply heavy braking for approximately 1 s while the vehicle is passing over the sensor array. Excessive negative acceleration (deceleration) should be indicated by the Violation Code DE (see Table 5). Compare the WIM-system estimates of loads and weights for these runs with those for steady-speed runs and include these comparisons in the data reported to ASTM Committee E-17 on Pavement Management Technologies. Proceed with 7.2.6.16.

7.4.6.5 In 7.2.6.18, calculate differences in weight and express the differences in pounds (kilograms).

7.4.7 *Calculation*—See 7.2.7 except as described in 7.4.6.

7.4.8 *Interpretation of Test Results and Report*—See 7.2.8.

7.4.9 *Precision and Bias*—The precision and bias of the procedure and calculations in this acceptance test for the Type IV WIM system are being determined.

7.5 *On-Site Calibration Procedure for Type I, Type II, and Type III WIM Systems*:

7.5.1 *Scope*—A procedure is given for on-site calibration of Type I, Type II, and Type III WIM systems. This procedure requires that vehicles selected from the traffic stream at the WIM site pass over the WIM-system sensors and stop for reference-value weighing and measurement.

7.5.2 *Significance and Use*—The dynamic tire force which is measured by the WIM system results from a complex interaction among the vehicle components, the WIM-system sensors, and the road surface surrounding the sensors. Road-surface profiles and sensor installation are different at every WIM site, and every vehicle has unique tire, suspension, mass, and speed characteristics. Therefore, it is necessary to recognize the effects of these site-specific and vehicle-specific factors on WIM-system performance and attempt to compensate for them as much as is practicable via calibration. The calibration procedure shall be applied immediately after the initial installation of a Type I or Type II WIM system at any site. It should be applied again when a system is reinstalled or when site conditions have changed.

7.5.3 *Site for Weighing Static Vehicles*—The calibration procedure requires that vehicles processed over the WIM system stop for reference-value weighing and measurement. Apparatus for weighing static vehicles and their use are described in 7.1.1 and 7.1.2. A suitable site for making these static measurements must be available within a reasonable distance from the WIM site so that specific vehicles can be identified at both locations. Appropriate safety and traffic control measures shall be considered in selecting and operating the static-measurement site. In all cases, traffic control procedures shall be approved in advance by the public authority which has jurisdiction over the site. For Type I and Type II WIM systems, a paved shoulder or a barricaded traffic lane may be considered if a more suitable area is not available. For Type III WIM systems, weighing apparatus will be in place at the weight-enforcement station.

7.5.4 *Test Unit for Calibration Loading*—The test unit for calibration loading shall consist of vehicles selected in random order from the traffic stream at the WIM site and shall, as a minimum, include the numbers and classes of vehicles shown in Table 7. Additional vehicles may be included in the test unit for calibration loading; this is particularly appropriate if a significant number of vehicles of a class(s) not represented in Table 7 are operating at the WIM site.

7.5.5 *Procedure*—The following steps are involved in the on-site calibration process:

7.5.5.1 Adjust all WIM-system settings to vendor's recommendations or to a best estimate of the proper setting based upon previous experience.

7.5.5.2 Select the required number of vehicles that have passed over the WIM-system sensors, or will later pass over them, from the traffic stream in random order and stop these vehicles for static weighing and measuring at the nearby site, using approved traffic-control measures (preferably including a uniformed law-enforcement officer). With a calibrated radar speed meter or by some other means (such as wheelbase/time) that is acceptable to both the user (or a recognized representative of user's interests) and the vendor, measure the speed of each selected vehicle as it passes over the WIM-system sensors.

TABLE 7 Composition of Test Unit for Calibration Loading of WIM Systems

Vehicle Class	Number of Selected Vehicles
23	2
31	3
51	5
71	3

7.5.5.3 Measure tire loads of the static vehicles as described in 7.1.1 and 7.1.2. Also, measure axle spacings of the static vehicles and record all data for reference values.

7.5.5.4 Calculate the difference in the WIM-system estimate and the respective reference value for each speed, wheel-load, axle-load, axle-group-load, gross-vehicle-weight, and axle-spacing measurement, express the difference in percent (see 7.2.7.2), and find a mean value for the differences for each set of measurements.

7.5.5.5 Make the necessary adjustments to the WIM-system settings which will make the mean of the respective differences for each basic measurement equal zero. For WIM systems which estimate wheel load, the adjustment will be to wheel-load estimates on each side of the vehicles, separately. For the systems which estimate axle loads only, the adjustment will be for axle loads. Some WIM systems allow calibration factors to be entered for selected wheels, axles, or axle groups with respect to their respective location on the vehicle or combination. Adjustment to the speed setting will probably affect axle-spacing estimates.

7.5.6 *Calculation*—In addition to the calculations described in 7.5.5.4 and 7.5.5.5, calculations should be made to determine whether the calibrated WIM system can be expected to perform within specification tolerances at this site. Adjust each calculated difference, as described in 7.5.5.4, by an amount equal to the amount that the mean of the differences varied from zero. Then calculate the percent of these adjusted differences that exceeded the tolerance shown in Table 2 by the method described in 7.2.7.2.

7.5.7 *Interpretation of Results*—If a large number of the adjusted differences for any applicable data item exceeded the specified tolerance shown in Table 2, the WIM system will probably not perform within tolerances at this site.

7.5.8 *Precision and Bias*—No justifiable statement concerning precision and bias of this procedure can be made at this time because there is no experience yet.

8. Keywords

8.1 loading; pavement and bridge; traffic; vehicle; weighing in highways; weigh-in-motion; WIM

ANNEX

(Mandatory Information)

A1. COMPUTATION OF EQUIVALENT SINGLE-AXLE LOADS (ESALs) BY WIM SYSTEMS

A1.1 Equivalency Factors

A1.1.1 Most pavement design procedures which are now in general use are based on theoretical considerations of materials behavior coupled with a complementary evaluation of the cumulative effects of traffic loading. Many of these procedures define the design thickness of a pavement in terms of the number of applications of a standard single-axle load. To use this concept, the damaging effect of each axle load in a mixed traffic stream must be expressed in terms of the equivalent number of repetitions of a selected standard single-axle load. The numerical factors that define the number of passes of a standard single-axle load which would cause pavement damage equivalent to that caused by one pass of a given axle load are called equivalent single-axle load (ESAL) factors.

A1.1.2 The equivalency factors that were derived from the AASHO Road Test[5] are perhaps the most commonly used equivalency factors for pavement design and analysis. These were derived from a statistical analysis of the AASHO (now AASHTO) Road Test data.[6] The standard axle load used by AASHO is an 18 000-lb (8.2-Mg) single-axle load. Analysis of the AASHO Road Test design equations[7] permits the determination of equivalency factors for both flexible and rigid pavements. These factors can be computed with the following equations.

A1.2 Flexible Pavement Equivalency Factors

A1.2.1 The design equations for flexible pavements presented in the AASHTO Interim Guide[7] are:

$$\log W_t = 5.93 + 9.36 \log (\overline{SN} + 1) - 4.79 \log (L_1 + L_2) + 4.33 \log L_2 + \frac{G_t}{\beta} \quad \text{(A1.1)}$$

and

$$\beta = 0.40 + \frac{0.081(L_1 + L_2)^{3.23}}{(\overline{SN} + 1)^{5.19} L_2^{3.23}} \quad \text{(A1.2)}$$

where:

W_t = number of axle load applications at the end of time t for axle sets with dual tires,

$\overline{SN}$ = structural number, an index number derived from an analysis of traffic, roadbed soil conditions, and regional factor which may be converted to a thickness of flexible pavement layers through the use of suitable layer coefficients that are related to the type of material being used in each layer of the pavement structure,

L_1 = load on one single axle, or on one tandem-axle set for dual tires, kips [1 kip = 1000 lb (1 kip = 4.536×10^{-1} Mg)],

L_2 = axle code (one for single axle, and two for tandem axle sets),

P_t = serviceability at the end of time t (Serviceability is the ability of a pavement at the time of observation to serve high-speed, high-volume automobile and truck traffic.),

G_t = a function (the logarithm) of the ratio of loss in serviceability at time t to the potential loss taken to a point where P_t = 1.5, or

G_t = log

$$\left[\frac{4.2 - P_t}{4.2 - 1.5}\right],$$

and

β = a function of design and load variables that influences the shape of the P-versus-W serviceability curve.

A1.2.2 As indicated above, for this design method the number of axle load repetitions to failure is expressed in terms of a pavement stiffness or rigidity value which is represented by Structural Number, $\overline{SN}$, load characteristics denoted by L_1 and L_2, and the terminal level of serviceability selected as the pavement failure point, P_t. Values commonly used to define terminal serviceability, P_t, are 2.0 and 2.5.

A1.2.3 The relationship between the number of applications, $W_{t_{18}}$, of an 18 000-lb (8.2-Mg) single-axle load and the number of applications, W_{t_i}, of any other single or tandem axle load, L_i, to cause the same potential damage to a flexible pavement can be found from the following equation:

$$E_i = \frac{W_{t_{18}}}{W_{t_i}} = \left[\frac{(L_i + L_2)^{4.79}}{(18 + 1)^{4.79}}\right]\left[\frac{10^{Gt/\beta_{18}}}{(10^{Gt/\beta i})L_2^{\ 4.331}}\right] \quad \text{(A1.3)}$$

A1.2.4 The ratio shown in Eq. A1.3 is defined as an equivalence factor, and is evaluated by solving the equation with any given axle load L_i. This factor defines the number of 18 000-lb (8.2-Mg) single-axle load applications that would be needed to cause damage to the pavement structure equivalent to one application of the given axle load. Because the term β is a function of $\overline{SN}$ as well as L_i, the equivalence factor varies with $\overline{SN}$.

A1.3 Rigid Pavement Equivalency Factors

A1.3.1 The basic equations for rigid pavements developed

[5] Highway Research Board, "The AASHO Road Test,'' Report 5, Pavement Research, *Highway Research Board Special Report 61E*, 1962.

[6] Highway Research Board, "The AASHTO Road Test,'' Proceedings of a conference held May 16–18, 1962, St. Louis, Missouri, *Special Report 73*, Washington, DC 1962.

[7] "AASHTO Interim Guide for Design of Pavement Structure—1972,'' American Association of State Highway and Transportation Officials, Washington, DC 1974.

from the AASHO Road Test are:

$$\log W_t = 5.85 + 7.35 \log (D + 1) - 4.62 \log (L_1 + L_2) + 3.28 \log L_2 + \frac{G_t}{\beta} \quad (A1.4)$$

and

$$\beta = 1.0 + \frac{3.63(L_1 + L_2)^{5.20}}{(D + 1)^{8.46} L_2^{3.52}} \quad (A1.5)$$

where:
D = thickness of rigid pavement slab, in. (mm), and
G_t = $\log [\frac{(4.5 - Pt)}{(4.5 - 1.5)}]$.

A1.3.2 As can be seen from analyzing Eq. A1.4 and Eq. A1.5, the pavement rigidity or stiffness value is expressed in terms of the pavement thickness, *D*.

A1.3.3 The relationship between the number of applications, $W_{t_{18}}$, of an 18 000-lb (8.2-Mg) single-axle load and the number of applications, W_{t_i}, of any other single or tandem axle load, L_i, to cause the same potential damage to a rigid pavement can be found from the following equation:

$$E_i = \frac{W_{t_{18}}}{W_{t_i}} = \left[\frac{(L_i + L_2)^{4.62}}{(18 + 1)^{4.62}}\right]\left[\frac{10^{Gt/\beta_{18}}}{(10^{Gt/\beta i})(L_2^{3.28})}\right] \quad (A1.6)$$

A1.3.4 The ratio is defined as an equivalency factor, and is evaluated by solving Eq. A1.6 with any given axle load, L_i. This factor gives the number of 18 000-lb (8.2-Mg) single-axle load applications that would be needed to cause damage to the pavement structure equivalent to one application of the given axle load. Because the term β is a function of *D* as well as L_i, the equivalency factor varies with *D*.

A1.1 CONVERSION FACTORS

To Convert From	To	Multiply By
pound (lb avoirdupois)	kilogram (kg)	4.536×10^{-1}
pound (lb avoirdupois)	megagram (Mg)	4.536×10^{-4}
kip (1000 lb avoirdupois)	megagram (Mg)	4.536×10^{-1}
inch	millimetres (mm)	25.4